LUND UNIVERSITY
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Master's Programme in International Economics with a focus on China

Air Quality Effects of Urban Forms in China

A Panel Data Analysis of changing PM_{10} concentration in 14 Chinese Cities between 2006 and 2013

by

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Abstract: The Chinese urban population face serious health issues due to the increasing concentration of air pollutants. Research has shown that air quality was influenced by urban forms, and that special combinations of city characteristics could contribute to sustainable urban development. This study aims to determine how urban forms affected air quality in Chinese cities. In this context, urban forms are the characteristics of cities that influence their local environment. Based on a review of the literature on air quality and urban forms, a panel dataset of 14 Chinese cities was collected and the Fixed Effects model was used in order to execute the analysis. The results indicate that cities with an efficient transport system noticed lower PM_{10} concentration, while greater population density and higher per capita road values suggested an increasing level of PM_{10}. Furthermore, the study surprisingly shows a positive relation between green land and particulate concentration, however, it does not imply causation. These findings indicate a strong relationship between urban forms and air pollutants in China and the study advances previous research by examining a more comprehensive combination of urban characteristics.

Key words: Urban Forms, Air Quality, PM_{10}, China, Urban Characteristics, Sustainable Urban Development

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Table of Contents

List of Tables

List of Figures

1 Introduction

“More than 90% of the world’s children breathe toxic air every day”, “9 out of 10 people worldwide breathe polluted air”, “Health must be the number one priority for urban planners”. These are just some of the recent articles published by the World Health Organization (WHO) regarding the giant problem of outdoor air pollution. The population of developed countries often assume that air pollution is a problem in developing areas of Africa and Asia, however, it stands far from the real conditions. Confirming this, Figure 1 shows the estimated deaths caused by air pollution from a regional perspective. The total direct health impacts are lower in developed areas but regarding the population, it is clearly high in Europe and America as well. The topic is not new as many scholars have already examined the health effects of air pollution during the 1990s (e.g. Pope et al., 1995), during the 2000s (Brunekreef & Holgate, 2002; Pope & Dockery, 2006) and it remained still a hot topic in the recent analyses as well (Kurt et al., 2016; Mannucci & Franchini, 2017). Not just the scholars found the topic important as governments have emphasized the importance of improving air quality and reducing the pollutant concentrations. Since the 1960s, it resulted in several laws, regulation and suggestions of air quality standards (US EPA, 2013; WHO, 2005).

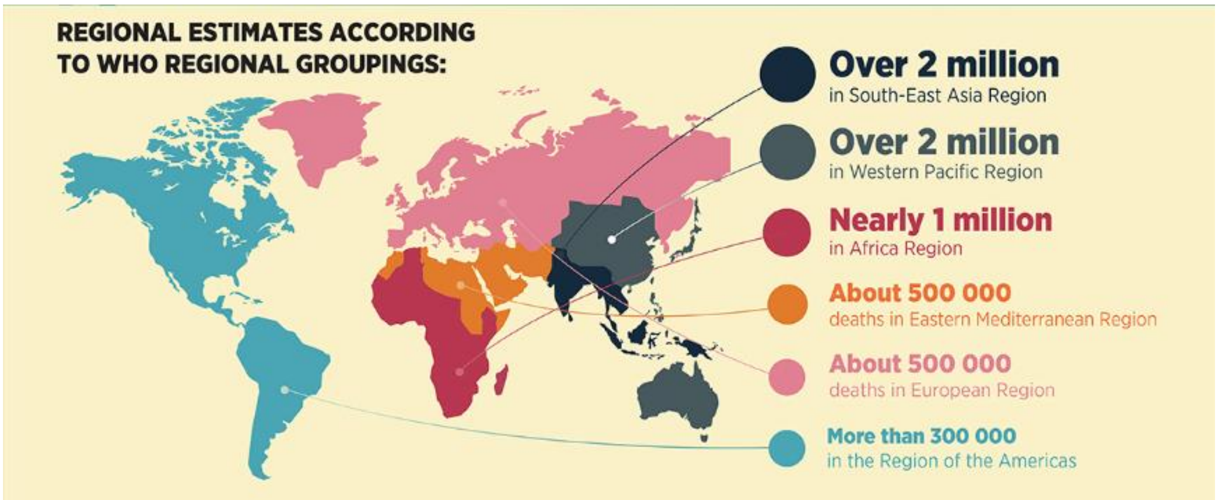

Figure 1 Number of deaths related to air pollution (WHO, 2013)

The most affected areas are cities, especially megacities that suffer mostly from local air pollution. The pace of urbanization boomed in the 1950s, so urban industries, infrastructure, modes of transportation and living space have transformed. These processes brought substantial problems of automobile dependence, reduction of green areas, high energy use and environmental issues of pollutants and noise. Fossil fuel combustion became the most important source of air pollutants (Chen, Jia & Lau, 2008; Grimmond, 2007; Jes, 1999; Kenworthy, 2018). These effects are even stronger in developing countries and especially in China, which according to public opinion is one of the most polluted areas in the world. This can be associated with fast and high economic development as the governments in developing countries tend to favour economic performance over environmental concerns. The special circumstances of big cities, such as reliance on built-up infrastructure, the building layout and the high concentration of people with substantial transport need resulted in lower air quality levels.

The above-elaborated issues of air pollution question the possibility of sustainable urban development. Scholars started to focus on urban patterns in order to find what makes a city development more sustainable. They found that urban forms are those physical and non-physical characteristics that influence greatly the air pollution outcomes (Dempsey et al., 2010; Jabareen, 2006). Urban form concepts combined the features that might improve the sustainability of cities. Compact city concept was considered being the most efficient urban form according to recent literature. It emphasized the importance of green areas and high population density, furthermore, it promoted the improvement of efficient public transport systems and mixed land use (Chen et al., 2008; Jabareen, 2006).

1.1 Aim and Scope

The focus of the studies aimed to find out what effects have urban features on air pollution in order to improve sustainable urban concepts. In China, urban outdoor air pollution became a main issue since the economic reforms started in 1978. As the former planned economy has been dismantled, the flow of rural people to cities resulted in not just economic opportunities but raised important urban planning questions. Urbanization has a price until environmental considerations do not play as important role as favouring economic development. Yuan and his colleagues (2018) examined the recent status of urban forms in China relating them to the concentration of different air pollutants. The findings suggested a strong relationship between urban forms and air quality in China. Others focused more on the sources of particulate matter pollution in Chinese cities and found the same strong association (Han et al., 2016). It is usual in a research topic that the signs of the effects differ, however, this topic has some generally accepted assumptions. Such as that the efficient public transport lowered air pollution (e.g. Gendron-Carrier et al., 2018; Goodman et al., 2005) and the private and freight traffic had strong positive effects on concentration of air pollutants (e.g. Ducret-Stich et al., 2013; Stroe et al., 2014). China is usually considered a special economy based on the enormous population they have, however, in this context the results were consistent with international assumptions as well (Clark et al., 2011; McCarty & Kaza, 2015; US EPA, 2013).

Thus, one aim of the thesis is to provide further empirical evidence of the relationship between urban forms and air quality in China. In order to do that, 14 Chinese cities from all over the country have been chosen and tested for the period between 2006 and 2013. The thesis focuses on the identification of the urban forms that influence air quality in Chinese cities and examine the nature of the relationship among them so that it can confirm or contradict former findings. Although the topic was highly researched, the paper could contribute to the research in several perspectives. First of all, the panel data factor strengthened the validity of the findings as the difficulties of collecting panel data in China prevented most scholars to examine the relationship between developing urban forms and changing concentration of air pollutants.

Former studies usually focused on specific urban characteristics, such as land use (McCarty & Kaza, 2015) or green areas (Yin et al., 2011) and some scholars tested combination of urban forms (Cárdenas, Dupont-Courtade & Oueslati, 2016; Yuan et al., 2018), however, the effects of traffic and transportation were only included in individual analysis. This thesis includes the most comprehensive combination of urban forms in order to test their effects. In the following parts, different hypotheses were formed in order to connect the empirical analysis to the research problem so that the research question can be answered and explained. Thus, the study aims to answer the following research question:

Research Question:

> *How urban forms affected the air quality in Chinese cities between 2006 and 2013?*

1.2 Outline of the Thesis

The structure of the thesis is built with the intention of answering the above-stated research question. Chapter 2 explains the theoretical background in order to provide a rationale for the thesis and forming the hypotheses for econometric testing. The third section interprets the sources, nature and limitations of the data to create reliability and validity for the empirical analysis. The China Statistical Yearbooks Database has been used to access to the 136 yearbooks used to collect data. The third section also contains the operationalization of the chosen variables. The following chapter explains the used econometric model. The Fixed Effects (FE) model have been chosen to test the data. Chapter 5 describes the results of the econometric model. The first part explains the key outcomes in order to test the stated hypotheses, while the second part discusses potential explanations, limitations of the findings and relates them to previous studies. The last chapter contains the conclusion section. It relates the findings and the main research question and summarizes the key results of the study.

2 Theory

This section explains and interprets the theory used in studies in a scholarly manner in order to give insight to the main findings, trends and theories of the relationship between urban forms and air quality. The researcher endeavoured to use the most recent and relevant studies. The structure of the section is built rationally with the intention of providing the clear and understandable theoretical background for the reader.

2.1 Urbanization

In the last century, people's living circumstances have changed due to urban development processes. The economic importance of cities grew in the second part of the 20th century hence the rate of urbanization changed significantly especially in developing countries (Chadchan & Shankar, 2009). Figure 2, based on World Bank's data, shows the urban ratio changes between 1970 and 2015 in China, Germany, South Korea, US with the world average value. It can be seen, that the world average urban ratio was increasing during the period and it was driven mostly by developing countries, while in developed countries the ratio stabilized around 80%. The study of Wu, Xiang and Zhao (2014) showed that China's urban population grew from 58 million in 1949 to 670 million in 2010 and suggested a continuous increase in the next decades. Although urbanization was a hand in hand process with economic development, it brought direct local problems as well. As the cities are covering limited space on Earth, identifying their contribution to global pollution and warming is too complex, however, in a local scale, direct urbanization effects on air pollution could be found in local climates (Grimmond, 2007). China, as the most populous country of the world and one of the fastest growing economies, is facing huge concerns regarding air quality, land preservation and water pollution. Being the world's manufacturer resulted in the highly growing local pollution in urban areas (Liu, 2005). All over the world, the growing issues of the urban environment provides high importance for sustainable urban development. Studies started to examine those specific urban forms that meet the requirements of sustainability for human settlements. The aim is to find the urban forms that might add lower pollution and energy consumption (Jabareen, 2006).

