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Impact of economic structure on air quality in first tier cities of China – analysis of pre-COVID 19 pandemic

Abstract: This paper investigates how economic structure and GDP affects environmental expenditure and air quality in first tier cities (Beijing, Shanghai, Shenzhen, Guangzhou) between 2010 and 2018. The statistical analysis from regressions (based on economic inputs and outputs) and the instrument variable (IV) method are used to quantify and analyze the impact of city-level economic structure on air quality. As an economy becomes more developed and shifts to be dominated by the secondary and tertiary sectors, GDP would tend to increase, allowing opportunities for allocations of more environmental expenditure. Such shift in expenditure allows more capacity to improve environmental quality (such as build parks and green spaces) and to alleviate environmental problems through environmental governance and management. Parks and green spaces are used as proxies for carbon sinks (to control for local air quality and pollution) in regressions. It is found that that economic structure can significantly influence the supply and demand of energy, and therefore induce changes in the quantity of pollution and affect air quality. This could be alleviated by better physical and environmental infrastructure. The economy of first tier cities are predominately composed of secondary and tertiary industries, suggesting that it is capital intensive but not necessarily labor intensive. Nevertheless, substantial demand for energy might still exist within industries, which have potential for higher emission and air pollution. It is evident that a balance needs to be reached (or needs to maintained). The obtained results will have implications and applications in city design, policy- and decision-making. For given GDP, different economic structure leads to different supply and demand of energy and therefore change the amount of emission and affect air quality.

Introduction

The Chinese economy experienced rapid growth over the last 30 years since the reform and opening up of China. Most of China's economy by GDP is composed of the manufacturing industry which is a major emitter of CO_2 through consumption of energy. In 2010, China became the world's largest energy consumer. During the "Twelfth Five-Year Plan" period, the Chinese government introduced a series of policies for energy conservation, emission reduction and environmental protection.

Climate change and environmental pollution are multifaceted threats to all countries around the world because not only are there physical and infrastructural change, these also have other socioeconomic and public policy implications. They are important issues because they concern sustainable development of societies. In this paper, we study first tier cities of China because they are the most developed cities of China and have access to a lot of different kinds of resources that contribute to environmental protection and pollution mitigation.

Development, policy, trade and finance and law and regulation are themes covered by the literature of this topic. These will be addressed in the literature review in the next section. Research has studied the effect of pollution such as SO_2 and NOx on GDP and economic activity, but none have incorporated economic structure and environmental quality with pollution. This paper will give insights about implications of environmentally protective actions from a macroscopic and societal perspective. This is strategically important because an ultimate goal of desirable policies is to be economically efficient and enable environmental objectives to be attained in at least cost-effective manner.

The contribution of this paper is that by studying the association between the structure of an economy and the air quality of first tier cities in China, a different perspective on how the economy affects air pollution and air quality will be presented, which might help to get a better insight into the air pollution of big cities of China. We show that the economic structure affects the GDP composition and environmental protection measures such as environmental expenditure and green area and eventually impacts pollution and air quality of the city. We will use the Cobb-Douglas production function framework to set the basic structure of model. Then, it will make assumptions based on the models' theoretical framework and use regression and instrumental variables to evaluate the impact of economic structure on air quality in first-tier cities.

Literature Review

Overall, the literature so far has found how to regulate CO_2 emission through understanding how the production processes in an economy might induce emission and have attempted to understand its mechanism. Current literature has covered a lot of different topics, ranging from development, policy, trade and finance and law and regulation. Further work needs to address how the state of industrialization can affect the way environmental quality is managed and governed (for example, whether environmental quality takes priority and the availability of environmental expenditure). Industrial structure upgrade in China has accelerated and the proportion of service industry substantially increased, indicating that secondary or tertiary sectors dominated the economy. Many have studied the problem through a sociological perspective. For example, the human sustainable development index (Shang & Song 2018) and policy evaluation index (Roo 2018) were designed to conceptualize how economic factors, climate changes, societal values, state of the environment, evolution of human population are among factors that can impact environmental quality. What is lacking is how these factors interplay within a larger system where human decisions and environmental processes interact. Therefore, environmental expenditure, GDP (overall and by sector), air pollution are variables that can be used to generate a regression model to demonstrate such relationship within an economic system and evaluate how they affect air quality and emissions .

