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HOW AIR POLLUTION IMPACTS THE ECONOMY? EVIDENCE FROM 31 PROVINCES IN CHINA

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ABSTRACT

This paper examines the relationship between air pollution and economic growth on the provincial level using China as the case study. Considering the economic heterogeneity of the different locations, a random effect regression model is built to analyze how the Air Quality Index (AQI) impacts Gross Domestic Product Per Capita (GDP Per Capita) using data from 31 provinces in China. After the application to the model, the results show that there is a negative relationship between the Air Quality Index (AQI) and the Gross Domestic Product (GDP Per Capita). When the Air Quality Index (AQI) decreases throughout the years, a reduction in GDP is shown in the results. This result is further examined from statistical perspectives, which includes residual assumption check, significant t-test, etc. This result of the research and model is believed to provide useful insights for the policy-makers to make economic and environmental-related decisions.

Keywords: Air pollution, Gross Domestic Product (GDP), Air Quality Index (AQI), Random effect regression model, Economic impacts, China

1. Introduction

In recent decades, China's economy has been rapidly growing. Within 32 years after the Reform and Opening Up, China has surpassed Japan and become the second-largest economy in the world in 2010 (Liping, 2013). Even during the COVID-19 pandemic, China's GDP has continued increasing, and reached 14.7 trillion USD in 2020 (GDP (current US$) - China).

However, some industries that accelerated the economic growth, such as heavy industries, also brought some environmental setbacks. To prevent and control pollution, governments impose

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pollution control policies and regulations. Nevertheless, the level of constraints that each of the environmental protection policies should have is disputed. Some may seek better environmental protection whereas others may concern that this may hinder many industries' performances and even contradict the economic growth. As a result, this is the motivation that brought me to investigate the impact of environmental pollution on economic growth and their relative relationships. In this paper, one type of pollution is particularly selected, which is air pollution and Air Quality Index (AQI). This is the independent variable to determine its effects on the economy, which is measured by Gross Domestic Product (GDP). As the AQI values get higher, this indicates that air pollution got worse.

Among all types of environmental pollution, air pollution is ultimately one of the most pressing environmental issues in many countries, harming both the environment and human health. In China, the air pollution problem is especially severe. According to the Environmental Pollution Index, China's overall environment performance ranks 120 and air quality ranks 137 out of the total of 180 countries (Windling et.al., 2020). With these results, China's air quality is among the second last tier of the overall ranking. Recognizing this serious issue, we decided to choose air pollution as the specific type of pollution to determine its effect on the economy's performance, hoping the results presented in this paper could provide some useful guidance to policy-makers when they are drafting relative air pollution regulations.

Previously, some researchers have set foot in this field before. For example, Zheng et. al. (2015) investigated the relationship between pollution and economic growth with evidence of 111 cities in China. He classified cities into 5 clusters depending on the Gross Domestic Product (GDP) level of each city, discovered that scale effect, compositions effect, and unobserved city effects result in the distinct income-pollution relationships that each cluster has. Moreover, Rao&Yan (2020) studied the interactive influence between environmental pollution and economic growth in Wuhan, and discovered that waste gases and air pollution hampers economic development as well. With similar intentions, this paper took a different approach to a similar topic. The data collection process in this paper differs from the paper by Zheng et. al. (2015) and Rao&Yan (2020) as I investigated the relationship between air pollution(AQI) and economic growth on the provincial level instead of the prefecture-level. As the previous research papers have already given a direction of policymakers to consider on the city or prefecture-level of decision, I decided to collect data on the provincial level so that it provides insight to policymakers on a macroscopic scale about the environmental protection of the entire province.

This paper aims to study the effect of air pollution, measured in Air Quality Index (AQI), on the economic growth, measured in the Gross Domestic Product Per Capita (GDP per capita), of each province. The data of both variables would be applied to the random effect model to determine their relationships. With results supported by other related studies, our hypothesis is that:

The reduction of air pollution and decrease in AQI will have a relative increase in the GDP per capita.

The first half of the paper following the introduction section presents the data and the models used in this paper, including the introduction and definitions of the models within the linear regression model type. The second half of the paper presents and analyzes the results by matching them with the city development pattern and using the fitted residual diagnosis. Then, the paper ends with the discussion and conclusion sections.

2. Model Set-Up

In this research paper, we employ the random effect model to the data of AQI and GDP per capita in order to determine their relationship. Before employing the data to the model, some summarized preliminary definitions of statistics, linear regression model, and the mixed effect model are discussed in this section for a better understanding of the model. Firstly, moment statistics definitions are shown as follows:

- Some moment statistics

$$E(X) = \frac{\sum_{i=1}^{n} \quad (X_i - \underline{X})}{n}$$

$$Var(X) = \frac{\sum_{i=1}^{n} \quad (X_i - \underline{X})2}{n-1}$$

$$Cov(X,Y) = \frac{\sum_{i=1}^{n} \quad (X_i - \underline{X})(Y_i - \underline{Y})}{n-1}$$

- Notice that

$$Var(aX) = \frac{\sum_{i=1}^{n} \quad (aX_i - a\underline{X})^2}{n-1} = a^2 \frac{\sum_{i=1}^{n} \quad (X_i - \underline{X})^2}{n-1} = a^2 Var(X)$$

$$Cov(X,X) = \frac{\sum_{i=1}^{n} \quad (X_i - \underline{X})(X_i - \underline{X})}{n-1} = Var(X)$$