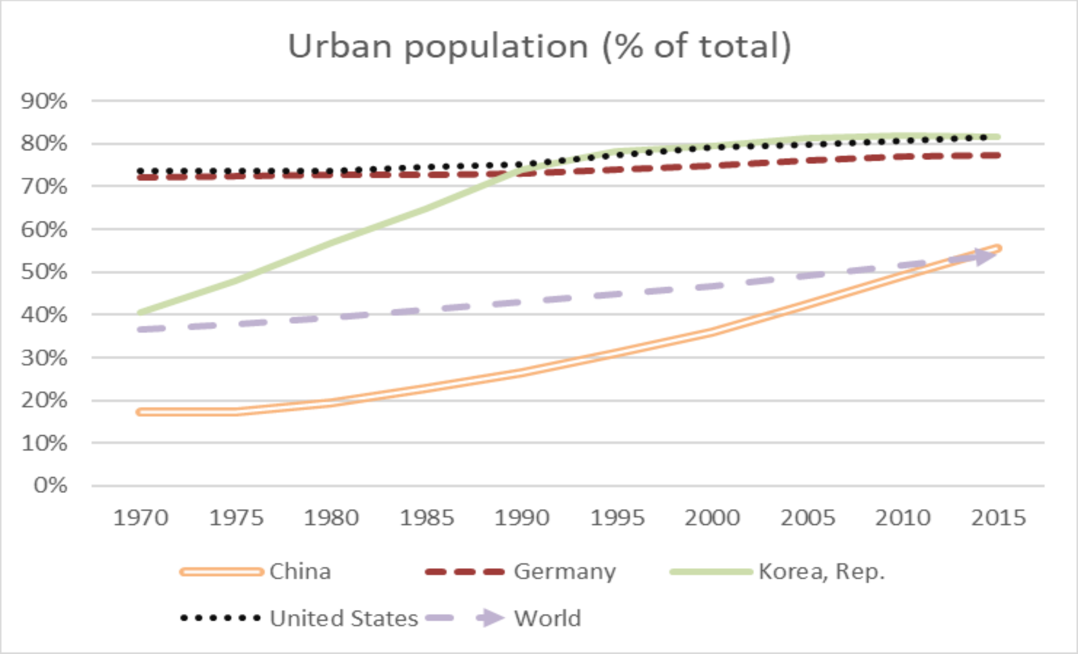

Figure 2 The ratio of urban population (World Bank, 2018)

2.2 Urban Forms

2.2.1 Definition of Urban Form

Although lots of studies used the term urban form, usually researchers did not define the exact meaning of it. However, they mostly agreed on that urban form was a complex definition for city features and it aimed to achieve more sustainable environments. The broadest explanation defined urban forms as “a number of physical features and non-physical characteristics” (Dempsey et al., 2010, p.22). Their theory covered most of the urban-related factors and identified five broader elements: density, transport infrastructure, housing types, land use and layout of green space. In other words, urban form represented the characteristics of cities that affected their local environment. Jabareen (2006) stated a quite similar definition. His theory included seven groups of urban elements: compactness, sustainable transport, density, mixed land use, diversity, passive solar design, greening. Furthermore, Chen and his colleagues (2008) investigated the compact city urban form in China and included density, infrastructure efficiency, public transport and energy consumption measured on environmental externalities. It can be seen that urban form usually contains similar characteristics, most importantly population density, land use factors and transportation. Some studies emphasized land use effects in their empirical analyses when examined the effects of urban patches (areas covered by urban land) on air quality and climate (McCarty & Kaza, 2015) or used sprawl indexes to examine US metropolitan cities (Stone et al., 2010). Others used the combination of most different factors, as Yuan and his colleagues (2018) did with using density, land use, transportation and energy factors to examine the effect of the urban forms on most air pollutants ($PM_{2.5}$, PM_{10}, NO_2, SO_2, CO, O_3). Their biggest problem was that the elements interacted with each other, thus, it was difficult to identify the specific effects. That was why Crane's investigation (2000) divided urban form and transportation in order to identify what effects have urban forms on travel behaviour in cities. The scholars of urban form provided guidance for this thesis to identify the factors should be considered in order to create the best possible measurement.

Sustainable urban form concepts

In recent times, researchers designed urban form concepts as combinations of city characteristics that might provide sustainable development and urban management. The key points of Jabareen's study (2006) were used to build a framework and the researcher defined with involving other studies (Cárdenas et al., 2016; Chen et al., 2008; Clark et al., 2011; Gendron-Carrier et al., 2018; McCarty & Kaza, 2015; Nowak et al., 2006; US EPA, 2013; Yin et al., 2011; Yuan et al., 2018) the key urban characteristics and urban form concepts. Table 1 summarizes the explanation of urban characteristics and how they contribute to more sustainable urban forms. As it can be seen, they overlap each other so the identification of true effects is more complex. The point of compactness is to reduce energy use, prevent commuting, support the efficient use of land and social life. It suggests that urban developments need to take place in existing city areas. It focuses on providing higher densities and use of undeveloped urban land with the efficient redevelopment of unnecessary infrastructure and industrial sites. Sustainable transport is the definition of an efficient travel system that limits emissions, provides sufficient public transportation, supports walking and cycling activities instead of car use. A sustainable transport system can minimalize the land use, provide the city livability by healthier neighbourhood and it is financially affordable. High population density contributes to integrated land use, better transport options and cost-effective infrastructure. It also promotes the improvement of cycling and walking facilities in order to lower the use of private vehicles. Mixed land use means the combination of commercial, industrial, business, residential and transportation sites in order to reduce transportation needs and support cycling and walking. It results in several service options within a reasonable distance for the inhabitants and this way promotes cycling and walking. The role of diversity is to improve and fulfil cultural and social needs by providing diverse activities and housing options for the population so similarly to mixed land use, it can reduce transport needs. The layout of urban areas provides potential energy saving options. Passive energy design supports the use of the built-up surface to utilize renewable and passive energy sources. Greening is another important factor in sustainable urban form concepts. The protection and enlargement of urban green areas can lead to lower air pollution, health benefits and maintenance of biodiversity.

Table 2 shows the four main concepts: neotraditional development, growth strategies, compact city and eco city. The scale of *Low*, *Moderate* and *High* shows the contribution of different urban form concepts to sustainability, for example, the high population density of new urbanism means that it supports sustainability through emphasizing high population density, while passive energy design is not a key characteristic according to new urbanism. The first main concept, neotraditional development has three approaches and they highly emphasize the need for high population density and the importance of mixed land use. Additionally to that, new urbanism put emphasis on high urban diversity. Transit orientated development (TOD) is a settlement close to a good transport option and it demands highly developed and sustainable transport system. The urban village concept has the same values as new urbanism, but the difference is that it is a greenfield investment for new settlements of megacities. Growth strategies show how growing cities can behave in order to reduce environmental impacts. Urban containment emphasizes the importance of urban boundaries so it prevents urban sprawl, while smart growth is a more complex idea to manage growth by keeping in mind to fulfil economic, social and environmental needs. According to the eco city concept, the form of the city is not as important for sustainability as the preservation, enlargement of green areas and the utilization of passive energy sources. The compact city concept is considered to be the most important and efficient urban form according to recent literature. It aims to enlarge urban green areas, promote high population density and sustainable transport. It also emphasizes diversity and mixed land use in order to fulfil social needs as well. The study of Chen, Jia and Lau (2008) examined Chinese cities in order to test the potential of compact city concept and found that it was feasible for China to maximize the environmental quality of urban areas.

2.2.2 Hypotheses

Therefore, based on the theoretical explanations and expectations, the following hypotheses are stated and tested in order to identify the effects of the urban forms on particulate matter (PM_{10}) concentration in China:

Hypothesis 1:

Increasing urban population density has a substantial negative effect on particulate matter (PM_{10}) *concentration.*

Hypothesis 2:

Population centering is negatively associated with particulate matter (PM_{10}) *concentration.*

Hypothesis 3:

The enlargement of urban green areas decreases the particulate matter (PM_{10}) *concentration.*

Hypothesis 4:

Street accessibility has a strong positive effect on particulate matter (PM_{10}) *concentration.*

Hypothesis 5:

More developed public transport systems have strong negative effects on particulate matter (PM_{10}) *concentration.*

Hypothesis 6:

Urban traffic has a positive relationship with particulate matter (PM_{10}) *concentration.*

Table 1 Urban characteristics (Jabareen, 2006)

Compactness	**Sustainable transport**	**Population density**	**Mixed land use**	**Diversity**	**Passive energy design**	**Greening**
Minimize resource use	Limit emissions	High population density	Diversity of land use (commercial, industrial, business, residential, transportation)	Diversity of activities	Reduce the demand for energy	Protect and enlarge green spaces
Minimize energy of transportation	Reduce car traffic	Integrated land use	Reduce transport needs	Encourage mixed land use	Support the use of passive energy	Protect biodiversity
Reuse of formerly underdeveloped urban land	Support walking and cycling	Provide good transit options	Encourage walking and cycling	Diversity of housing option	Use the surface of built areas	Reduce air pollution
Support social life	Efficient and sufficient public transport	Reduce car traffic	Reduce air pollution	Fulfil cultural and social needs	Collect more solar energy	Improve the quality of life
Prevent commuting	Fulfil residential needs	Cost-effective infrastructure			Use passive energy for heating, cooling, producing electricity	Health benefits

Table 2 The relationship of urban form concepts and characteristics (Cárdenas et al., 2016; Chen et al., 2008; Clark et al., 2011; Gendron-Carrier et al., 2018; Jabareen, 2006; McCarty & Kaza, 2015; Nowak et al., 2006; US EPA, 2013; Yin et al., 2011; Yuan et al., 2018)

Urban form concepts	**Approaches**	**The idea**	**Compactness**	**Sustainable transport**	**Population density**	**Mixed land use**	**Diversity**	**Passive energy design**	**Greening**
Neotraditional development	**New urbanism**	Mixed land use with high density; street options for walking; traditional architectural characters; emphasize social life.	Moderate	Moderate	High	High	High	Low	Moderate
	Transit orientated development (TOD)	Mixed land development; settlement close to a good transit option (e.g. train station); reduce car traffic.	Moderate	High	High	High	Moderate	Low	Moderate
	Urban village	Greenfield settlement; high density with mixed land use; mix of housing tenures; social values; high quality of infrastructure;	Moderate	Moderate	High	High	High	Low	Moderate

		walking based. Good option for expanding megacities.							
Growth strategies	**Urban containment**	Prevent the outward expansion of cities; preserve green and agricultural areas. Green belts: protected natural areas. Urban growth boundaries (UBGs): politically limit the city boundaries. Urban service area: limits the provided service area.	Moderate	Moderate	Moderate	Moderate	Low	Low	Low
	Smart growth	Manage the growth with fulfiling economic, social, environmental needs. Mixed land use; high quality of transportation; prevent urban sprawl.	Moderate	High	Moderate	High	Low	Low	Low
Compact city		Create compactness and density to avoid modern problems: reduce transport; improve resource efficiency and accessibility; preserve rural land; emphasize diversity; economically viable (low per capita maintaining costs).	High	High	High	High	High	Low	High
Eco-city		Urban management by environmental, social, institutional policies. The key concepts are greening and passive energy design. The form of the city is not so important for sustainability.	Low	High	Moderate	Moderate	Moderate	High	High

2.2.3 Previous Research

Air quality measurements

The air quality measurements provide efficient estimates for testing the sustainability of urban forms. Urban patterns, such as city development, transportation system, building layout and design affect directly the city environment. They also have indirect effects on environmental pollution (air, land, water) and health by influencing people’s everyday mobility and travel decision (US EPA, 2013). The concerns about urban air quality are not new, some laws took place already in the middle ages. However, most of the regulations have been set up since the 1950s. The Clean Air Acts in the UK (1956) and in the US (1970) were some of the first big steps in order to regulate air pollution. These regulations led to the spread of better air quality monitoring systems all over the world and, furthermore, air quality standards were created in order to measure air pollution. Each standard defines the specific chemical elements and set up limitations for maximum concentrations per averaging period. Table 3 contains the standards of the WHO, the European Union, the United States and China. It can be seen that the air quality standards differ across countries and regions, however, it is important to state, that these standards serve as guidelines and not as concrete legal acts (Chow, 1995; Enviropedia, 2019; US EPA, 2019a).