Allocation of CO_2 emissions reduction quota using a model based on the 2 stage Sharpley information entropy model demonstrated larger development gap between different provinces and necessity to scientifically allocate CO_2 emission reduction quota (Yang et al. 2018). Such allocation of CO_2 reduction was supported by research to calculate social cost of carbon with a balanced efficiency and equilibrium, where the pareto optimality maximizes the aggregate surplus and Nash equilibrium will aim to ensure maximized net benefits (Kotchen 2018). The theoretical underpinning of the social cost of carbon provided the framework for global benefits of reducing greenhouse gas emission for setting and evaluating policy. The same can be done for air quality and pollution.

Environmental policy and measures are not used in isolation and measures to reduce impact of human activity on pollution is overlapping because tax and cap on a regulated pollution may reduce the emission of this particular pollution, but may cause emission of unregulated pollutions to increase (Novan 2015). Public participation in environmental regulation and monitoring rely partly on complaints, where people are assumed to be well informed about pollution process (Dasgupta & Wheeler 1996). As environmental expenditure is partially responsive to demand for better environment (due to increased societal wealth and more observable pollutions), regulation, monitoring and compliance of firms through response to regulations (Dasgupta et al.1997a) could demonstrate the competency of the local government about environmental protection, management and regulation. Not all market agents play by the rules because under reporting and underassessment are common (variable regulation is systematic, not at random). These reflect social and environmental concerns. Scenario analysis have also (Dasgupta et al. 1998) found that key factors to improve performance are multifaceted, which reaffirmed that local communities can independently influence abatement decisions through various forms of informal pressure on plant managers.

Research in this area has extended to much application and practice. For example, a model for a decision matrix on CO_2 emission, population, GDP, marginal abatement cost and carbon intensity of each of the 30 Chinese provinces to calculate the allocation of quota by weight of province and equity based on the efficiency principle (Yang et al., 2018). In application, the results of this research can be used to contribute to giving a direction for development in environmental policy, management and governance. In the policy area, mechanism of official regulation, economics of compliance and regulators' discretion play significant role in compliance and enforcement and concluded that China's regulators frequently bend rules (Dasgupta et al. 1997). Industrial pollution problems and the possibilities for significant improvement through policy reform was analyzed (Dasgupta et al. 2017) – economic reform and pollution change system are two major determinants of changes.

In trade and finance, research have demonstrated the influence of market forces on energy supply and demand, which could potentially impact usage of energy and subsequently impacts pollution. In the context of the impact of trade liberalization on local and global emissions, relative market size, level of trade costs, the ease of abatement, degree of product differentiation at the sector level are generally relevant variable for empirical studies on trade and pollution (Forsid et al. 2013). Research about the consequences of the speculative aspect of carbon as a standard of value and as a potential currency is merely based on the speculative nature and commodification of matters in capitalism (Dalsgaard 2013). Dasgupta et al 2006 examined the reactions of investors to the publication of enterprises that fail to comply with national environmental laws and show that enterprises appearing on these costs have experienced a significant decline in their market valuation (Dasgupta et al. 2004). Furthermore, it was also found that international energy interdependency is an observed phenomenon in the energy market. What occurs internationally can influence activities in the domestic market (Wang and Chen 2016). Nevertheless, market forces are not only influenced by the supply of energy resources, but also the economy's demand as a result of economic output indirectly influence the existence of such markets found in the literature.

There are also a lot of different research on law and regulations, whose results can be linked to policy and development. For example, the political logic of China's new environmental courts is that increases in environmental law in china is a trend that will promise to reshape environmental law (Stern 2014). This is linked with research on the effect of complaints, education and independence property rights on decision to emit. This has been demonstrated empirically because a lot of activities are crackdowns against powerless rural residents rather than the more ambitious attempts to hold polluters accountable (Dasgupta & Wheeler 1996; Hahn & Stavins 2010). Analysis on how the World Bank undertakes resource allocation to find strong association between country lending activities (both analytical and advisory) relate to the overall severity of environmental problems (Buys et al. 2004). As the World Bank is the largest source of financing environmental improvement in developing countries, this research is related to environmental expenditure because money for expenditure either comes from revenue (from tax, which is based on GDP and governments' decision making) or borrowing and lending.

