Does China's "Two Control Zones" Policy Control Sulfur Dioxide Emissions?

The Effect of Acid Rain and Sulfur Dioxide Control Zones Policy on China's Industrial Sulfur Dioxide Emissions

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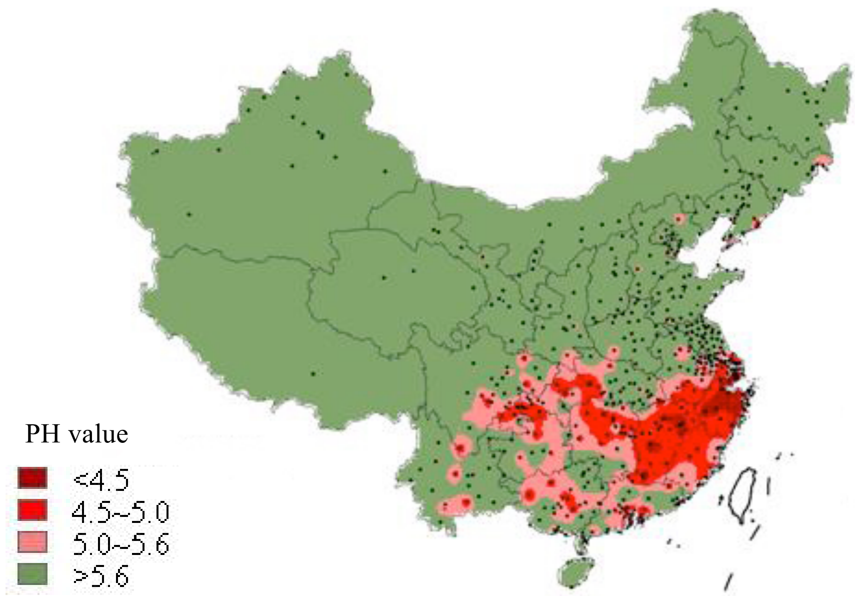

2007 Regional Distribution of the Acid Rain in China

Source: Ministry of Environmental Protection of China. *2007 Report of China's Environmental Conditions*. Available at <http://jcs.mep.gov.cn/hjzl/zkgb/2007zkgb/200811/t20081117_131297.htm>

Abstract: In order to control sulfur dioxide (SO_2) emissions, the Chinese government in 1996 implemented a policy entitled "Acid Rain and Sulfur Dioxide Emission Zones" (the "Two Control Zone" policy, hereafter referred to as TCZ policy). This paper attempts to assess the impact of the TCZ policy on China's industrial SO_2 emissions. A fixed effects model shows that the TCZ policy did not actually reduce the absolute per capita SO_2 emissions but that it did decrease emissions relative to GDP. In other words, each unit of industrial production led to less SO_2 emissions within the two control zones. However, this paper will also discuss problems related to endogeneity and dependent variable design, both of which cast doubt on the success of the TCZ policy in promoting "green GDP".

Introduction

China's rapid economic growth has resulted in a similar trend in energy consumption growth over the last two decades. In 2005, coal still represented more than 70 percent of China's total energy consumption, and even the most optimistic alternative policy scenario from the IEA showed that coal use would still be used to meet more than 60% of China's total energy demand in 2030[1]. In China, coal-fire power plants have been recognized as the main source of industrial SO_2 emissions. Illustrated in Graph 1 of Appendix 1, total SO_2 emissions in China climbed rapidly in the last two decades, and China became the biggest emitter in 2005 with total SO_2 emissions of 21 million tons. In 1996, the Chinese Government formulated and promulgated the Two Control Zone (TCZ) policy, resulting in the establishment of acid rain and sulfur dioxide control zones through the implementation of a package of policies. The "two control zones" covers a total of 1.09 million sq km, comprising 175 cities/districts in 27 provinces which account for about 11.4% of China's territory. On a general level, the policy package[2] includes the following provisions: (1) Shutdown any new coal mine with a sulfur content greater than 3.0% and limit output of existing coal mines with a sulfur content greater than 3.0%; (2) The construction of new thermal power plants will not be approved in cities or suburbs of large and medium-size cities; for newly built or rebuilt thermal power plants, if the sulfur content in burning coal exceeds 1.0%, desulfurization facilities must be installed; (3) Existing plants should take measures to reduce SO_2 emissions and install desulfurization facilities. Since provinces that were included

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[1] Cao Jing. *Benefits and Costs of SO2 Abatement Policies in China.* Harvard University and Resources for the Future. Draft, April 15, 2008

[2] Information Office of the State Council of the People's Republic of China. Full Text: Environmental Protection in China (1996-2005). June 2006.

in the two control zones received and executed the same package of polices at almost the same time, this paper will take the TCZ policy as a whole and focus on the integrated impact on China's industrial SO_2 emissions.