As it can be seen from Table 3, six pollutants, $PM_{2.5}$, PM_{10}, NO_2, SO_2, O_3 and CO are considered critical regarding the air quality acts of countries. PM is a mixture of microscopic solid and liquid matter in the atmosphere. There are two main measurements for them: $PM_{2.5}$, which is the particles with the diameter less than 2.5 and PM_{10}, which contains all particles with diameter less than 10 mm including $PM_{2.5}$ (Fuzzi et al., 2015; Han & Naeher, 2006; Marcazzan et al., 2001; Querol et al., 2004). Scholars greatly used that framework in order to examine urban air pollution. Some studies focused on more regional trends of air pollution. Baldasano and his colleagues (2003) used publicly available air pollution data of SO_2, NO_2, Ozone, total suspended particles (TSP) and PM_{10} to examine the air quality in large cities. They found that SO_2 was the biggest problem for developing countries in Asia and some Middle East cities. The concentration of NO_2 was high in both developing and developed areas and connected with a high number of vehicles. Chinese cities have experienced really high NO_2 levels. Particulate matter is a critical problem in most Asian cities and some areas in Latin America. Others found less varying results and showed that air pollution is a typical problem of megacities (Mage et al., 1996). They examined 24 big cities all over the world and found that 20 of them have experienced so low air quality level, which was enough to cause serious health impacts. Their investigation found that particles and SO_2 are huge issues in most of the megacities no matter if they were in developing or developed countries and, furthermore, some of them had serious problems with CO, NO_2 and O_3 as well. Most studies pointed out the importance of sustainable urban development.

Table 3 Air quality standards (Clean Air Asia, 2019; European Commission, 2019; US EPA, 2019b; WHO, 2005)

Air pollutants	Averaging period	Unit	WHO	European Union	United States*	China*
Particulate matter 2.5 ($PM_{2.5}$)	annual	µg/m³	10	25	12	35
	24-hrs	µg/m³	25	-	35	75
Particulate matter 10 (PM_{10})	annual	µg/m³	50	40	-	70
	24-hrs	µg/m³	20	50	150	150
Nitrogen Dioxide (NO_2)	annual	µg/m³	40	40	100	40
	24-hrs	µg/m³	-	50	-	80
	1-hr	µg/m³	200	200	188	200
Sulphur Dioxide (SO_2)	annual	µg/m³	-	-	-	60
	24-hrs	µg/m³	20	125	-	150
	1-hr	µg/m³	500*	350	200	500
Ozone (O_3)	8-hrs	µg/m³	100	120	140	160
	1-hr	µg/m³	-	-	-	200
Carbon Monoxide (CO)	24-hrs	mg/m³	-	-	-	4
	8-hrs	mg/m³	-	10	10	-
	1-hr	mg/m³	30	-	40	10

*The EPA in the US set some of the standards in other units (ppm, ppb), it was changed to µg/m3 and rounded.

*In China, the Grade 2 standards were taken into consideration as they apply to all non-specific areas including cities.

*The WHO has SO_2 standard for 10 minutes instead of 1 hour.

Previous empirical results

Scholars used different air pollutants for testing effects on air quality. Some have used all or most of the aforementioned pollutants, while others included only one or two of them. Table 4 summarizes the air pollutants used by urban form related studies. It can be seen that researchers have included a great variety of measurements. Nevertheless, PM_{10} was included in most studies, while $PM_{2.5}$, NO_2 and SO_2 were represented approximately in the half of the studies and the data of CO and O_3 were the least used among the air pollutants.

Table 4 also summarizes the aim of the studies in order to improve the transparent overview of previous findings. Some researchers focused on examining the effects of urban element combinations (Cárdenas et al., 2016; Clark et al., 2011; Han et al., 2016; US EPA, 2013; Yuan et al., 2018; Zhu et al., 2018), while others tested specifically some elements of urban forms, like subway effects (Gendron-Carrier et al., 2018; Tabatabaiee & Rahman, 2011) or road related pollution (Amato et al., 2010; Colbeck et al., 2011; Ducret-Stich et al., 2013; Stroe et al., 2014). Urban traffic and effects of motoric vehicles on air quality were also highly researched (Abu-Allaban et al., 2007; Basarić et al., 2014; Ducret-Stich et al., 2013; Han & Naeher, 2006; Longley et al., 2015; Stroe et al., 2014), while some targeted the examination of urban green areas (Nowak et al., 2006; Yang et al., 2008; Yin et al., 2011). McCarty and Kaza (2015) emphasized land use patterns in their examinations. This part overviews these studies in order to provide a rationale for the expected relationships of the thesis.

According to the studies, one of the most important urban factors was population density. The general expectation was a negative association between population density and the concentration of urban air pollutants as higher population density could reduce the need for transportation. Some analyses of this relationship proved the expected relationship between population density and $PM_{2.5}$, PM_{10}, O_3 (Yuan et al., 2018) and SO_2 (Cárdenas et al., 2016), while Clark and his colleagues (2011) published the opposite results when they tested for $PM_{2.5}$. The true effect of population density was controversial, in some cases, low-density urban forms could improve air quality (McCarty & Kaza, 2015), however, scholars have always emphasized the importance of high population densities in sustainable urban forms (Chen et al., 2008; Jabareen, 2006). A connecting factor is the level of centering in urban areas. It assumed that more centered cities experience higher air quality compared to urban sprawl. Analyses confirmed the negative association with most of the important air pollutants: PM_{10}, $PM_{2.5}$, SO_2, CO and O_3 (Clark et al., 2011; Yuan et al., 2018). However, a potential limitation of the positive effects of centering was that in polycentric cities (cities with more than one center) the positive effect might not exist at all as the distribution of population density is more equal so centrality did not have any effects on most air pollutants but only the O_3 (McCarty & Kaza, 2015). The level of polycentricity in China is quite various, a study of 318 cities found that 90% of the cities had four or fewer centers and from that 40% of the cities had only one center (Liu & Wang, 2016).

Table 4 Urban form related studies

Studies	$PM_{2.5}$	PM_{10}	NO_2	SO_2	CO	O_3	Aim
Gendron-Carrier et al. (2018)		x					Subway effects on air quality
Yuan et al. (2018)	x	x	x	x	x	x	The effects of urban form elements on air quality
Zhu et al. (2018)	x	x					Potential sources of particles
Cárdenas et al. (2016)		x	x	x			The effects of urban form elements on air quality
Han et al. (2016)	x						Changes of $PM_{2.5}$ concentration in Beijing between 1973-2013
Longley et al. (2015)		x	x				Roadside air pollution
McCarty & Kaza (2015)	x					x	Land use effects on air quality
Basarić et al. (2014)		x	x				Traffic-related effects on air quality
Stroe et al. (2014)		x	x		x		Environmental effects of Italian highways
Ducret-Stich et al. (2013)		x					Highway traffic effects on PM_{10} in Switzerland
US EPA (2013)	x	x	x	x	x	x	Discussing urban trends and their effects on air quality
Clark et al. (2011)	x					x	The effects of urban form elements on air quality
Colbeck et al. (2011)		x					The air pollution of roads in Pakistan
Tabatabaiee & Rahman (2011)		x	x	x	x		Urban rail transit effects on air pollution in Ahvaz
Yin et al. (2011)		x	x	x			Effects of urban parks on air quality in Shanghai
Amato et al. (2010)		x					PM emissions of roads
Chen et al. (2008)				x			Effective compact city form in China
Yang, Yu & Gong (2008)		x	x	x		x	The effects of green rooftops on air quality in Chicago
Abu-Allaban et al. (2007)	x	x					The effects of motor vehicles on PM_{10} and $PM_{2.5}$ in the US
Han & Naeher (2006)	x	x	x		x		Traffic-related effects on air quality
Nowak et al. (2006)		x	x	x	x	x	The effects of urban trees on air quality

The term mixed land use means that land use in a built-up area is mixed among commercial, business, industrial, residential and transport sites. The mixed land use was considered to be a strong positive influencing power of air pollution, however, the complexity of measurements made it difficult to include in studies (Chen et al., 2008; Jabareen, 2006). Yuan and his colleagues (2018) gathered GPS data and created a regressor to test the effects of mixed land use. Their findings showed contradiction to the expectations as higher land use mix in China was associated with a higher concentration of $PM_{2.5}$. A possible explanation was that traffic jams in rush hours offset the positive effects of land use mix. The use of street accessibility provides a less complex measurement of urban facilities. Studies found a positive association between roads and air pollution with a possible cause of road dust and exhausted gases of vehicles (Amato et al., 2010; Colbeck et al., 2011). Higher road density led to a higher concentration of PM_{10} (Clark et al., 2011). However, a study of Yuan and his colleagues (2018) found that street accessibility could reduce the concentrations of $PM_{2.5}$, PM_{10} and SO_2 as a result of that better urban road infrastructure could lead to higher vehicle speed and fewer traffic congestions.

The effects of transportation cannot be dissociated from the road factor. The first part of transportation is individual and freight traffic. As cities demanded an increasing amount of supplies of food and consumer products, the importance of freight transportation grew as well. In most cases, local freight transportation meant heavy trucks. The other side was the private vehicle use in cities, which was typically increasing in developing countries. Previous studies for several countries have shown that the road traffic had serious polluting impact on the environment (e.g. Basarić et al. (2014) in Novi Sad, Stroe et al. (2014) in Italy, Longley et al. (2015) in New Zeeland, Ducret-Stich et al. (2013) in Switzerland). Scholars found that traffic was a source of air pollution. They found that exhausted gases were the most important source of road emissions, and more specifically gases from diesel-powered heavy vehicles (trucks and buses) were accountable for higher PM_{10} pollution than normal highway traffic (Ducret-Stich et al., 2013). Moreover, PM_{10}, $PM_{2.5}$, NO_2 and CO were the most used air pollutants to examine road traffic effects. A study of Basarić and her colleagues (2014) found that street layout and housing influenced greatly the traffic pollution of Novi Sad.

The second part of urban traffic is public transport systems and more importantly buses and subways. With developing economies and emerging cities, the importance of fast and efficient public transport increased significantly. The subway systems could contribute to the goal without putting pressure on surface infrastructure but keeping the uptight schedule (Zhang et al., 2011). Tabatabaiee and Rahman (2011) examined the air pollution effects of the first subway line in Ahvaz and the results showed considerable effects of decreasing PM_{10} concentration. Gendron-Carrier and his colleagues (2018) found similar results, when they tested for NO_2, CO, SO_2, PM_{10} concentrations after opening a new subway line. Their study showed that the pollutant concentrations were reduced by 4% in the core city center and even calculated a potential \$594m per year mortality benefit of a subway line. The bus system is another important part of public transport. It has several advantages compared to the subway system. It is flexible so routes can be planned and changed easily without significant costs as they use urban infrastructure. Although the total pollution effect of a bus can be high, the per capita emissions are much lower compared to passenger vehicles. Furthermore, the spread of bus rapid transit systems (BRT) were attractive for residents by lowering the travel time (Goodman et al., 2005; Mishra et al., 2010). The promotion of alternative solutions for buses result in significantly lower emissions. In the 2000s, China started to promote the use of LPG, hybrid electric and fuel cell technology, while the European Union focused on clean fuel cell electric buses in order to decrease transport emissions. However, the development of fuel cell electric buses was still in progress according to recent studies (Chen et al., 2010; Hua et al., 2014; Ou et al., 2010).