Bargaining power of Chinese factories as a form of enforcement of pollution regulation demonstrates the necessity of using GDP as well as economic structure and composition to understand how market forces deal with pollution. Another perspective on bargaining power is its influence on pollution control and mediations (Wang et al. 2002). Impact of inspection on environmental performance in China (Dasgupta et al. 2000) was motivated by a ceiling imposed on emission, which does not necessarily imply that emission will fall and environmental quality will improve. Research on justice, climate change and the dispatch of natural resources highlight the need for a critical reassessment of existing and evolving principle of international resource governance and ideas concerning the normative foundation and distribution of rights to natural resources (Schuppert 2016). These can be used to analyze the boundaries of pollution and responsibility of local economies as we evaluate the impact of an action or particular aspect of the society on pollution. Adaptation cost can be affected by socioeconomic development and this interaction (Blankespoor et al. 2020). Further research in this area require studies involving GDP and economic composition to evaluate and justify a system's capacity to neutralize the threat and vulnerability of affected communities.

In cities, occupant behavior is the most important factor for the relationship between climate condition, household building characteristics on residential energy consumption (Feng et al. 2016). This is extended by study on energy based cities of China using quantified comprehensive system capacity of these cities through evaluation index system established by PCA (Zhang et al. 2016). Quantification of the source of emissions growth (Hu et al. 2016) using an IO-SOA framework, where further investigation through studying production linkages through GDP composition via instrument variable regression and Index analysis to find true association between variables used in the modelled system.

Data

Cross-sectional data (i.e. across cities and across time) was used. Data came from city yearbooks and variables on GDP (both overall and by sector), green variables such as greeneries, parks and coverage, product oil import and export were included. Environmental expenditure was also used to test how they are associated with environmental pollution (PM2.5, PM10 and air quality). It is interesting to link these variables to GDP and environmental regulations (as higher GDP indicates an option to shift public expenditure to public utilities and goods to improve environment). Also, it is linked with economic structure that make up the economy and GDP. For example, some industries and sectors are energy and or labor intensive while some are not. These may influence energy trading and might be influenced by population (which indicate the size of labor force and potential for development). The case of first tier cities of China are used because of their economic status (by GDP). The model will seek to determine whether economic composition gives some insight about how the economy impacts the environment, especially how it impacts relevant factors such as oil markets and expenditure, as well as what role these variable play in this relationship.

Data visualization:

Data visualization is used to understand the data in order to form a sound understanding of the background information the question addresses. It is also used to formulate and support model assumptions. It covers several dimensions: parks and green, population and population growth, air quality and pollution as well as environmental expenditure and GDP.

The number of parks and green spaces in first tier cities have been stable over the years. There are no major spikes in growths in number of parks and park sizes. Although growths exist across cities and time exist to demonstrate the differences in characteristics of different cities despite high standing in economic development, Beijing, Shanghai and Shenzhen have much larger area of gardens space than that of Guangzhou. The same is true for the constructed area of the green space of the gardens. However, Beijing has much smaller green space (by area) compared to the other cities.

Regarding population, Beijing and Shanghai have much larger population bases than Shenzhen and Guangzhou. Among these cities, slow or no growth exists. Regarding population and population growth, no apparent pattern exists except for Guangzhou, where it was evident that years with higher natural growth is associated with population increase. In terms of population growth, Shanghai is the only city with negative (or close to 0) growth rate (by percentage). Therefore, from an economic and labor market perspective, one can infer that over time, labor supply might be limited or even be exacerbated by aging population. Furthermore, this trend is supportive of the fact that the economic pillars of the economy in these cities are not labor intensive, and even capital intensive given that it is a leader in China in terms of GDP.