2.1 Linear Regression

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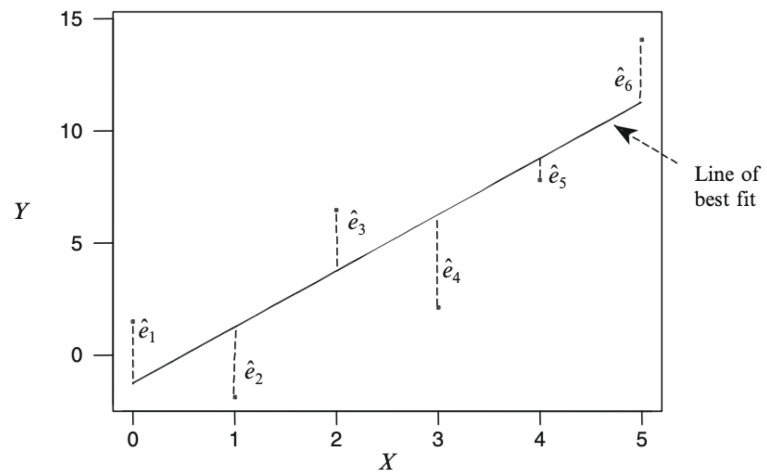
Since the random effect model used in this paper belongs to the category of linear regression, the overall definitions of linear regression models are needed in order to understand the random effect model. The linear regression model would be explained using a bivariate regression as an example, the model aims to find the slope and intercept that minimize the point distance:



For a multivariate regression, one needs to solve the following minimization problem:

$$L\{\beta_0^*, \beta_1^*, \ldots, \beta_p^*) = \sum_{i=1}^{n} \left(Y_i - \beta_0 - \beta_1 X_1 - \beta_2 X_2 - \cdots - \beta_p X_p\right)^2$$

The solution can be found by using calculus to set the derivative equal to 0:

$\frac{dL(\ldots)}{d\beta_0} = 0, \frac{dL(\ldots)}{d\beta_1} = 0, \ldots, \frac{dL(\ldots)}{d\beta_p} = 0$

Statistically, the model is equivalent to assuming:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \cdots + \beta_p X_p + \epsilon$$

where:

- Y is the response variable
- $X_1, X_2, \ \ldots X_p$ are p variables relevant to the response variable
- $\epsilon \sim N(0, \sigma^2)$ is the residual, which follows a normal distribution

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One aims to maximize the following probability:

$$argmax_{\beta}\prod_{i=1}^{n} P(Y_i|X_i)$$

Where $P(Y_i|X_i)$ follows from a normal distribution with mean βX and variance σ^2

2.2 Random Effect Model

The random effect model is the statistical model that is used in this research paper to determine the relationships between AQI and GDP per capita. This was setted up using the generalized statistics setup in linear regression by assuming:

$$Y_{ij} = \beta_0 + \beta_1 X_j + b_i + \epsilon_{ij}$$

where:

- Y_{ij} is the outcome for subject i at fixed effect x_j
- X_j is the fixed effect relevant to predict outcome Y_{ij}
- $b_i \sim N(0, \sigma_b^2)$ is the random effect, which can be interpreted as random slope
- $\epsilon_{ij} \sim N(0, \sigma_e^2)$ is the residual, which follow a normal distribution

The model is generalizing the linear regression as it permits within-group variation defined by σ_b^2. Thus, this model is assuming that the intercept differs randomly across i different provinces but the GDP is overall linearly related to the variable $X_{1j}, X_{2j}, \ldots X_{pj}$, which are called fixed effects. Now if we take a look at the covariance of a specific province i at two different time steps i, k:

$$Cov(Y_{ij}, Y_{jk}) = Cov(b_i + e_{ij}, b_i + e_{ik})$$

$$= Cov(b_i, b_i)$$

$$= Var(b_i) = \sigma_b^2$$

In other words, the model assumes that for a GDP level of specific province i, the covariance relationship is the same regardless of the different time steps. In my data study, this assumption is more realistic as I expect the AQI-economy relationship to vary across different provinces and to be correlated for the same provinces across different time steps.

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2.3 Maximum likelihood solution to mixed effect model

As it is compared to ordinary linear regression solution, the mixed effect model tries to find the set of parameters through maximizing the likelihood:

$$argmax_{\beta}\prod_{i=1}^{n}\prod_{j=1}^{d}P(Y_{ij}|X_j)$$

And $P(X_j) \sim N(\beta_1 X_j + b_j, \sigma_e^2 + \sigma_b^2)$ within the same group j, Y_i are correlated with covariance σ_b^2. To apply my data to this model, I used R to compute the maximized solution through the R lmer package.

2.4 Applying mixed effect model to AQI data

To measure the economic impact on city pollution across different locations, I applied the mixed effect model on the AQI dataset of 31 Chinese Provinces. Specifically, I assume:

$$log\ log(AQI_{it})\ =\ \beta_0 + \beta_1\ log\ log(aGDP_{it})\ + b_i + GDP_t + \epsilon_{it}$$

Where:

- Index i is ranged from 1 to 31 to indicate the i-th province
- Index t is ranged from 2014 to 2019 to indicate the year of the observation
- $\epsilon_{it} \sim N(0, \sigma_e^2)$ is assumed to follow a normal distribution
- $b_i \sim N(0, \sigma_b^2)$ is assumed to follow normal distribution to describe the city effect

The model is proposed by Zheng, et al., 2015) to examine the city effect. The hypothesis is that city development can be generally classified into an environmental-friendly economy, environmental-neural economy, and economy-unfriendly economy. The coefficient b_i quantitatively measures this economic pattern by demonstrating the significant positive effect, significant negative effect, and significant zero effect. After the model fitting, the following solution outputted from R are found:

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```
Linear mixed model fit by REML. t-tests use Satterthwaite's method ['lmerModLmerTest']
Formula: log(AQI_data$AQI) ~ log(GDP_Per_Capita) + (1 | Province) + offset(GDP)
   Data: AQI_data

REML criterion at convergence: 669.3

Scaled residuals:
    Min      1Q  Median      3Q     Max
-3.2379 -0.4962 -0.0568  0.4601  6.3391

Random effects:
 Groups   Name        Variance  Std.Dev.
 Province (Intercept) 1.524e+10 1.234e+05
 Residual             1.814e-02 1.347e-01
Number of obs: 186, groups:  Province, 31