The importance of urban green land was also pointed out by scholars. Former studies were consistent on that green areas had strong positive effects on air quality. Yang and his colleagues (2008) found that green roofs in Chicago cleaned a significant amount of O_3, NO_2, PM_{10} and SO_2. Furthermore, another study showed that urban parks in Shanghai were accountable for a significant decrease of air pollutant concentrations: 9.1% of PM_{10}, 5.3% of SO_2 and 2.6% of NO_2 (Yin et al., 2011), while Nowak, Crane and Stevens (2006) estimated that the total annual air pollution removal of trees was as high as 711000 metric tons per year in the US.

The use of control regressors is important in air pollution measurement in order to separate the urban form effects from other external circumstances. Scholars used different controls, however, there were clear trends for controlling the wealth of the city, climate, industrial emissions and urban boundaries. In order to control for the wealth, scholars used per capita GDP and found that the richer the city was the less it polluted. The studies found that the negative relationship was substantial for the concentration of $PM_{2.5}$, PM_{10}, CO, SO_2 and O_3 (Cárdenas et al., 2016; Yuan et al., 2018). The various climatic factors could influence the formation and dispersion of pollutants, so they affected the concentration of air pollutants (Jacob & Winner, 2009; US EPA, 2013). Scholars mostly included four climatic regressors: the average temperature, humidity, precipitation and wind speed. The analyses showed that higher average temperature and humidity were positively associated with air pollution especially with particles, while the speed of wind and precipitation had a negative relationship with the concentration of air pollutants (Cárdenas et al., 2016; Clark et al., 2011; Jacob & Winner, 2009; Longley et al., 2015; Yuan et al., 2018). The industrial emissions were a key source of air pollutants in cities so it was important to control in order to identify the true effects of urban forms. Studies found that the industrial emissions or share of industries had strong positive effects on all type of air pollutants (Cárdenas et al., 2016; Yuan et al., 2018). Finally, urban boundaries or urban land size were important controls for urban sprawl. Researchers were suggesting that increasing urban land could lead to a higher concentration of air pollutants (Yuan et al., 2018), the analysis of Cárdenas and his colleagues (2016) showed a positive association with PM_{10} and SO_2 concentrations.

3 Data

This section provides a critical review of the data sources used to test the hypotheses by arguing their advantages, limitations, reliability and validity. The section also contains the operationalization of variables in order to explain their measurements and provide help to the understanding of the econometric results.

3.1 Source Material

This thesis studies a sample of 14 Chinese cities between 2006 and 2013. The researcher gathered secondary data with the intention to create a panel dataset. Data was collected by accessing 17 different Chinese yearbooks published between 2007 and 2014. The yearbooks were downloaded from the China Statistical Yearbooks Database. The detailed list of yearbooks used can be found in Appendix A. The dataset contains different regressors including measurement for air pollutants, the elements of urban forms (transportation, roads, green areas, population density) and more general data of GDP, population, urban land and climate. The researcher collected 112 data points for every variable without missing values. The total list of variables and their measurements are discussed in the next section. Panel data or longitudinal data contain data from two dimensions, cross-sectional dimension and time series dimension. In other words, panel data is the observation of individuals over time. A panel dataset is balanced when each individual is observed every year if this is not the case, the data is unbalanced. There are general advantages of using panel data instead of cross-sectional or time series data. Thanks to the two dimensions, it provides more sample variation, less collinearity and more degrees of freedom. Furthermore, it makes easier to observe the individual heterogeneity among the individuals so more efficient modelling is possible. It also provides a better understanding of change over time and contributes to before- and aftereffects examination. Two big general limitations are the cost factor and complexity. Thus, the collection of panel data is much more costly, and the design is more complex than in the case of cross-sectional or time series data (Hsiao, 2013).

The created dataset contains 14 cities, which are Beijing, Chengdu, Chongqing, Guangzhou, Harbin, Hefei, Jinan, Nanjing, Shanghai, Shenzhen, Tianjin, Wuxi, Xi’an and Zhenjiang. Most of them are regional centers with high population, ranging from 3.2 to 33.5 million inhabitants in 2013. Hence, they represent regional differences as they are situated in different parts of China. They are all observed for the years between 2006 and 2013 without missing values for the measured variables. The reader should be aware of the special Chinese land administration in order to understand how the thesis used the dataset. In China, administrative city boundaries often include a huge amount of rural land with villages and smaller cities. This is referred in the thesis with the distinction total city (e.g. total city land, total city population), while the core built-up area of the city is indicated with an urban tag (e.g. urban land, urban population). The Chinese statistical yearbooks are edited by Chinese authorities, which reduces the reliability of the dataset, but also provides standardized measurements for the observations. The collection of the data was highly time-consuming so the observed number of cities remained low. However, it provides sufficient measurements in order to test the hypotheses. The model used for testing was built based on the quality and data availability in order to provide balanced panel data for hypotheses testing.

3.2 Model Variables and Expectations

The dependent variable measures the air quality in Chinese cities based on the annual average concentration of PM_{10}. The unit of the measurement is $\mu g/m^3$. The model contains 12 explanatory variables that all vary over time and individuals, so no time-invariant variables are included. Table 5 summarizes their short explanations, units and expected signs based on previous findings.

Table 5 Explanation of model variables, unit and expected sign

Variables	*Explanation*	*Unit*	*Expected sign*
udencity	Population density urban area	persons/km^2	-
centering	Ratio of urban area and total city population densities	percentage	-
greenland100	Area of greenland in the city	100 hectares	-
percapitaroad	Per capita urban road	m^2/person	+
subpasstraffic	Subway passenger traffic	1million passenger times	-
btpasstraffic	Bus and trolley passenger traffic	1million passenger times	-
highwaypasstraffic	Highway passenger traffic	1million passenger times	+
trucks	Number of trucks	1000 vehicles	+
urbanland	Urban area	km^2	+
secondaryGDP	Share of secondary industry in total GDP	percentage	+
percapitaGDP	Per capita GDP	Yuan/person	-
temperature	Average annual temperature	Celsius	+

3.3 Operationalization

The following part explains the measurement and rationale of the chosen variables with the most relevant descriptive statistics and previous literature in order to explore the dataset and provide a better understanding of the empirical findings. The model consists 1 dependent variable and 12 explanatory variables. All of them have the same number of observations as the panel database is balanced. Appendix B contains the main statistics including the means, standard deviations, minimum, maximum values and a highly detailed descriptive analysis of the data and variables as well. Comparing the between and within variations of the variables, it can be seen that they have changed slowly over time, while there are significant differences among the cities.

3.3.1 Dependent Variable - PM_{10}

The PM_{10} concentration was chosen in order to provide the measurement of air quality in Chinese cities. The selection of the dependent variable was based on previous literature. Since the measurement of air quality is a complex problem, former studies were collected and summarized in Table 4. It can be seen that they usually included particle concentration, either $PM_{2.5}$ (in 8 studies) or PM_{10} (15 studies). PM was accountable for serious air quality problems and results suggest that urban areas suffer from serious health and environmental impacts associated with PM (Fuzzi et al., 2015; US EPA, 2013; WHO, 2005; Zhu et al., 2018). The importance of particulate matters is justified by their presence in air quality standards and, furthermore, the impact of all relevant urban characteristics has been examined on $PM_{2.5}$ or PM_{10} earlier. The final choice of PM_{10} was based on data availability as the yearbooks used contained mostly the PM_{10} concentration only so the available data of $PM_{2.5}$ was limited. The variable shows the daily average of PM_{10} concentration for every year between 2006 and 2013 and it is measured on $\mu g/m^3$. Exploring the data showed that the total PM_{10} emissions increased by 12.4% over the period considered and, although there were 6 cities where it decreased, the reduction was only substantial in Beijing with 33% and in Zhenjiang with 18%. The worst performer was Jinan with almost 75% increase in the related period, so the city had the highest value of PM_{10} with 199 $\mu g/m^3$ in 2013. On the other side, the measurements showed only 54 $\mu g/m^3$ in Shenzhen in 2012, which was the lowest value. Nevertheless, it was still higher than the PM_{10} annual standard of WHO, which is 50 $\mu g/m^3$, but did not exceed the Chinese annual average 70 $\mu g/m^3$ standard (Clean Air Asia, 2019; WHO, 2005).

3.3.2 Independent Variables

The independent or explanatory variables were identified based on the previous studies in order to test the formerly stated hypotheses. They represent measurements for urban characteristics that influence air quality. Some variables represent one urban form element (e.g. population density) while others are combined with each other as their combination measures the effects of an urban characteristic (e.g. subway and bus passengers measuring for public transport). The reader should be aware of the previously explained difference between urban and total city areas. The former contains the core built-up area of the city, while the latter includes urban area and huge amount of rural land with villages and smaller cities.

Population density – udensity

The udensity variable is the measurement for urban population density. It is the ratio of urban population and urban land in persons/km^2. Studies emphasized the importance of high population density for sustainable urban development and showed that Chinese cities have favourable initial conditions with quite high population densities (Chen, Jia & Lau, 2008; Jabareen, 2006). Furthermore, the empirical results also induced that population density and air pollution had a negative relationship as a higher population density could lower the transportation needs and infrastructure costs. (Cárdenas et al., 2016; Yuan et al., 2018). The descriptive statistics indicate huge differences among cities based on the minimum (665.2) and maximum value (5578.38) of population density. 9 cities have experienced 15-70% population density increase, while the others remained stable. The data examination showed that these changes were consequences of increasing urban population and stable urban land areas. Table 5 shows that a negative association is expected between urban population density and PM_{10} concentration.

Population centering – centering

Population centering is a ratio of urban population density and total city population density. It basically shows how much the urban population is centered into the urban built-up area. The previous literature suggested that higher centrality resulted in better air quality. The negative association was confirmed for several air pollutants (Clark et al., 2011; Yuan et al., 2018), however polycentric structure of Chinese cities could lower the effect or even change it to a positive relationship between centrality and air pollutants (McCarty & Kaza, 2015). Examining the data, one can see that centering in Hefei or Chongqing was quite high, suggesting that their urban centers were much more populous than the total city area. On the one hand, population centering could reduce transportation in the urban area, while on the other hand, it could generate higher emissions due to the increased commuting. Nevertheless, the researcher awaits that a higher population centering results in lower PM_{10} concentration.