Among the four first tier cities, ranking by GDP is as follows: Shanghai>Beijing>Guangzhou≈Shenzhen. Although GDP has grown during 2010-2018 period, GDP of primary sectors is minimal in all cities. More specifically, Shenzhen has almost no primary industry, Beijing and Shanghai have similar GDP for primary sector GDP while Guangzhou has more primary industry (higher proportion by GDP). In the case of secondary sector's GDP, there is much more secondary industry. However, its weight by GDP is less than that of the tertiary industry. In particular, Beijing and Guangzhou have a similar amount of secondary GDP in the economy over these years while Shenzhen's secondary GDP has grown progressively to be at the same level as Shanghai. Regarding the GDP of tertiary sectors, it has seen growth over time and the same pattern exist across all four cities. Ranking for size of the tertiary sector by GDP is as follows (from largest to smallest): Beijing, Shanghai, Guangzhou and Shenzhen. Over this period, there has been growth in tertiary sector in all four cities (with respect to the overall GDP).

When environmental expenditure and air quality are scrutinized, Beijing and Shanghai have very little environmental expenditure and there is no particular pattern between environmental expenditure and air quality in Guangzhou or Shenzhen. On the other hand, both PM2.5 and PM10 reduced every consecutive year. Beijing's air quality index increased consequently for 3 years, but in Guangzhou and Shanghai, there is no observable pattern. Shenzhen, on the other hand, has had stable air quality over these years. These indicate that air quality naturally gets better when polluting industries no longer operates and it is not affected by environmental expenditure spent on regulating the environment (through some remediating effort). This is supported by the fact that there is more tertiary industry, which are not only capital intensive (some of the economic outputs are unlikely to be directed to environmental expenditure) but also less polluting.

Analysis:

Correlation matrix by population and economic indicators:

This is an opportunity to learn about population and economic structure of the first-tier cities during 2010 -2018, which can be used to prepare for regression models. Negative association exists between population and its growth yet it also has large, negative association with GDP. Population and population growth have almost no impact on the GDP of the primary, secondary and tertiary industries. This means that GDP as an output of the economy is not dependent on population or labor size.

Primary industry is more heavily associated with the secondary industry, while secondary industry is more heavily associated with tertiary industry. Overall GDP demonstrates stronger association with environmental expenditure, but GDP from the primary, secondary and tertiary industries (singularly) are not that strongly associated with environmental expenditure. It is because the monetary output of each sector is unlikely to be directly involved with expenditure in this area as final output of the production of each firm as they become the input of another production rather than be directly expended on the environment. Furthermore, GDP is only a monetary measure of output and cannot be used to objectively reflect and measure the degree of impact GDP has on environmental expenditure. Money per se does not necessarily (and not capable of) saying anything meaningful about the relationship and association between GDP (productive output in monetary terms) and environmental expenditure.

The fact the expenditure has different degrees of association with actual population and population growth means that they do not necessarily motivate expenditure. Instead, environmental expenditure is motivated by the desire to improve the environment, constraint by available resources such as technology. As a decision and value judgement, they still rely in part by the amount of money available and the preferences of the policy makers. Import and export have small correlation coefficient with respect to GDP. Economic structure plays an important role as secondary and tertiary industries are more energy intensive and hence require more affordable energy.

Ordinary Least Square Regressions:

In OLS regression, it was found that when using population, secondary industry's GDP, air quality and oil import to run a regression on PM2.5, it was found that oil import has almost 0 impact on PM2.5. Air quality has negative association with PM2.5 (moderately) likewise with population. Secondary industry GDP is negatively and moderately associated with PM2.5. this indicates that secondary industry could be relatively clean or simply it is not associated with production of PM2.5. This sector is traditionally not too labor intensive as it relies on machineries or that it might be simply because the economy of the first-tier cities is predominately in the secondary industry and/or tertiary industry. R^2 of the regression is 0.8244, indicating a reasonably good fit on the data. The coefficients are all very small, indicating the independent variables having negligible impact on PM2.5. More days with better air quality mean less measures of PM2.5, and maybe better air quality attracts people to move there, which is a motivation for population growth.