Fixed effects:
                     Estimate Std. Error        df t value Pr(>|t|)
(Intercept)         -1.591e+05  2.216e+04  1.840e+02  -7.180 1.67e-11 ***
log(GDP_Per_Capita) -2.642e-01  4.558e-02  1.840e+02  -5.796 2.90e-08 ***
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Correlation of Fixed Effects:
            (Intr)
lg(GDP_P_C) 0.000
```

The t statistics (-5.796) on β_1 indicates a significant negative relationship between GDP and AQI, which is consistent with the previous data analysis that stated that GDP and AQI are negatively correlated. The random effect model took the data correlation into consideration thus the hypothesis testing results are more reliable in comparison to the original linear regression. The negative correlation between GDP and AQI tends to support my hypothesis that the reduction of air pollution and decrease in AQI typically corresponds to an increase in GDP per capita.

3. Data and Methodology

Gross Domestic Product Per Capita (GDP per capita) and Air Quality Index (AQI) are used in this paper and the data ranges from 2014 to 2019, with a total of 6 years span. Since the AQI data is collected on the provincial level, thus the GDP values are collected at the provincial level as well. As China has 31 provinces, therefore, there are 31 different data boxes presented (shown in Figure.1).

3.1 Data Source

In this research paper, all Air Quality Index (AQI) data is gathered from the Air Quality Historical Data Platform that the World Air Quality Index (WAQI) project team provides. The

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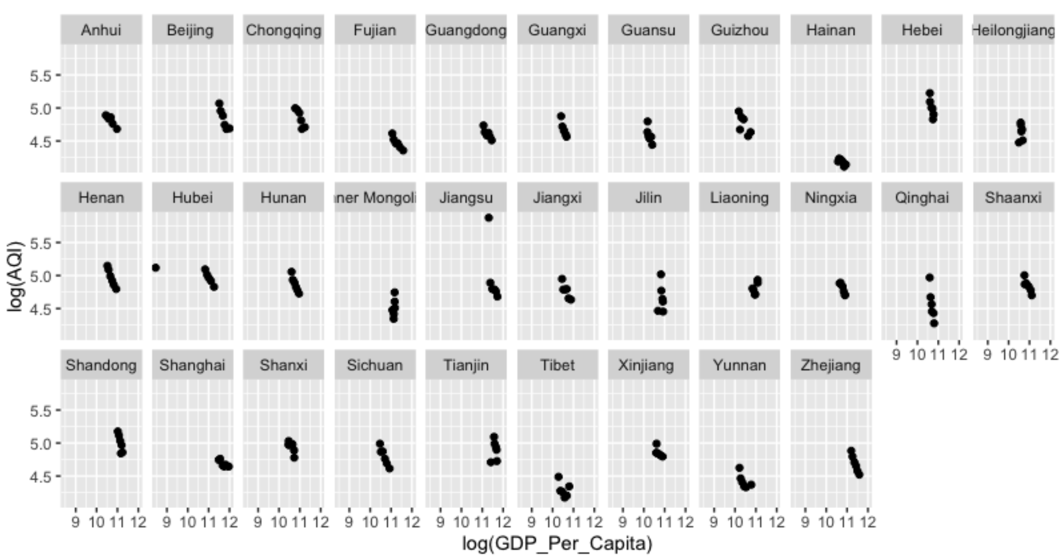
World Air Quality Index (WAQI) cooperated with many relevant international organizations, including United Nation Environmental Program (UNEP), World Resource Institute (WRI), and many others. This platform contains free and unlimited data from more than 100 countries, including both historical and real-time data, and is accessible to everyone. The Gross Domestic Product (GDP) data is collected from China Statistical Yearbooks published from 2015 to 2020, which are yearbooks published by China Statistical Press that record statistical information about China in economic and social aspects.

3.2 Data Collection

Since the Air Quality Historical Data Platform could only download AQI data of each city and the data is on a daily basis instead of a yearly basis, several steps were needed to clean up the data before applying it to the models. Firstly, an R program was built to read and average the data when the source code of the file is typed into the program. Secondly, the data of every city needed to be downloaded in CSV file format from the Air Quality Historical Data Platform. Using the program would calculate the average AQI for each of the provinces from 2014 to 2019. Thirdly, the AQI data of the cities in the same province need to be organized together to get an overall average AQI for the entire province. After organizing the data, it is presented as follows (raw data collection would be presented in Appendix) :

Figure.1: The Relationship between Air Quality Index (log AQI) and Gross Domestic Product Per Capita (GDP per capita) between 2014 to 2019 after applying to random effect model



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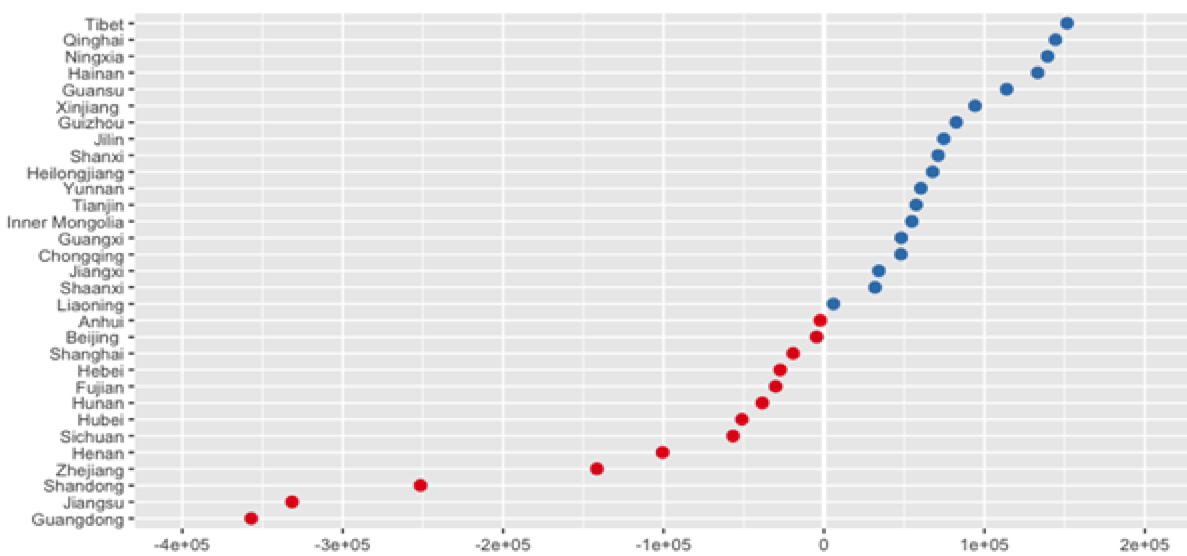
(Each data point on the graph above indicates the GDP per capita of each year.)

Overall, the AQI tends to demonstrate a negative relationship with the province's GDP. This observation is consistent with how a pollution-free green economy tends to be much more efficient in comparison to a pollution-generating economy. It is also observed from the plot that the provinces with higher GDP tend to focus on the service industry where economic development does not come at the cost of pollution. However, in certain provinces (such as Liaoning and Heilongjiang), the slope is slightly negative, indicating a potential economic dependence on pollution-generating industries. (Further detailed analysis is provided in the discussion section)

Moreover, the random effect (intercept) of all 31 provinces are plotted and organized into Figure.2 for the analysis of province development patterns:

Figure.2: City effects of 31 Provinces (Intercept)



4. Discussion

4.1 Relationship Analysis

The data shown in Figure 1 illustrates the relationships between the Air Quality Index (AQI) and Gross Domestic Product Per Capita (GDP per capita) after its application to the random effect model for all provinces in China. Overall, the Air Quality Index for 31 provinces generally tends