Green areas – greenland100

According to the Chinese yearbooks, the data of green land contained all the green areas open to public and green coverage of arbours, shrubs and plants. They included parks, street side green land and gardens. One unit change in the variable means 100 hectares increase or decrease. The positive impacts of green areas have been pointed out by several researchers. For example, a study of urban parks in Shanghai found a significant decrease in air pollutants connected to green areas (Yin et al., 2011). The panel data analysis showed significant increasing trends of green land in Chinese cities. Chongqing and Guangzhou have almost tripled their green land areas, while the least green developments have happened in Wuxi and Shanghai, where the increase was smaller than 30% between 2006 to 2013. This trend showed that China emphasized the enlargement of green areas in cities. As Table 5 shows, a negative relationship is assumed between green areas and PM_{10} concentration.

Street accessibility – per capita road

The per capita road or road density is a ratio of the total city road surface and total city population with the unit m^2/person. The area of roads referred to the area of roads, squares, bridges and tunnels including the pavement area as well. The per capita road ratio was a highly used measurement for street accessibility and for urban public facilities. Former studies tested the relationship of per capita road and air pollutants. Clark and his colleagues (2011) found that higher value of per capita road resulted in a greater concentration of PM_{10}, while other scholars provided evidence for potential sources, such as road dust and vehicle emissions (Amato et al., 2010; Colbeck et al., 2011). The study of Yuan and his colleagues (2018) also used the per capita road measurement for street accessibility, however, they found a negative relationship between air pollutants and road density. The statistics of data showed a 7.65 m^2 per person overall average, however, it varied significantly among the cities. In most cities, the road density increased during the period and it was due to the enormous road developments which could even compensate the increasing population in some cases. According to the previous findings, a positive relationship is expected between per capita road and PM_{10} concentration.

3.3.3 Measurement of Urban Traffic

The following part discusses the air quality effects of urban traffic. Their measurements are explained now to improve the clarity of the text. When a passenger starts a trip it is counted as one without considering the covered distance or the ticket price. The unit of the variables is 1 million passenger times and in order to provide better interpretation, the phrase passenger equals passenger trip. This measurement refers to the subway, bus and trolley, and highway variables, while the truck variable is measured on the number of trucks. The unit of the truck variable is 1000 vehicles.

Subway passenger traffic – subpasstraffic

The subway passenger traffic measures the number of passengers used the subway service with travel purpose. The exact measurement of the variable was explained above and the unit is 1 million passenger times. Subway system can replace substantial surface traffic and reduce the travel time and consequently, it can decrease the concentration of air pollutants. The air quality effects of subways were highly researched topic, empirical analyses showed that subway systems had substantial reducing effects on PM_{10} concentration (Gendron-Carrier et al., 2018; Tabatabaiee & Rahman, 2011). In this case, the variable provides the measurement to examine the conditions and development of subway systems in the cities. The collected data showed that 5 cities did not introduce any subway lines until 2013, while Chengdu and Xi’an opened their first lines in 2010 and 2012. The overall number of subway users increased more than 5 times between 2006 and 2013, which definitely showed the importance and efficiency of subway infrastructure in Chinese cities. Thus, the researcher’s expectation is that a higher number of subway passengers result in lower PM_{10} concentration.

Bus and trolley passenger traffic – btpasstraffic

The bus and trolley passenger traffic is a measurement for passengers used the buses or trolleys in urban areas. The measurement of the variable is based on the former explanation of passenger traffic and the unit is 1 million passenger times. The bus system is an important factor in most public transport systems. Although the emission of buses is usually high, the per capita pollution was low. However, the introduction of cleaner energy sources could increase the potential pollution lowering the effect of bus traffic. Furthermore, new infrastructure developments like BRT could make the bus system more attractive and less polluting (Chen et al., 2010; Goodman et al., 2005; Ou et al., 2010). The data showed that the number of passengers used buses or trolleys were increased by an average 49% in the cities and the total number of users reached 25.2 billion times in 2013, which indicated the importance of the systems. Based on that, a negative association is expected between bus and trolley passengers and concentration of PM_{10}.

Highway passenger traffic – highwaypasstraffic

The variable is a measurement of the number of highway passengers. The explanation of the measurement is explained earlier, and the unit is the same 1 million passenger times as it was for the two former variables. The highway passengers included those residents, who travelled by passenger vehicles on suburb highways, bridges and tunnels. The data showed how the transport infrastructure of cities have been used and how the travel demand has developed during the period. Hence, the variable provides information on changing road traffic. Previous studies have shown the direct air polluting effects of road traffic in several countries, and the main source of that pollution was connected to vehicle emission (Basarić et al., 2014; Ducret-Stich et al., 2013; Longley et al., 2015; Stroe et al., 2014). In developing countries, the motorization was extremely fast in the last decades so reducing road traffic pollution started to be more appreciated. The analysis of descriptive statistics showed increasing road traffic in the cities that might result in more traffic congestion and air pollution, so a positive relationship is expected between highway passenger traffic and PM_{10} concentration.

Number of trucks – trucks

The trucks variable measures the number of trucks that were registered and received a license tag from the Transport Management Office of the city. Due to the high number of trucks in the cities, the unit is 1000 vehicles so that the interpretation can be clearer. As it was explained earlier, the demand for freight transportation resulted in higher use of trucks. Scholars have tested the impacts of heavy vehicles (buses and trucks) on air pollution and found a significant increase in PM_{10} concentration (Ducret-Stich et al., 2013; Longley et al., 2015; Zhu et al., 2018). The descriptive statistics illustrated an increasing trend, as the number of registered trucks almost doubled between 2006 and 2013. Based on the data and previous findings a positive association is expected between the variable and the concentration of PM_{10}.

3.3.4 Control Variables – urbanland, percapitaGDP, secondaryGDP, temperature

The model contains four different control variables in order to separate the effects of urban forms on PM_{10} concentration from the effects of external circumstances. The first variable, urbanland measures the urban land area changes over time for the cities. The concept of sustainable urban forms emphasized the importance of preventing urban sprawl as it could result in more commuting (Chen et al., 2008; Jabareen, 2006). In parallel with that, the data showed no significant variation over time, which indicated that urban boundaries remained stable. Secondly, percapitaGDP is a measurement of population wealth in the cities. Scholars found that higher per capita GDP resulted in a lower concentration of several air pollutants including PM_{10} as well, which suggested that richer areas tended to care more about air pollution (Cárdenas et al., 2016; Yuan et al., 2018). The data illustrated the difference between the cities, which was quite high between the best and worst performers, however, all of them have experienced fast growing values between 2006 and 2013. According to previous studies, the emissions of industries highly influenced air quality. The secondaryGDP variable represents the share of industries in the total GDP. Cárdenas and his colleagues (2016) found a strong positive relationship between PM_{10} and the share of industries in GDP. The data showed huge variation among the cities and over time as well. Cities were averaging from 23% to 56% shares, while over the years the industrial cities (Chengdu, Hefei, Xi'an) have experienced growing shares, However, the secondary GDP share decreased significantly in more service-based cities like Shanghai or Beijing. Last, but not least temperature is the variable for controlling climate circumstances in the cities. The variable shows the average annual temperature in degree Celsius for every year between 2006 and 2013. Previous studies found a positive relationship between increasing temperature and PM_{10} concentration (Cárdenas et al., 2016; Jacob & Winner, 2009; Longley et al., 2015). Examining the data, highly differing values were observed in the cities, which was obviously because they were situated in different areas of China.

4 Methods

This section elaborates the concrete terms of the method used in order to test the hypotheses. The thesis used Fixed Effects (FE) model as it provided the best fit for the dataset. The model was compared with the pooled OLS and the Random Effects (RE) models. Based on Breusch-Pagan Lagrange multiplier (LM) test and the Hausman test, the FE model was found consistent and the most efficient. Furthermore, the section contains the explanation of the econometric model.

4.1 The Fixed Effects Model

Previous researchers have used different models for evaluating panel data depending on the nature of the dataset to be used. This thesis used FE model with the fixed effects estimator as it provided the best fit for the dataset based on the Breusch-Pagan Lagrange multiplier (LM) test and the Hausman test. In order to build a rationale for the FE model, in the following section, first, the models then the estimators and finally, the tests are discussed. Three models were considered by understanding their main characteristics, advantages and disadvantages to find the consistent and most efficient estimator. Besides the FE model, the other two models were the pooled OLS model and the Random Effects model (RE). The pooled OLS model provides constant coefficients based on the assumption of the cross-sectional analysis. It uses the simple OLS regression on panel data so ignores the panel nature of the dataset. Due to its restrictions, the pooled OLS model was not used often in the literature. The individual-specific effects models are much more popular and assume that there is unobserved heterogeneity over the individuals. These effects vary over the individuals but do not change over time. The difference between FE and RE models is their assumptions on the correlation between the individual effects and the independent variables. The RE model assumes that the distribution of the individual-specific effects are independent among the explanatory variables and includes the unobserved heterogeneity effects in the error term. On the contrary, the FE model assumes that the individual effects are correlated with the independent variables so it lets these effects to vary over the individuals but not over time. In order to choose the right model for the dataset that is consistent and efficient, three panel data estimators were selected to the aforementioned models. If the independent variables are exogenous then the pooled OLS estimator is consistent and the estimator is efficient, the error terms are homoscedastic but that is really unlikely in real circumstances. The random effects estimator assumes that the individual-specific effects can vary among individuals. The fixed effects estimator assumes that there is one effect size which is true for all individuals and the standard error is the random error among the individuals. Although it can be used to estimate both the pooled OLS model and the RE model, the fixed effects estimator is the most efficient if the right model is the FE. That is true for the random effects estimator as well, which provides a good fit for pooled OLS but it is the most efficient if the right model is the RE (Allison, 2009; Bell & Jones, 2015; Hsiao, 2013; Wooldridge, 2010).

4.1.1 The Breusch-Pagan Lagrange Multiplier Test

There are two tests that were executed in order to compare the different estimators. Firstly, the Breusch-Pagan Lagrange multiplier (LM) test gives the results to decide between the RE model and the pooled OLS. The null hypothesis assumes that the variance across individuals is equal to zero. If the P value is smaller than 0.05, we can reject the null hypothesis, thus, the variance of random effects is not zero. In that case, the RE model is more appropriate than the pooled OLS model. The results summarized in Table 6 shows that the null hypothesis can be rejected, so the pooled OLS model is not the appropriate model for the dataset (Breusch, Trevor S., 1980). It also suggests that the variance of the random effects among the individuals are not zero, however, it cannot help to decide between RE and FE models.

Table 6 Breusch and Pagan Lagrangian multiplier test for random effects and pooled OLS

Estimated results:		
	Var	sd = sqrt(Var)
PM_{10}	608.5971	24.6698
e	195.2171	13.9720
u	29.6187	5.4423
Test: Var(u) = 0		
chibar2 (01) = 23.48		
Prob > chibar2 = 0.0000		

4.1.2 The Hausman Test

The Hausman test helps to decide this question. The test compares two estimators in order to find out which is efficient and unbiased. It compares the expected values and the variances of the proposed estimator and an alternative estimator which assumed to be not efficient under the proposed specification. The construction of the test provides that the estimators are considered separately without any interaction. In Stata, the first estimation is efficient if the null hypothesis is rejected, otherwise, the second estimator is efficient. The hypothesis can be rejected if the P value is smaller than 0.05. In our case the null hypothesis assumes that the coefficients of the FE and RE model are equal, so the rejection of the hypothesis means that FE is the efficient model and if it cannot be rejected then the RE is more efficient. Table 7 shows the Hausman test, it compares the results of the FE and the RE models and suggests that the hypothesis can be rejected at 5% significance level so the FE model is more efficient for the panel dataset (Chmelarova, 2007; Hausman, 1978).