Furthermore, when using population, primary industry GDP, constructed green, coverage and import on air quality to run a regression, it was found that again, import has almost no association with any of the variables except primary industry GDP, indicating that this sector is energy intensive but in practice, first tier cities have very little primary sector. Population is weakly associated with all the other variables in the regression, possibly because very few people are employed in the primary industry anyways (possible due to the fact that most work in this sector is replaced by machines and it does not represent a significant portion of the overall GDP).

Instrumental Variable Method:

Instrumental Variable method was incorporated into the ordinary least square regression to determine the impact of GDP and economic structure (reflected by composition of GDP by sector) as causation of air pollution. Both PM2.5 and PM10 are used as the dependent variables respectively to find the impact of the instrument on either pollutant. Additionally, it was found that when using air quality as the dependent variable, the regression output gives insignificant results. When GDP is the variable of interest as the instrument, it was found that in both PM10 and PM2.5 cases, tertiary industry sector GDP gives p-value <0.05. Secondary and primary sector GDP both gives insignificant results, and the difference in results is due to each of the three sectors being very different in terms of inputs, processes and outputs. The p-values is confirmed by the fact that primary and secondary sectors are polluting while tertiary sectors are not. This is most likely because of the economic mechanisms in these sectors that produce these outputs. Further, using overall GDP of these first-tier cities shares a similar result with that of the regression where tertiary sector GDP is singled out because first tier cities' economic output and composition are predominately made up of the tertiary sector.

The reason behind such observed mechanism is likely that economic transition is a contributing factor to pollution regulation and environmental governance and could replace efforts in environmental management. Likewise, environmental expenditure would shift according to societal preferences (which could change demands on societal and public utility) of better-quality environment (including environmental and pollution control). Regarding environmental expenditure, PM2.5's P-value <0.05 but PM10's p value is at the borderline of statistical significance (p value = 0.0054). One can also use the regression results to infer and support this argument because these indicate that management tools such as expenditure likely have minimal roles in controlling pollution when an economy has undergone transition toward that mostly made up of the tertiary sector.

Logarithmic regression:

PM2.5 and PM10's coefficients (i.e. elasticity) are all between -1 and 0, suggesting change in these independent variables changes in the opposite direction to the quantity of demand of good air quality. Obviously, poor air quality is undesirable and this result is justified by economic theory, which argues that a commodity with this characteristic is a poor product with low quality (confirmed by data and elasticity). Generally speaking, the elasticity of demand (of income, which we represent by GDP, a monetary outcome of economic wealth) of necessities is greater than 0 and less than 1, and that of luxury goods, is greater than 1. Although all the coefficients are negative but the specific number is different, suggesting different degrees of poorness of each variable as an influencing factor on PM10 and PM2.5.

Relatively speaking, ln(export) and ln(import) are close to 0, indicating that it is by nature a necessity in air quality (park area is also quite low, suggesting that it is also a necessity for good air quality). GDP (overall and tertiary industry) gives p value <0.05. Air quality and constructed green are closer to -1, suggesting that these factors are like inferior goods, which should be avoided when trying to regulate environmental quality and PM. It also suggests that none of these factors are necessities in regulating PM and air pollution. GDP is not necessarily a useful and meaningful factor to consider as tier 1 cities are predominated by tertiary sectors (which intuitively would not influence environmental pollution). This is demonstrated by the coefficient of tertiary GDP. Park area is close to necessity because although parks are public utilities, by having a park in place, it prevents opportunities for pollution generating behavior in the short term. The case for import and export is similar because by importing energy from elsewhere, the pollution generated from mining stayed at the source. Further, export means that production (where energy is needed) will take place elsewhere. Hence, regarding reduction in pollution and improvement in air quality, they may reflect differences. For example, air quality index already includes PM but also contains other factors. Only certain production produces PM while air quality index is a composite and comprehensive measurement that reflects the big picture. Constructed green is so different from park area. Maybe it is because it's not about having a nice ambiance, but more about having an area that does not have pollution sources (or far away from it).