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to demonstrate a negative relationship with the GDP per capita value that the province had. This means that if the AQI decreases, then the GDP per capita would have a relative increase, which preliminarily matches with the hypothesis stated in the introduction section. Although there are not tremendous differences between each of the data points since it is in log form, the overall trend still exists. Take Beijing as an example, the upper data point has a log AQI of 5.1 and a log GDP per capita of 11.5; the lower data point has a log AQI of 4.2 and a log GDP per capita of 12. Therefore, as log AQI has decreased and log GDP has increased over the years, this demonstrates the negative relationships between the two variables. Furthermore, many provinces such as Hebei, Qinghai, Shandong, Jilin, etc. also show similar trends as Beijing does.

In addition, according to figure above, almost all provinces have an obvious decrease in AQI. This observation is aligned with the intuition that a pollution-free green economy tends to be much more efficient compared to a pollution-generating economy. According to China's Progress Report on Implementation of the 2023 Agenda for Sustainable Development, China has implemented policies that aim to achieve a low-carbon industry mix. Various measures have been taken so far to promote a greener economy. For example, China has promoted the reduction of energy consumption to improve energy efficiency (Ministry of Foreign Affairs, 2019). Moreover, the production of renewable energy vehicles rose from 328,000 to 1.15 million (Ministry of Foreign Affairs). Furthermore, the capacity of wind power has increased to reach 22 GW, so that more renewable energy could be used instead of the traditional ones (Ministry of Foreign Affairs). All these implemented measures have cut down China's carbon footprint, as CO_2 emissions per RMB 10,000 of GDP was down by 14.6% ((Ministry of Foreign Affairs). Therefore, China's recent implementation of sustainable development policies supports the reduction in the AQI values across many provinces in China. Vice versa, the data reduction of the AQI values also presents the effectiveness of these current policies to reduce the air pollution levels. Some provinces that are more dependent on the relative industries mentioned above might have a higher

As observed from figure.1, the data points are closer to the right border of the plot if the GDP per capita values get higher. These high GDP provinces such as Beijing, Guangdong, and Zhejiang (with data points that are closer to the right border), mostly exhibit a negative relationship between the AQI and the GDP per capita. One explanatory reason for this observation would be that these provinces with higher GDP per capita are more reliant on tertiary industries that are not heavily polluting the environment, such as the service industries. Therefore, this means that economic development does not necessarily come at the cost of pollution in these provinces. This is supported by the statistics that the Beijing Statistical Yearbook 2020 provides. According

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to this publication, the tertiary industries account for more than 80% of the overall GDP income in Beijing from 2014 - 2019 (National Bureau of Statistics of China, n.d.). Moreover, the tertiary industry's overall contribution to the regional GDP of Zhejiang, another high GDP province, is around 56% (HKTDC Research, n.d.). In this example, tertiary industries also contribute to more than half of the regional GDP of the province. As a result, the environmental protection policies that restrict heavy industries' performances to a certain level do not negatively impact the tertiary industries that rely on high GDP income provinces.

Not only does the lowering of air pollution levels have no negative impacts, but it could also even boost the economy in many provinces and lead to economic growth. Studies have discovered that air pollutants such as pm2.5 significantly decrease workers' productivity.