Table 7 Hausman test for fixed and random effects

	Coefficients			
Variables	(b) Fixed	(B) Random	(b-B) Difference	sqrt(diag(V_b-V_B)) S.E.
udensity	0.0315469	0.0025812	0.0289657	0.0115297
centering	-0.1642339	0.0187382	-0.1829721	0.0664294
greenland	0.0015131	0.0005245	0.0009886	0.0006083
percapitaroad	3.906543	3.424999	0.481544	1.276611
subpasstraffic	-0.0142043	-0.0090163	-0.005188	0.0025738
btpasstraffic	-0.0198206	0.0172945	-0.0371151	0.006403
highwaypasstraffic	-0.0132535	-0.0130321	-0.0002214	0.0071593
trucks	0.0387147	-0.0459671	0.0846818	0.014345
urbanland	-0.0637249	-0.0006104	-0.0631145	0.0320303
percapitaGDP	0.0000045	-0.0002743	0.0002788	0.0001279
secondaryGDP	-0.9557602	0.1968272	-1.1525874	0.9648146
temperature	13.40209	-3.404126	16.806216	3.056165

b = consistent under Ho and Ha; obtained from xtreg

B = inconsistent under Ha, efficient under Ho; obtained from xtreg

Test: Ho: difference in coefficients not systematic

chi2(11) = (b-B)'[(V_b-V_B)^(-1)](b-B)

= 95.79

Prob>chi2 = 0.0000

4.1.3 General Limitations of the FE Model

The reader has to be aware of the general limitations of the FE model. First of all, due to the high number of regressors, degrees of freedom fall, and error variances rise. It also can lead to unattractive results and complex interpretation. Another problem can be that the explanatory variables can have predicting effects on each other, which leads to multicollinearity problems. Moreover, the model is unable to include the effects of variables, which are invariant over time such as sex or education(Allison, 2009; Hsiao, 2013; Vijayamohanan, 2017). A more general issue with quantitative studies is the problem of causality and correlation. The researcher endeavoured to include most of the relevant variables in order to provide the best possible explanations of the findings. People often misunderstand the difference between the two statistical terms. Correlation tells how strongly two variables are associated. It shows how these variables change together. However, it does not imply that they have a causal relationship with each other. Hence, it is important to take most circumstances into consideration so that the research can explore whether an association is causal or correlational (Liebetrau, 2015; Wright, 1921).

4.2 Econometric Model

Based on the previous explanations the following econometric model was chosen in order to execute the FE model on the panel data.

$$Y_{it} = \beta_0 + \beta_i x_{it} + \alpha_i + \varepsilon_{it}$$

Y_{it} – the dependent variable

β_0 – the intercept

β_i – the coefficients

x_{it} – the independent variables that vary over time

α_i – unobserved heterogeneity (vary over individuals, but not over time)

ε_{it} – idiosyncratic errors

5 Empirical Analysis

This section first presents the results of the econometric model. Table 8 states the results of the econometric model. Afterwards, the result section provides the key outcomes in order to test the formerly stated 6 hypotheses. The second section discusses the potential argumentation of the findings from different theoretical perspectives and relates them to previous findings.

5.1 Results

Table 8 The regression results of the FE model

Hypotheses	VARIABLES	(1) FE (robust)
H1	udensity	0.0315**
		(0.0116)
H2	centering	-0.164**
		(0.0630)
H3	greenland100	0.151*
		(0.0726)
H4	percapitaroad	3.907**
		(1.677)
H5	subpasstraffic	-0.0142*
		(0.00673)
H5	btpasstraffic	-0.0198**
		(0.00681)
H6	highwaypasstraffic	-0.0133***
		(0.00393)
H6	trucks	0.0387**
		(0.0148)
Control	urbanland	-0.0637**
		(0.0253)
Control	percapitaGDP	4.49e-06
		(0.000149)
Control	secondaryGDP	-0.956
		(0.917)
Control	temperature	13.40**
		(4.768)
	Observations	112
	Number of citynum	14
	R-squared	0.365
	Year FE	YES

Robust standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

H1: Increasing urban population density has a substantial negative effect on particulate matter (PM_{10}) concentration.

The statistically significant result of udensity suggests that the urban population density is positively associated with PM_{10} concentration. More specifically, an increase of standard deviation in urban population density (1442 people/km^2), which was approximately the difference between Wuxi and Guangzhou in 2013, results in 45.42μg/m^3 higher PM_{10} concentration in a city. This result confirms the findings of Clark, Millet and Marshall (2011), who tested the air quality in US cities and found a strong positive relationship between urban population density and $PM_{2.5}$ level. On the other hand, the study of Yuan and his colleagues (2018) reported contradicting results of a strong negative relationship between air pollutants and urban population density. Furthermore, sustainable urban form concepts included the need for high urban population density in order to reduce transport needs and utilize smart infrastructure planning (Chen et al., 2008; Jabareen, 2006). Nevertheless, the H1 hypothesis can be rejected as the finding of the model suggests the opposite effect.

H2: Population centering is negatively associated with particulate matter (PM_{10}) concentration.

The centering variable of the model is significant at the 95% significance level. The result of the model shows a negative relationship between population centering and PM_{10} concentration. One unit increase results in a 0.164μg/m^3 decrease of PM_{10}. The average change of centering during the eight years was 7.66, which only accounts for 1.26μg/m^3 per city. It shows that the effect of centering has not changed a lot over time, however, among the cities it had significant effects. In 2013, while the average effect of centering was only 42.49μg/m^3 lower PM_{10} concentration, in Harbin and Chongqing it was accountable for a much more significant 137.59 and 113.65μg/m^3. The finding is consistent with the former study of Yuan and his colleagues (2018) that found a negative association between centering and the level of several pollutants including PM_{10}. In respect of the hypothesis, H2 cannot be rejected, the findings support the hypothesis that population centering is negatively associated with PM_{10} concentration.

H3: The enlargement of urban green areas decreases the particulate matter (PM_{10}) concentration.

One of the most surprising findings is that the area of green land is positively associated with the concentration of PM_{10}. The variable is significant, although only at the 90% significance level. One unit increase has a substantial positive effect of 0.151μg/m^3 on PM_{10} concentration. There was only one year in only one city (Wuxi, 2008) when the urban green land area decreased compared to the previous year, which showed the importance of green area developments in Chinese cities. One standard deviation increase results in 11.50μg/m^3 higher PM_{10} concentration. This finding contradicts with previous results of most scholars. Yang and his colleagues (2008) found that green roofs in Chicago cleaned significant amount of air from pollutants, especially PM_{10}, while another study estimated that trees annual air pollution removal was as high as 711000 metric tons in the US (Nowak et al., 2006). The result of the model contradicts with the expectations of the researcher so the H3 hypothesis can be rejected, the enlargement of urban green areas does not lower the PM_{10} concentration.

H4: Street accessibility has a strong positive effect on particulate matter (PM_{10}) concentration.

A significant positive association can be observed between per capita road and PM_{10} concentration. The outcome of one m^2 per person higher street accessibility value is 3.907μg/m^3 higher PM_{10} emission. As the average per capita road increased by 1.61 m^2 per person in the cities during the period, it resulted in an average 6.30μg/m^3 higher PM_{10} concentration in the cities. The finding is consistent with a study about Pakistan that found a strong positive association between roads and air pollution (Colbeck et al., 2011). It was not only the impact of fuel combustion but also the weight and pressure of vehicles creating a significant amount of dust (Amato et al., 2010). However, other results pointed out a negative relationship and assumed that the enlargement of road infrastructure might have positive effects on reducing traffic congestions, which could result in lower air pollution (Yuan et al., 2018). Nevertheless, the result supports the H4 hypothesis that street accessibility has a strong positive relationship with PM_{10} concentration.

H5: More developed public transport systems have strong negative effects on particulate matter (PM_{10}) concentration.

The statistically significant subway passenger traffic variable has a negative relationship with the concentration of PM_{10}. Hence, with 1 million more metro passengers the PM_{10} concentration decreases by 0.0142μg/m^3. The analysis of the total number dynamics makes the result more essential. The length of the subway systems has more than tripled during the period and it brought 5.5 times more passengers. In 2013, the number of new subway passengers in Beijing, Shanghai, Guangzhou and Shenzhen were accountable for 35.52μg/m^3, 26.28μg/m^3, 25.20μg/m^3 and 11.75μg/m^3 higher decrease in PM_{10} concentration compared to 2006. These finding confirms previous studies, Tabatabaiee and Rahman (2011) found that the first line in Ahvaz it reduced the concentration of different air pollutants including PM_{10}, while Gendron-Carrier and his colleagues (2018) found that the particulate concentration (PM_{10} and $PM_{2.5}$) was 4% lower in city centers after a subway line was opened.

The finding shows that the bus and trolley passenger traffic has also a negative relationship with PM_{10} concentration. The 0.0198μg/m^3 decrease per 1 million bus users is even higher than it was at the metro passengers. The observed cities with the biggest changes of bus user numbers have experienced an annual average increase of 100 million passengers, which resulted in 12.87 to 17.10μg/m^3 PM_{10} concentration reduction per years. Literature emphasized the important cost advantages of bus and trolley systems and, furthermore, the new developments might be able to continuously reduce the air polluting effects of buses (Goodman et al., 2005; Mishra et al., 2010; Ou et al., 2010).

The effects of the two aforementioned variables need to be combined in order to summarize the potential effects of public transport systems. Both variables are negatively associated with PM_{10} concentration. In 2006, 17.94 billion passengers used buses and trolleys, while the subway system had 1.82 billion users. In the next eight years, a lot of developments happened, so the bus and trolley system had 7.26 billion extra passengers and with an even higher increase, 8.32 billion more people chose the subway system for transportation. Hence, in 2013, the increasing number of passengers used public transport resulted in 261.89μg/m^3 higher decrease of PM_{10} concentration in the cities compared to 2006. Based on these findings, the H5 hypothesis cannot be rejected, the results support that developing public transport systems have a strong and negative effect on PM_{10} concentration.

H6: Urban traffic has a positive relationship with particulate matter (PM_{10}) concentration.

Another surprising and statistically significant result is the negative relationship between highway passenger traffic and PM_{10} concentration. The finding shows that 1 million more passengers using their private vehicles on the highways results in 0.0133μg/m^3 reduction of PM_{10} concentration. Based on that, the PM_{10} emissions decreased by an average 4.23μg/m^3 between 2006 and 2013 because of the increasing highway passenger traffic. Scholars have shown that road traffic has serious polluting impact on the environment in different areas of the world: in Novi Sad (Basarić et al., 2014), in Italy (Stroe et al., 2014), in New Zeeland (Longley et al., 2015), in Switzerland (Ducret-Stich et al., 2013).