Further work:

Example of further work include data envelopment analysis to look at how input and output operate in such an economic system, especially when it would be operating at an optimal size with correct inputs and outputs. Analysis can be undertaken to determine if current economic process is optimal and feasible. This can be used to extend the analysis of regression results so that we can extend our understanding of regression outcomes in order to gain a more in depth understanding of the problem at hand. Another direction of further work involves factor analysis and using index made using variables in regression. Making an index to analyze this particular aspect of environmental problem to address how to apply what we have learned from the regression outputs and measure the air quality and pollution in a timely manner. This way, we can observe how the results of the regression reflect systematic change and volatility of sector GDP as an economic factor. Lastly, one can use the results from the index to extend an analysis of how economic factors are associated with air quality.

Conclusion and implications:

The regressions results shed light on different aspects of our understanding of the problem. The OLS regression results tell us about the degree of impact of the independent variables on air pollution. IV-OLS demonstrated that a causation from the instrument variable exists to impact air pollution. This is important because as a controlled experiment cannot take place. In the regression model, when there is a correlation between the explanatory variable and the error term (endogenous problem), the instrumental variable method can get a consistent estimate. Endogenous problems generally arise from the problems of ignored variables or measurement errors. When endogenous problems arise, common linear regression models will have inconsistent estimates. At this time, if there are instrument variables, then people can still get consistent estimates. According to the definition, the instrument variable should be a variable that does not belong to the original explanatory equation and is related to the endogenous explanatory variable. The log regressions demonstrate the elasticity of change of each variable, which demonstrates the rate of change and the nature of interaction between all the variables modelled.

According to traditional economic theory, it was expected that higher GDP means higher productivity, which induces more pollution. However, more GDP and income induces more taxation in absolute amount, which takes care of differences in tax policies), meaning that there can be more allocation to various types of expenditure and the choice of expenditure depends on governance and priorities of the government. However, it was found that there is high correlation coefficient in some (but not all) of these variables. While regression results do not necessarily report high level of association between independent variables, the log regression show elasticity of change and that impact of these variables demonstrate this degree of change of this variable impacts the change in air pollution, PM2.5 and PM10. Market activities such as oil trading (import and export) in the regression were included and it was expected that higher GDP means more economic activity (productivity) would draw demand for energy. Therefore, import and export might impact air pollution. These did not have much impact on air pollution. The instrumental variable also demonstrate that expenditure did not have much role on pollution. The results indicate that traditional economic theory is unable to explain this observed phenomenon. In particular, the interaction of these variables in the hypothetically contained system indicates that shift in environmental quality (exemplified by air quality and pollution level) and method of governance is dependent on the economic structure rather than only GDP. This is because some industries are rich in both economic output and pollution while others are not. In the latter case, some industries that are rich in economic output but not rich in pollution, while others are only rich in pollution. This indicates that precision in environmental governance is impacted by the necessity to look closely at how an economy is structured and built up rather than only GDP.

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Appendix 1: Tabulations:

Table 1: description of variables

Symbol	Variable name	Description	Unit
Pop	Population	Permanent Population	10000 persons
Pop_growth	Population growth Rate	Natural Growth Rate (of population)	%
GDP	Gross Domestic Product	The final results of all resident units in an area from their productive activities over a given period of time.	100 million RMB
Env_Expend	Environmental expenditure	Expenditure on environmental protection and conservation	10000RMB
Urban_PM10	Mean concentration of PM10 in urban area	Mean concentration of PM10 in urban area	microgram/meter cubed
Urban_PM2.5	Mean concentration of PM2.5 in urban area	Mean concentration of PM2.5 in urban area	microgram/cubic meter
Good_AQI	Good AQI	Number of days where AQI being at least level 2	Days
Import_Petrol	Import of refined petroleum product	Import of refined petroleum product	Tonnes
Export_Petrol	Export of refined petroleum product	Export of refined petroleum product	Tonnes
Area_green	Area of greenspace	Area of greenspace	Hectare
Developed_green	Developed area in greenspace	Developed area in greenspace	Hectare
Rate_developed_Green	Rate of green area in developed space	Rate of green area in developed space	%
Num_park	Number of parks	Number of parks	By one count
Area_park	Area of Parks	Area of Parks	Hectare