According to Chang et al., (2016), p. 163, every 10-unit change in PM2.5 will decrease the worker's productivity approximately by 6 percent. Furthermore, the office workers are also affected by the air pollution levels besides those outdoor labor workers. A 10-unit increase in the levels of air pollution will decrease 0.35 percent daily calls that workers could handle. In the same paper, it suggests that these productivity reductions have a linear negative relationship with increasing pollution levels (Chang et al., 2019, p. [Page 169]). As shown in these previous researches, if the air pollution levels are regulated, it could increase the productivity of workers. This increase in workers' productivity would help to improve the economy because more work could be done within the same office hours, so that there would be more economic activities that lead to economic growth. Therefore, this is consistent with the findings of Beckerman, which found that increasing economic development is one of the ways to improve the environment, which demonstrates the negative relationship between the economy and the AQI (Beckerman, 1992).

As a result, the implementation of environmental protection policies did not have a negative impact on the economy but rather increased the GDP values to a certain extent due to the improvements in workers' productivity. This provides a reasonable explanation for the negative relationships between the AQI and the GDP per capita values of each province.

However, in certain provinces (such as Liaoning and Heilongjiang), the slope is slightly negative. This means that these provinces do indicate a potential economic dependence on pollution-generating industries. Although the improved air pollution levels might have increased the productivity of workers and led to some degree of increase in economic growth, this growth can not compensate for the GDP reductions that the heavy industries contribute to air pollution regulations. As a result, the provinces present a different AQI-GDP relationship as it is positively

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related. Moreover, a few anomalies exist in figure 1, which did not show any trend but rather as clusters. This implies that both GDP per capita and the AQI numbers remained similar throughout the six years (from 2014 to 2019), thus, no trend would be shown as the variables.

4.2 Province Development Pattern Analysis

Figure.2: City effects of 31 Provinces (Intercept)

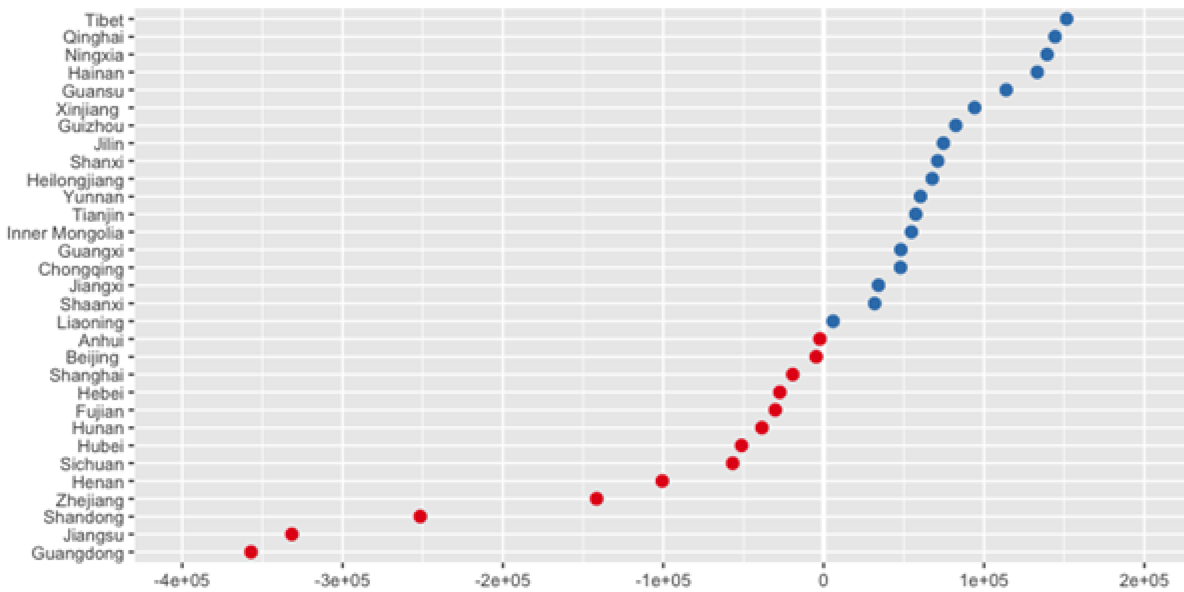

Figure.2 presents the city effects of the relationship between the Air Quality Index (AQI) and the Province's Gross Domestic Product (GDP per capita) across 31 provinces. Moreover, these intercept values are assumed to be random but could be estimated. More specifically, this is the realization of the normal distribution with different mean and the mean is estimated for each of the provinces. If a province's city-effect is a positive value, then it indicates that there are more AQI after taking the GDP development into consideration. These intercept values are then reorganized to be plotted into the same graph seen in Figure 2.

As shown in Figure.2, provinces from Liaoning to Tibet (blue data points) have positive intercept values, which means that there are additional pollution effects caused by the city development in addition to the average GDP contribution. Conversely, provinces from Guangdong to Anhui (red data points) that have negative intercept values, do not have any additional pollution effects caused by the city development.Provinces having positive and

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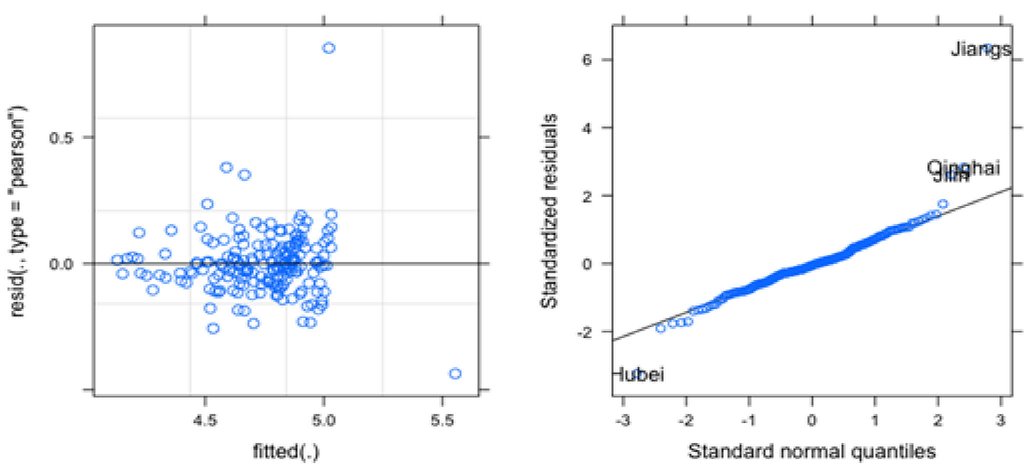
negative intercept values could be classified into 2 clusters called: Positive Intercept Cluster (PIC) and Negative Intercept Cluster(NIC).

After organizing the provinces into clusters, the development patterns of each cluster could be detailedly discussed. Considering the provinces in the Positive Intercept Cluster (PIC), they generally have high GDP values in comparison to the provinces in the Negative Intercept Cluster(NIC). For example, Tibet (a province in NIC) had a GDP value of ¥1687 (100 million RMB) in 2019 whereas Guangdong (a province in PIC) had a GDP value of ¥107671 (100 million RMB) (National Bureau of Statistics of China, n.d.). Since the provinces in PIC generally have a higher GDP value, this means that they are more economically developed and are developed earlier than the provinces in NIC. Thus, provinces in PIC would already have decent infrastructures since they are developed earlier. However, provinces in the NIC would not have enough capital to build decent infrastructures until recent years that are more economically developed. Therefore, as they are building more infrastructures, this would contribute to the fine-particle emissions and cause air pollution, a part of the activities that contribute to the GDP (Sun et al., 2018). Since infrastructure is not a GDP contributing activity, this leads to the result that there are more AQI added to these data after taking the GDP development into consideration.