The number of trucks is positively associated with the PM_{10} concentration as it was expected. A unit increase of the variable, means 1000 extra trucks registered in a city, results in 0.0387μg/m^3 higher PM_{10} concentration. In 2013, the trucks were accountable for 128.51μg/m^3 PM_{10} emissions, which was 92% higher than they were for eight years earlier. The finding is consistent with previous studies assuming that heavy trucks are the main source of PM_{10} pollution in highway traffic (Longley et al., 2015; Stroe et al., 2014).

As these two variables represent the urban traffic, their united effect is needed in order to test the H6 hypothesis. The effect signs are different for the variables as increasing highway passenger traffic reduce PM_{10} concentration, while the truck variable has a positive association with the PM_{10} level. Summarizing both impacts shows a substantial negative effect on PM_{10} concentration. The annual average of the combined effects was 82.78μg/m^3 decrease of PM_{10} emission between 2006 and 2013. The detailed yearly effects can be seen in Appendix C. Hence, the H6 hypothesis can be rejected, so urban traffic does not have a positive relationship with PM_{10} concentration.

Control variables

Among the control variables, urban land and temperature are statistically significant variables. Urban land area is negatively associated with PM_{10} concentration and has a relatively strong effect of 0.0637μg/m^3 decrease, however, the data analysis showed that urban land areas were stable during the period so the total effects were limited. The temperature is strongly positively associated with PM_{10} concentration. It is not surprising as former studies indicated that the meteorological circumstances could influence the creation of particulate matters (Cárdenas et al., 2016; Yuan et al., 2018). Furthermore, no statistically significant association can be found between per capita GDP and PM_{10} concentration. The variable shows a positive effect on PM_{10} emissions suggesting that as the population can afford, the individual transportation starts to become more popular. The share of the industry has a negative and statistically not significant relationship with PM_{10} concentration. The negative association might be the result of the out moving "dirty" industries as the economies of the cities were transforming from industry perspectives towards the service sector.

5.2 Discussion

This section summarizes the findings, relates them to the former literature, provides explanations of the potential causes, elaborate the limitations and interpret the contribution of the thesis.

As the research question stated, the thesis aimed to examine how urban forms affected air quality in Chinese cities between 2006 and 2013. The researcher used previous studies to identify the most comprehensive combination of urban forms with the intention to discover the research topic and answer the main research question. Based on the results of the econometric model, the hypotheses testing suggests that centering, public transport, private passenger traffic have a negative association, while urban population density, area of green lands, street accessibility and freight traffic have a positive relationship with PM_{10} concentration. The analysis endeavoured to separate external circumstances by including controls of climate, people's wealth, industrial emission and urban boundaries. Thus, the key findings of the thesis indicate a strong relationship between urban forms and PM_{10} concentration, which is consistent with the main findings of related scholars.

The results do not fit with the theory that a higher urban population density results in a lower concentration of air pollutants. Generally, scholars expected a negative relationship between urban population density and air pollutants. Moreover, it was an important feature of sustainable urban form concepts as it could lower the need for transportation (Chen et al., 2008; Jabareen, 2006) and empirical studies also pointed out the negative relationship measured on $PM_{2.5}$, PM_{10}, O_3 and SO_2 (Cárdenas et al., 2016; Yuan et al., 2018). Nevertheless, the contradicting findings have possible explanations as well. In the case of polycentric cities, high population densities might not result in any reduction of transport needs as people travelled among the centers. Connecting to that, a recent study of Liu & Wang (2016) tested polycentricity of Chinese cities and found that 60% of the cities had more than one centers. According to their findings, 6 out of the cities (Shanghai, Shenzhen, Chongqing, Tianjin, Harbin, Nanjing) examined in this thesis had 5 or more city centers. This factor might change the sign of the effect in the analysis. Furthermore, some scholars questioned the generally accepted view and suggested that in some cities lower urban population densities might improve air quality (McCarty & Kaza, 2015). The measurement of the variable might limit the validity of the result as some scholars emphasized the need for distribution of population density, which could be collected from landscan databases, however, the data availability did not support panel modelling. On the other side, the variable was statistically significant and showed a strong positive association with PM_{10} concentration.

The result builds on existing evidence that centering is negatively associated with the concentration of air pollutants. The findings are consistent with the previous examination of the relationship of centrality and concentration of PM_{10}, $PM_{2.5}$, SO_2, CO and O_3 (Clark, Millet & Marshall, 2011; Yuan et al., 2018). A possible explanation might be that higher centrality of cities could reduce the need for commuting so consequently it could lead to a decrease of PM_{10} concentration. The variable has the advantage of containing the distribution factor of population density, which considered an important factor by scholars (Yuan et al., 2018). Furthermore, it is highly connected to the previous urban population density variable, which might raise multicollinearity issues, however, the coefficient is statistically significant and shows a strong effect, which points out that centering is a strong predictor of PM_{10} concentration.

The experiment provides new insight into the relationship between urban green areas and PM_{10} concentration in China. It is a surprising finding that increasing green areas in cities boosts the concentration of PM_{10}. Especially that former studies emphasized the strong negative association between green areas and air pollutants. In Chicago, the green roofs cleaned significant amount of air pollutants (Yang, Yu & Gong, 2008), even in Shanghai, an analysis showed that the urban parks were accountable for a substantial decrease of air pollutants (Yin et al., 2011). The data showed significantly increasing urban green areas in Chinese cities. One possible explanation for the positive association might be that the highly polluted cities tried to compensate and clean air pollution by enlarging the green areas in urban districts, which led to a controversial result. This finding suggests a correlation between green areas and PM_{10} concentration, due to both increased significantly during the period. However, it does not imply a causal relationship between the variables.

The finding related to street accessibility shows high consistency with previous results. Scholars found that roads are not directly connected to air pollutants but through the road traffic of passengers and freight transportation (Basarić et al., 2014; Ducret-Stich et al., 2013; Stroe et al., 2014). During an experiment of road-related air pollution in Pakistan, the overall mean concentration of PM_{10} was $103\mu g/m^3$, which is more than double of the WHO limit suggestion (Colbeck et al., 2011). Others found a limited but negative relationship and assumed that more road surface available in city center might result in reducing traffic jams and increasing average speed which were associated with lower exhaust gas pollution (Tong et al., 2000; Yuan et al., 2018). However, infrastructure plays an important role in urbanization. The data suggested that per capita road has increased significantly showing that the development of roads could even offset the growing population, which was also substantial during the period. Furthermore, the street layout could influence greatly the air pollution in city centers (Basarić et al., 2014) and the weight and pressure of vehicles could create also a significant amount of dust (Amato et al., 2010).

The effects of Public transport cannot be fully separated from street accessibility. Internal combustion engines of buses emit a significant amount of exhaust gases, however, comparing a bus full of people with a car 1-2 persons, the difference of per capita emissions can be significant. The increasing number of bus passengers suggest that the lines have been enlarged and developed in order to provide good public transport options for the citizens and the introduction of BRT systems might make it even more attractive for residents by lowering the travel time (Goodman et al., 2005; Mishra et al., 2010). Furthermore, the government of China have started to promote alternative vehicle fuels for buses since the 2000s in order to decrease the transport emissions (Ou, Zhang & Chang, 2010). The number of bus and trolley passengers increased significantly during the period so these systems could prevent a substantial amount of private passenger traffic. With the development of new energy sources, the cost-effective bus lines have a high potential for playing an important role in future traffic systems. Another important part of Chinese public transportation is the fast-growing system of subways. The results build on existing research of that introduction of subway lines strongly reduce the air pollution in cities. Scholars found that opening a new line could reduce significantly the PM_{10} concentration (Gendron-Carrier et al., 2018; Tabatabaiee & Rahman, 2011). The data suggest that China has emphasized subway system developments as the length of the subway more than tripled and the number of passengers increased by 5.5 times during the period. The dynamics of the data suggest continuous developments of subway lines in Chinese cities so passengers can save time and the pollutant concentration can decrease in the future. The results of both variables are negatively associated with PM_{10} concentration so a strong effect of public transportation can be observed on PM_{10} concentration.

Road traffic is also connected to street accessibility and public transport. While previous studies found that road traffic was strongly positively associated with air pollutants, the results of the study did not fit fully with them. Two variables were tested to examine urban road traffic effects. The result of the truck variable is consistent with previous findings. Researchers found that traffic exhaust was the most important source of road emissions, and more specifically diesel-powered heavy vehicles (mostly trucks or buses) were accountable for higher PM_{10}

pollution than normal highway traffic (Basarić et al., 2014; Ducret-Stich et al., 2013; Longley, Somervell & Gray, 2015; Stroe et al., 2014). The local number of trucks almost doubled in the cities according to the database. This might be the consequence of increasing demand for food and consumer products by the urban population, which could be only served by local freight traffic. The other variable, highway passenger traffic shows a highly surprising sign. It contradicts with previous studies and indicates that an increase of private passenger traffic results in lower PM_{10} concentration. Based on previous findings the result of highway passenger traffic implies correlation and not casualty. The main private transport modes are automobile or motorbikes so the source of pollution is mainly fuel combustion. The result suggests that per capita emission decreased and it could be true only if the total PM_{10} emission got lower as the number of passengers increased during the period. It might be a consequence of a higher number of motorbike users and a decreasing number of cars or the average number of passenger per car increased significantly. Another aspect might be the formerly mentioned higher average speed in city centers due to the traffic favourable infrastructure developments (Tong et al., 2000). The next possible explanation might be that due to the significant economic development in China, the older and more polluting vehicles have been replaced by newer and cleaner options. Finally, the effects of traffic on highways of built-up and outer areas could differ as circumstances such as higher wind speed or precipitation might reduce the PM_{10} concentration outside of the city center. Nevertheless, the combination of the two results indicates that road traffic is negatively associated with PM_{10} concentration.

Some potential limitations need to be elaborated. Due to the difficult separation of different characteristics, one of the issues might be multicollinearity among the variables. Roads and the road traffic cannot be fully separated and the same is valid for urban population density and centering as well. Another factor can be to examine the chosen urban features. Some might argue the missing of accurate measurement for mixed land use. Scholars highly emphasize the importance of mixed land use in sustainable urban forms (Jabareen, 2006; Yuan et al., 2018). Furthermore, the role of bicycles might be added as well in order to better understand the processes of urban traffic. However, the data available didn't make it possible to include those measurements as well. The correlation and causation problem was a key issue as well. In the cases of green areas and highway passenger traffic, the results imply a correlation between the variables and PM_{10} concentration. This made difficult the interpretation of the results and suggested that in a future study other circumstances need to be included in order to clarify the relationships.

In sum, the thesis provided a good insight into the air quality effects of urban forms. The recently increasing air quality issues drew attention to serious health problems. As the process of urbanization boomed, cities became the most affected areas and their inhabitants suffered the most from health issues. The results do not confirm all the theory based expectations. On the other hand, some findings are consistent with previous studies as well. Scholars mostly focused on urban forms without including the direct traffic effects, while these results suggest that urban traffic is an important urban characteristic and it has a substantial impact on the concentration of PM_{10} in Chinese cities. Chinese cities have favourable initial conditions that make sustainable urban development possible. Based on the results, the key point is to support developments into a sustainable and efficient transport system. In China, population centering plays a more important role than high population density as it can prevent regional commuting, while the polycentric features of the cities can offset the positive effects of higher urban population density. Furthermore, the recent public transport developments resulted in a substantial reduction of PM_{10} concentration. The decision makers need to continuously support the improvements of the subway and bus systems in order to provide efficient public transport options instead of private transport. They also need to focus on enlarging green areas and support the facilities of walking and cycling. The compact city concept can guide them in sustainable urban development. However, it is also important to increase the awareness of inhabitants what they can do in order to reduce their emissions. Lowering air pollution is the only way to reduce serious health impacts. China already took some potential steps but they need to continue the sustainable improvements of urban forms because that can provide clean air for the next generations.