Table 2: Summary statistics

	Number of observations	Mean	Standard variation	Skewness	Kurtosis	Year
Regular population (10000)	36	1621	658	-0.0019614	1.1981	2010-2018
Natural population growth rate	36	8.23554	7.749384	.5999134	2.151565	2010-2018
GDP	36	201000000	58100000	.2917286	2.441845	2010-2018
pri_GDP	36	1364872	977291.6	.6751998	4.091689	2010-2018
Sec_GDP	36	64300000	19100000	.3857996	2.082906	2010-2018
ter_GDP	36	136000000	49800000	.37918	2.310855	2010-2018
reg_env_exp10000rmb	36	1982035	1489933	1.17513	4.488396	2010-2018
pm10_yr_concmicrogrammetercubed	36	75.93978	23.66869	0.63488	2.459886	2010-2018
pm25_yr_concmicrogramcubicmeter	36	55.76244	22.53569	0.7755908	2.722944	2010-2018
air_quality	36	292.6111	55.5718	-0.7655277	2.690839	2010-2018
product_oil_import_ton	36	531519.9	1610299	4.977786	27.906	2010-2018
product_oil_export_ton	36	1672353	7173283	5.613417	32.9991	2010-2018

Table 3: Correlation matrix by gdp, environmental expenditure and air quality indicators

	GDP	reg_env_exp10000rmb	pm10_yr	pm2.5_yr	air_quality
GDP	1				
reg_env_exp10000rmb	0.8068	1			
pm10_yr	-0.1877	-0.0275	1		
pm2.5_yr	-0.1881	-0.0452	0.9899	1	
air_quality	-0.5398	-0.03758	-0.4283	-0.4150	1

Table 4: correlation matrix of key variables used in the regression

	Regular population	Natural population growth rate (%)	GDP	pri_GDP	sec _GDP	ter_GDP	reg_env_exp10000rmb	Product oil import	Product oil export
Regular population	1								
Natural population growth rate	-0.7314	1							
GDP	0.6419	-0.3302	1						
pri_GDP	0.1575	-0.4523	0.3450	1					
sec _GDP	0.2533	0.0907	0.5321	-0.3907	1				
ter _GDP	0.6467	-0.4105	0.9515	0.5248	0.2463	1			
reg_env_exp10000rmb	0.7271	-0.4670	0.8068	0.2097	0.5072	0.7389	1		
Product oil import	-0.0483	0.0132	0.1785	0.5661	-0.1453	0.2414	0.1032	1	
Product oil export	0.0745	-0.0008	0.2828	0.5352	-0.0729	0.3354	0.2022	0.9697	1

Table 5: Variance inflation factor of variables used in regression model

Variable name	**VIF**
Oil export	23.09
Oil import	22.33
Environmental expenditure	3.44
Population	2.95
Tertiary sector GDP	2.66
Constructed green	1.39
Mean VIF	9.31