4.3 Fitted Residual Diagnosis

Since the independent normality assumption is one of the most important assumptions in mixed-effect models and linear regression models in general, the residual versus fitted value plot and the quantile to quantile plot are employed to examine those two assumptions:

Figure. 3: Residual Versus Fitted Value Plot and the Quantile to Quantile Plot



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The residual versus that fitted value plot indicates great independence for the fitted residual except for one outlier point. The QQ plot on the residual also indicates a great normality result. Those two observations in turn validate the regression assumption and thus re-confirm the result discovered in section 4.1.

4.4 Improvements and Future Work

This research paper could be improved if more programs are used to average the AQI numbers across different cities in the same province, which would save more time. Moreover, it could also be improved if all GDP values are discussed in GDP per capita. This is because the population of each province is different, thus might have the possibility of contributing to different GDP values apart from development patterns.

This paper examines the relationship between the Air Quality Index (AQI) and the Gross Domestic Product per capita (GDP Per Capita) in China only. Therefore, more research on the same topic in other countries could be done so that there are multiple different countries' AQI-GDP Per capita relationships. Then, there could be meta-analyses on general AQI-GDP Per capita relationship across multiple different countries to present this relationship on a global scale. As a result, this might help with the environmental policy decision-making process when considering the air quality of the globe.

5. Conclusion

This paper investigates the relationships between the Air Quality Index (AQI) and the Gross Domestic Product per capita (GDP Per Capita). Using the AQI data from the World Air Quality Index (WAQI) and the GDP per capita data from China Statistical Yearbooks published (2015 to 2020), a random effect regression model was built to consider its relative impacts and relationships.

After the application of data in the models, it is discovered that there is a negative relationship between the Air Quality Index (AQI) and the Gross Domestic Product Per capita (GDP per capita) for most of the provinces in China. This implies that if the air quality index is lowered as the air pollution situations improve, the GDP per capita would increase accordingly, which validates the hypothesis. If the air pollution regulations are imposed in order to lower air pollution levels, this would not affect the majority of the provinces as they mainly rely on service sectors as their main source of GDP income. Moreover, the productivity of workers would decrease by 6%, if the levels of air pollution increase(Chang et al., 2016, p. 163). These 2 factors in combination explain the negative relationship between Air Quality Index (AQI) and

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the Gross Domestic Product Per Capita (GDP per capita). However, there are certain exceptions as some provinces show a positive relationship, due to their reliance on heavy industries. In addition, some provinces have more AQI added after taking GDP development into consideration since they are developed relatively later than those provinces that do not have AQI added. Therefore, the building of infrastructure in these provinces may contribute to the additional AQI.

Since the majority of provinces present a negative correlation, I conclude that the Air Quality Index (AQI) impacts Gross Domestic Product per Capita (GDP per capita) by how GDP Per Capita in most provinces would increase if the Air Quality Index decreases. In the future, this result might be able to aid and serve as a reference to policymakers when making decisions on environmental protection policies on the provincial level in China.

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Appendix

Table 1: Raw Data Table of Air Quality Index (AQI) and Gross Domestic Product (GDP) Data of all provinces in 2014

2014								
Province	**pm25**	**pm10**	**o3**	**no2**	**so2**	**co**	GDP (¥100 million)	Per capita (¥)
Beijing	159	88	47	28	12	14	21330.83	99995