6 Conclusion

This section summarizes the key points of the study.

6.1 Research Aims, Findings and Future Research

The thesis aimed to identify how urban forms affected air quality in Chinese cities between 2006 and 2013. Based on the quantitative analysis of the relevant urban form elements, it can be concluded that urban population density, green land, street accessibility and the number of trucks are positively correlated with PM_{10} concentration. The results also indicate a negative association between population centering, subway, bus, highway passenger traffic and PM_{10} emissions. The main results strengthen the validity of the model, as the characteristics chosen were statistically significant and had a substantial influence on PM_{10} concentration. In sum, the discussion in section 5.2 indicates that the study meets its objectives. Based on previous research, it can contribute to the topic of urban forms and air quality at least in three perspectives. Firstly, the results confirm the strong association between urban forms and PM_{10} concentration. Secondly, the panel database can add to the validity of the research as the lack of necessary data prevented most scholars to collect panel database. Finally, the thesis identified a more comprehensive set of urban forms than scholars tested earlier. However, ample space for further research remains. The results clearly illustrate the negative correlation between private passenger traffic and the PM_{10} level, but it raises the question of what other circumstances could affect that relationship. The positive association of green areas and PM_{10} can also be further researched in the future. China is a fast-changing country, sustainable urban development is important to reduce health issues caused by air pollution. Future studies can collect more comparable and broader urban form data across time in order to research sustainability and improve accuracy.

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Appendix A – List of Yearbooks

Table 9 List of Chinese Statistical Yearbooks

Name of yearbook	Year
China City Statistical Yearbook	2007-2014
China Statistical Yearbook on Environment	2007-2014
China Meteorological Yearbook	2007-2014
City yearbooks	
Beijing Statistical Yearbook	2007-2014
Chengdu Statistical Yearbook	2007-2014
Chongqing Statistical Yearbook	2007-2014
Guangzhou Statistical Yearbook	2007-2014
Harbin Statistical Yearbook	2007-2014
Hefei Statistical Yearbook	2007-2014
Jinan Statistical Yearbook	2007-2014
Nanjing Statistical Yearbook	2007-2014
Shanghai Statistical Yearbook	2007-2014
Shenzhen Statistical Yearbook	2007-2014
Tianjin Statistical Yearbook	2007-2014
Wuxi Statistical Yearbook	2007-2014
Xi'an Statistical Yearbook	2007-2014
Zhenjiang Statistical Yearbook	2007-2014

Appendix B – Descriptive Statistics

The PM_{10} variable provides the measurement for the air quality, so it is crucial to explore the data. The total PM_{10} emissions increased by 12.4% over the period considered. There were 6 cities where it decreased, but the reduction was only substantial in Beijing with 33% and in Zhenjiang with 18%. The worst performer was Jinan with almost 75% increase in the related period, thus, the city had the highest value of PM_{10} with 199 $\mu g/m^3$ in 2013. On the other side the measurements showed only 54 $\mu g/m^3$ in Shenzhen in 2012, which was the lowest value. The overall mean value was 101.79 $\mu g/m^3$ for the cities. Furthermore, the between variation was higher than the within variation pointing out that the values vary more between the cities than within them.

Udensity is the variable for urban density. As the descriptive statistics show there huge difference between the minimum value (665.2) and the maximum value (5578.38) suggesting that the cities have different structures with varying land and population. In 5 cities the urban density has not changed drastically or even remained stable during the period, the other have experienced 15%-70% population density increase. Most of these changes were due to the increasing population. Examining the population data, which was used to calculate the urban density, one can see that there were no growing population in cities with low density changes, but the population in all the other cities have grown by an average 36%. The urbanland variable measures the urban area development over time. The low value of the within variation illustrates that the urban areas have not varied a lot therefore there are only two of them which have experienced significant changes. It also explains why the population changes determine most of the density developments. Hence, the area variation among the cities caused most of the overall variation.

Centering is highly connected to population and city borders as it is a ratio of the urban area density and the prefectural level city density. As the data shows there is one city where the values are equal, Shenzhen. On the other end, in Hefei or Chongqing the urban area densities are 8 and 7 times higher than the total area densities. It means their actual city centers are much more populous than the area which is connected to the city as well so less commuting required to get access to city life and services.

The greenland100 variable measures the total green areas of the cities in 100 hectares. The regressor varies from 53 to 480 among the cities and all the cities have enlarged their green spaces during the period. Chongqing and Guangzhou have almost tripled the green land, while Wuxi and Shanghai have not reached 30% increase from 2006 to 2013.

The percapitaroad regressor is measuring the road m^2 per person in the cities. The overall mean was around 7.65 m^2 per persons, but in Chongqing it was only 2.12 while Shenzhen had 14.46 m^2 in 2006. This shows that there is a huge variation among the cities. Only in Shenzhen and Guangzhou declined the value of per capita road, Beijing, Hefei and Shanghai remained close to zero change, but the other 9 cities have experienced increasing numbers. In most of the cases the area of roads has grown during the period except Shenzhen. Hence, in the 9 cities that growth was higher than the population change over time, while in the stable cities the growth was close to equal and in Guangzhou and Shenzhen it led to decreasing figures.

The subpasstraffic variable measures the amount of people used the subway in the cities. As it can be seen, the minimum value is zero which points out that there were no subways at that year. More specifically, Chengdu opens its line in 2010, Xi'an in 2012 and there were 5 cities that has not opened any lines until 2013. However, it is an important measurement as the subway lines are supposed to be the less pollutant way of public transportation. It clearly shows the potential of the subway that the cities with data for the whole period experienced an average 9.9 times more passengers in 2013 than 8 years earlier. The lack of subway lines in some cities and the fast development in others explain the high between and within variations.

The next variable - btpasstraffic – is the measurement for the number of people used the buses and trolleys in the period. The bus and trolley systems are cheap and effective mode of public transportation and provides good accessibility as the routes can be planned and replanned with low costs. The within variation suggests that the bus systems have experienced serious developments over the years, more specifically the number of the bus and trolley passengers increased by an average 49% in the 14 cities. The between variation shows that there was a huge difference among the cities, but that's reasonable because of the varying population and city area.

The next variable, highwaypasstraffic representing the amount of times passengers travelled on the highways. The data suggests that there are huge differences among the cities, which is mostly due to the formerly mentioned structural, populational and areal differences. However, it is more interesting, that all the cities have experienced growing highway passenger traffic over the years. The average annual increase was 19.63%, which shows the growing importance of highways in passenger traffic in China.

PercapitaGDP measures the GDP per persons in yuan. The high within and between variation suggest that there are differences among the cities, but also substantial improvements have happened during the related period. The cities had positive changes in every year with a more than 13% annual average increase, which is a clear sign for the growing economy. Shenzhen had the highest with more than 130 thousand yuan per person while Xi'an had the lowest with almost 57 thousand in 2013, however Xi'an has achieved 200% increase during the period, which was the clearly the highest development among the cities.

The secondaryGDP is a measurement for the share of secondary GDP in the total GDP. The data shows that there are significant differences among the cities. Shenzhen has a really low share of secondary GDP with averaging 3.09%, while the other cities averaging from 23% to 56% over the years. Comparing the numbers from 2006 and 2013, one can see that only three cities (Chengdu, Hefei, Xi'an) have experienced growing share of secondary GDP, while in Shanghai or Beijing it has decreased by more than 20%.

The temperature variable measures the annual average temperature in degrees Celsius. Not surprisingly, as China is a huge country, the temperature varies a lot among the cities. The coldest place is clearly Harbin with average from 4 to 6 degrees Celsius, while the hottest is Guangzhou with always higher than 21 degrees Celsius and the overall average is around 16 degrees Celsius. This regressor has not varied a lot over time, the temperature averages were quite stable.

Table 10 Descriptive statistics

Variable	Mean	Std.Dev.	Min	Max	Observations
PM10					
overall	101.795	24.67	54	199	N=112
between		20.895	59.75	130.625	n=14
within		14.125	80.17	175.17	T=8
udensity					
overall	2318.661	1442.356	665.2	5578.38	N=112
between		1457.842	667.92	5009.851	n=14
within		298.522	1178.797	3479.467	T=8
centering					
overall	240.045	191.115	100	839	N=112
between		193.003	100	659.25	n=14
within		40.298	87.42	443.42	T=8
greenland					
overall	152.464	76.164	53.37	48100	N=112
between		68.25253	64.2675	34987.5	n=14
within		37.899	-19.411	28358.91	T=8
percapitaroad					
overall	7.66	3.269	2.12	15.59	N=112
between		3.193	2.931	12.399	n=14
within		1.062	5.001	11.971	T=8
subpasstraffic					
overall	373.858	687.426	0	3204.69	N=112
between		612.971	0	1712.854	n=14
within		347.154	-684.066	1865.694	T=8
btpasstraffic					
overall	1594.957	1110.046	277.84	5165.17	N=112
between		1121.94	364.762	4770.103	n=14
within		229.854	804.045	2178.35	T=8
highwaypasstraffic					
overall	681.828	853.744	38.07	3748	N=112
between		858.725	83.082	3240	n=14
within		194.867	-73.091	1189.828	T=8
trucks					
overall	177.822	137.225	21.238	837.002	N=112
between		126.576	26.847	524.154	n=14
within		61.803	-108.003	490.67	T=8
urbanland					
overall	4336.073	2985.627	839	12187	N=112

between		3083.838	871.25	12187	n=14
within		60.378	4177.448	4720.448	T=8
percapitaGDP					
overall	62377.29	27778	13939	136947	N=112
between		22592.14	27222.88	97150.38	n=14
within		17128.92	27637.79	107623.8	T=8
secondaryGDP					
overall	41.964	14.018	2.636	60.441	N=112
between		14.312	3.101	56.795	n=14
within		2.145	35.888	47.316	T=8
temperature					
overall	16.148	4.176	4.3	23.5	N=112
between		4.284	5.263	23.087	n=14
within		0.492	15.048	17.486	T=8

Appendix C – Annual Effects of Urban Traffic

Table 11 Annual effects of urban traffic on PM10 concentration

Year	Highway passenger traffic (1 million times)	Number of trucks (1000)	PM_{10} effect of highway passenger traffic	PM_{10} effects of number of trucks	Yearly total PM_{10} effect
2006	10312	1747	-137.15	67.61	-69.54
2007	11577	1894	-153.97	73.30	-80.68
2008	12797	1975	-170.20	76.43	-93.77
2009	13444	2390	-178.81	92.49	-86.31
2010	14548	2656	-193.49	102.79	-90.70
2011	14948	2881	-198.81	111.49	-87.31
2012	15879	3051	-211.19	118.07	-93.12
2013	14235	3321	-189.33	128.52	-60.80