Appendix 2: Visualizations

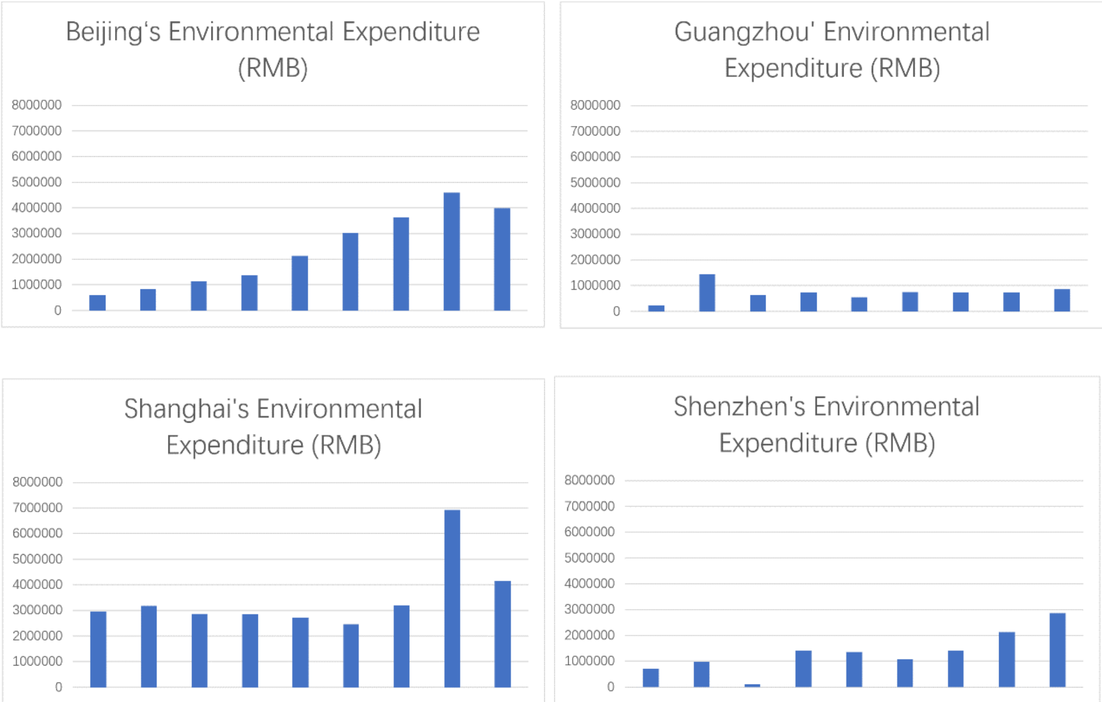

Figure 1: Environmental expenditure in first tier cities (2010 – 2018)

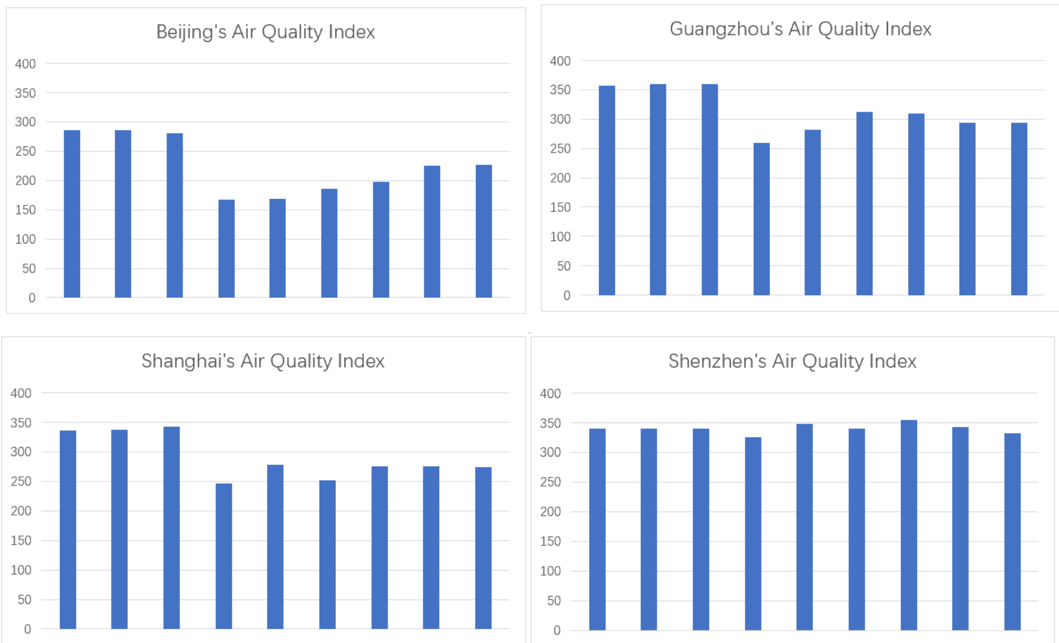

Figure 2: Number of Days when Air Quality Index exceeds grade 2 in first tier cities (2010 – 2018)