Tianjin	163	105	39	28	29	17	15726.93	105231
Hebei	186	140	49	30	33	17	29421.15	39984
Shanxi	153	103	40	24	38	24	12761.49	35070
Inner Mongolia	115	97	36	27	24	16	17770.19	71046
Liaoning	139	85	41	24	29	19	28626.58	65201
Jilin	151	99	/	29	23	14	13804.14	50160
Heilongjiang	119	74	28	20	19	12	15039.38	39226

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Shanghai	115	55	43	22	7	6	23567.7	97370
Jiangsu	145	82	49	22	45	356	65088.32	81874
Zhejiang	132	68	47	21	15	10	40174.03	73002
Anhui	133	92	19	20	15	14	20848.75	34425
Fujian	101	56	43	15	12	10	24055.76	63472
Jiangxi	141	85	42	22	27	13	15714.63	34674
Shandong	177	125	57	31	40	16	59426.59	60879
Henan	172	11	45	28	28	13	34938.24	37072
Hubei	167	103	52	24	22	20	27379.22	4715
Hunan	157	73	27	20	12	13	27037.32	40271
Guangdong	114	59	46	18	12	12	67809.85	63469
Guangxi	131	70	44	17	17	13	15672.89	33090
Hainan	66	34	33	7	4	7	3500.72	38924
Chongqing	148	80	/	27	17	12	14262.6	47850
Sichuan	147	82	36	22	20	12	28536.66	35128
Guizhou	141	76	37	20	21	9	9266.39	26437
Yunnan	102	55	/	13	14	14	12814.59	27264
Tibet	89	57	45	12	8	10	920.83	29252
Shaanxi	149	105	22	24	20	19	17689.94	46929
Guansu	121	97	35	18	25	16	6836.82	26433

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Qinghai	144	92	38	21	21	13	2303.32	39671
Ningxia	132	83	29	21	30	13	2752.1	41834
Xinjiang	147	97	23	26	12	17	9273.46	40648

Table 2: Raw Data Table of Air Quality Index (AQI) and Gross Domestic Product (GDP) Data of all provinces in 2015

2015								
Province	**pm25**	**pm10**	**o3**	**no2**	**so2**	**co**	GDP (¥100 million)	Per capita (¥)
Beijing	142	77	45	26	8	11	23014.6	106497
Tianjin	147	90	37	22	18	15	16538.2	107960
Hebei	163	114	46	27	26	17	19806.4	40255
Shanxi	145	89	46	21	37	22	12766.5	34919
Inner Mongolia	100	65	39	14	14	8	17831.5	71101
Liaoning	133	80	43	21	25	16	28669	65354
Jilin	118	69	40	17	15	10	14063.1	51086
Heilongjiang	115	66	36	15	15	11	15083.7	39462
Shanghai	117	56	44	22	8	7	25123.5	103796
Jiangsu	133	77	46	21	16	14	70116.4	87995
Zhejiang	121	62	45	20	12	9	42886.5	77644
Anhui	131	66	46	18	15	11	22005.6	35997

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Fujian	92	49	39	14	8	9	25979.8	67966
Jiangxi	120	62	37	16	21	12	16723.8	36724
Shandong	167	113	56	26	30	16	63002.3	64168
Henan	162	94	51	30	18	14	37002.2	39123
Hubei	163	109	45	23	19	15	29550.2	50654
Hunan	139	71	51	16	19	11	28902.2	42754
Guangdong	103	52	42	16	8	10	72812.6	67503
Guangxi	112	55	36	12	12	11	16803.1	35190
Hainan	69	36	37	6	3	7	3702.8	40818
Chongqing	145	78	29	31	10	12	15717.3	52321
Sichuan	130	69	42	18	14	12	30053.1	36775
Guizhou	129	68	38	19	15	9	10502.6	29847
Yunnan	87	44	32	9	10	10	13619.2	28806
Tibet	72	40	34	8	7	10	1026.4	31999
Shaanxi	130	78	39	19	14	16	18021.9	47626
Guansu	103	73	45	14	16	10	6790.3	26165
Qinghai	107	67	37	10	10	8	2417.1	41252
Ningxia	133	86	44	19	28	11	2911.77	43805
Xinjiang	128	121	37	16	11	13	9324.8	40036

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Table 3: Raw Data Table of Air Quality Index (AQI) and Gross Domestic Product (GDP) Data of all provinces in 2016

2016								
Province	**pm25**	**pm10**	**o3**	**no2**	**so2**	**co**	GDP (¥100 million)	Per capita (¥)
Beijing	132	69	44	23	5	10	25669.13	118198
Tianjin	140	84	37	25	13	14	17885.39	115053
Hebei	149	99	47	27	22	15	32070.45	43062
Shanxi	144	93	44	22	35	21	13050.41	35532
Inner Mongolia	91	60	38	13	12	7	18138.1	72064
Liaoning	122	71	46	19	23	15	22246.9	50791
Jilin	104	58	40	15	13	10	14776.8	53868
Heilongjiang	104	58	33	15	13	10	15386.09	40432
Shanghai	106	49	44	21	6	6	28178.65	116562
Jiangsu	121	69	46	20	14	11	77388.28	96887
Zhejiang	111	57	42	17	9	8	47251.36	84916
Anhui	126	65	47	20	14	10	24407.62	39561
Fujian	87	46	39	12	7	9	28810.58	74707
Jiangxi	120	66	41	15	19	12	18499	40400
Shandong	153	103	56	24	24	14	68024.49	68733
Henan	147	83	50	27	11	13	40471.79	42575

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Hubei	150	95	49	21	17	15	32665.38	55665
Hunan	133	66	41	15	14	10	31551.37	46382
Guangdong	98	48	41	16	7	9	80854.91	74016
Guangxi	105	50	36	12	9	9	18317.64	38027
Hainan	68	33	34	6	3	7	4053.2	44347
Chongqing	138	70	34	31	8	11	17750.59	58502
Sichuan	131	69	47	18	14	12	32934.54	40003
Guizhou	125	65	39	19	10	9	11775.53	33246
Yunnan	82	42	37	8	8	9	14788.42	31093
Tibet	71	48	33	8	6	6	1151.41	35184
Shaanxi	132	79	44	19	12	13	19399.59	51015
Guansu	97	69	44	14	13	9	7200.37	27643
Qinghai	96	59	34	9	10	9	2572.49	43531
Ningxia	126	79	40	18	24	10	3168.59	48194
Xinjiang	128	112	35	17	9	13	9649.7	40564

Table 4: Raw Data Table of Air Quality Index (AQI) and Gross Domestic Product (GDP) Data of all provinces in 2017

2017								
Province	**pm25**	**pm10**	**o3**	**no2**	**so2**	**co**	GDP (¥100 million)	Per capita (¥)

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Beijing	115	67	45	22	4	8	28014.94	128994
Tianjin	134	75	52	24	9	12	18549.19	118944
Hebei	147	97	51	26	17	13	34016.32	45397
Shanxi	146	94	54	22	29	17	15528.42	42060
Inner Mongolia	88	62	40	13	11	8	16096.21	63764
Liaoning	119	71	46	19	19	12	23409.24	53527
Jilin	100	61	40	15	11	11	14944.53	54838
Heilongjiang	107	62	35	15	10	9	15902.68	41916
Shanghai	104	47	48	21	5	6	30632.99	126634
Jiangsu	120	68	50	20	10	9	85869.76	107150
Zhejiang	105	54	45	17	7	7	51768.26	92057
Anhui	129	71	55	19	11	9	27018	43401
Fujian	87	47	47	13	6	8	32182.09	82677
Jiangxi	121	64	40	16	16	11	20006.31	43424
Shandong	144	97	59	23	17	12	72634.15	72807
Henan	137	76	42	26	7	12	44552.83	46674
Hubei	143	89	52	22	12	13	35478.09	60199
Hunan	125	65	41	15	11	9	33902.96	49558
Guangdong	102	51	44	17	6	9	89705.26	80932
Guangxi	105	51	37	13	9	10	18523.26	38102

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Hainan	66	30	34	6	3	6	4462.54	48430
Chongqing	123	66	34	31	7	10	19424.73	63442
Sichuan	117	63	42	18	10	10	36980.22	44651
Guizhou	107	53	36	15	7	6	13540.83	27956
Yunnan	77	42	36	9	7	8	16370.34	34221
Tibet	65	41	39	7	5	7	1310.92	39267
Shaanxi	126	77	42	20	11	12	21898.81	57266
Guansu	94	72	44	14	11	7	7459.9	28497
Qinghai	86	55	41	10	10	9	2624.83	44047
Ningxia	117	81	47	20	19	9	3443.56	50765
Xinjiang	126	106	39	18	9	12	10881.96	44941

Table 5: Raw Air Quality Index (AQI) and Gross Domestic Product (GDP) Data of all provinces in 2018

2018								
Province	**pm25**	**pm10**	**o3**	**no2**	**so2**	**co**	GDP (¥100 million)	Per capita (¥)
Beijing	108	64	44	20	3	7	30319.98	140211
Tianjin	113	64	/	19	6	9	18809.54	120711
Hebei	135	90	51	23	13	11	36010.27	47772
Shanxi	133	90	52	20	18	13	16818.11	45328

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Inner Mongolia	83	62	41	11	8	7	17289.22	68302
Liaoning	112	65	43	16	15	11	25315.35	58008
Jilin	86	52	39	12	8	9	15074.62	55611
Heilongjiang	91	54	39	13	8	8	16361.62	43274
Shanghai	107	43	43	18	4	5	32679.87	134982
Jiangsu	117	63	46	18	7	8	92595.4	115168
Zhejiang	97	49	40	15	5	7	56197.1	98643
Anhui	117	63	55	17	8	8	30006.82	47712
Fujian	82	45	46	12	6	7	35804.04	91197
Jiangxi	105	56	38	14	12	11	29184.78	47434
Shandong	129	86	60	21	12	13	76469.67	76267
Henan	129	66	49	24	6	11	48500.86	50152
Hubei	137	86	51	20	7	10	39366.55	66616
Hunan	119	59	40	14	8	9	36425.78	52949
Guangdong	96	46	41	15	6	8	97277.77	86412
Guangxi	99	49	36	12	8	9	20352.51	41489
Hainan	61	29	31	5	3	6	4832.05	51955
Chongqing	108	55	37	25	5	8	20363.19	65933
Sichuan	109	56	42	16	8	8	40678.13	48883
Guizhou	97	48	36	15	7	6	14806.45	41244

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Yunnan	76	40	36	8	6	7	17881.12	37136
Tibet	67	44	38	7	3	6	1477.63	43398
Shaanxi	119	75	42	19	10	11	24438.32	63477
Guansu	96	74	40	12	8	6	8246.07	31336
Qinghai	84	55	42	10	8	8	2865.32	47689
Ningxia	110	73	47	16	12	9	3705.18	54094
Xinjiang	121	123	38	15	6	11	12199.08	49475

Table 6: Raw Air Quality Index (AQI) and Gross Domestic Product (GDP) Data of all provinces in 2019

2019								
Province	**pm25**	**pm10**	**o3**	**no2**	**so2**	**co**	GDP (¥100 million)	Per capita (¥)
Beijing	109	58	47	18	3	7	35371.28	164220
Tianjin	111	60	/	19	5	9	14104.28	90371
Hebei	125	78	50	21	10	10	35104.52	46348
Shanxi	119	75	50	19	14	17	17026.68	45724
Inner Mongolia	77	51	38	11	8	6	17212.53	67852
Liaoning	111	65	42	16	12	10	24909.45	57191
Jilin	87	51	38	11	6	8	11726.82	43475
Heilongjiang	88	50	34	11	7	7	13612.68	36183

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Shanghai	104	46	44	20	3	6	38155.32	157279
Jiangsu	108	60	47	16	5	7	99631.74	123607
Zhejiang	92	48	41	15	4	6	62351.74	107624
Anhui	108	59	50	15	6	7	37113.98	58496
Fujian	78	41	43	10	4	7	42395.00	107139
Jiangxi	103	54	40	13	10	9	24757.5	53164
Shandong	127	79	55	20	9	6	71067.53	70653
Henan	121	55	48	20	9	9	54259.2	56388
Hubei	125	67	51	15	7	8	45828.31	77387
Hunan	113	54	42	13	9	8	39752.12	57540
Guangdong	91	44	44	14	5	7	107671.07	94172
Guangxi	96	45	38	11	7	8	21237.14	42964
Hainan	63	30	35	5	4	5	5308.93	56507
Chongqing	111	53	36	24	4	8	23605.77	75828
Sichuan	101	48	37	14	6	7	46615.82	55774
Guizhou	103	48	42	13	9	6	16769.34	46433
Yunnan	79	37	39	8	5	6	23223.75	47944
Tibet	77	39	39	9	5	6	1697.82	48902
Shaanxi	110	64	38	16	6	8	25793.17	66649
Guansu	85	54	39	13	7	6	8718.3	32995

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Qinghai	72	38	41	9	7	5	1966.95	48981
Ningxia	111	46	46	13	12	6	3748.48	54217
Xinjiang	121	99	37	16	6	9	13597.11	54280