Data[3]

This paper uses Chinese province-level panel data from 1991 to 2007 to evaluate the effect of the TCZ policy on China's industrial SO_2 emissions. One important clarification is that Chongqing Municipality lacks data for six of the years under study because it did not become an administrative district until it separated from Sichuan Province in 1997. In order to keep consistency and avoid omitting data, this paper merges data of Chongqing Province into data of Sichuan Province between 1997 and 2007, considering these two provinces as one during the whole time frame.

Independent variables include GDP per capita (GDPPC), GDP per capita squared (GDPPC_sq) and population density (pop_density) for each province. In this paper, regional GDP per capita (GDPPC) is used as an index to indicate economic growth or regional production for each province. Since China's economic activities such as industrial production require large energy consumption provided by coal, it is probable that higher GDP would lead to increased SO_2 emissions. Models used here include population density as well because a higher population density tends to intensify the negative impact of sulfur pollution. Hence, a densely populated province should have fewer pollution problems when compared with a province that has the same income level but a lower population density. Therefore, we should expect to see a negative coefficient on this variable.

[3] See Appendix 2, Data Summaries: Table 1&2

In order to evaluate the TCZ policy, this analysis incorporates a treatment dummy (Treatment) into each model. The treatment dummy is set equal to 1 after year 1996 for provinces that were incorporated into SO_2 and acid rain control zones and is set to 0 for observations before 1996 for all provinces. All of these data are taken from the China Statistical Year Book, so it is reasonable to assume that they are consistently measured overtime.

Methodology

Baseline Models

Model I:

$$SO_2PC_{it} = \beta_0 + \beta_1 GDPPC_{it} + \beta_2 GDPPC^2_{it} + \beta_3 pop\_density_{it} + \beta_3\, Treatment_{it} + \sum_{1991}^{t} \delta\, time_t + a_i + \mu_{it}$$

Model II:

$$SO_2PGDP_{it} = \beta_0 + \beta_1 GDPPC_{it} + \beta_2 pop\_density_{it} + \beta_3\, Treatment_{it} + \sum_{1991}^{t} \delta\, time_t + a_i + \mu_{it}$$

Since observations are collected at the province level over time, there may be many unobserved factors that could influence SO_2 emissions. Problems arise when these factors are also correlated with the decision to implement the TCZ policy. If we use Random Effects or Pooled OLS methods, we must assume that there is no correlation between SO_2 per capita and unobservable provincial variation. However, because each province has its own unique features and characteristics, it is difficult to defend this assumption. Therefore, the safest way to address these factors is to remove them with a fixed effects analysis. Appendix 3 presents the results of a Hausman Tests for both models I and II. Because the test indicates that we reject the null hypothesis, we can say that fixed effects—rather than random effects—is the preferred method.

The initial dependent variable for my baseline model (Model I) is industrial SO_2 per capita (SO2PC) for each province. However, in Model II, this indicator is replaced by a new dependent variable measuring industrial SO_2 per GDP (SO2PGDP). Model I attempts to analyze the effect of the TCZ policy on absolute industrial SO_2 per capita emissions, while Model II is designed to determine industrial SO_2 emissions relative to GDP. SO_2 per GDP measures the sulfur dioxide emissions per unit of real Gross Domestic Product which indicates the "green degree" for each unit of gross production in terms of sulfur dioxide pollution. On the right hand side of Model I, the three variables, GDPPC, $GDPPC^2$ and population density, are empirical independent variables for the Environmental Kuznets Curve (EKC) Hypothesis. Almost all EKC literature[4] supports the inverted-U shape relationship between SO_2 pollution and national income, which implies that, with economic growth, pollution should increase at first and then diminish once the income level of the nation has attained a determined level. However, the EKC relationship does not come from the increase in per capita income itself. Under this hypothesis, the income growth could lead to the increase in environmental consciousness of the society, which could spur government to adopt environmental regulations that essentially fulfill the EKC hypothesis. Thus, in order to focus on the specific impact of the TCZ policy on industrial SO_2 emissions, empirical variables in the EKC model must be added to models in order to control for the Chinese government's overall regulation of SO_2 emissions. In other words, empirical EKC's variables should be incorporated into Model I as controls in case the EKC hypothesis does hold for China's industrial SO_2 emissions. Moreover, there is no empirical evidence that improved

[4] David I. Stern and Michael S. Common. *Is there a Kuznets Curve for Sulfur?* Journal of Environmental Economics and Management 41, 162-178 (2001)

SO_2 per GDP is expressed in the classic inverted-U shape against national income. Therefore, Model II gets rid of the $GDPPC^2$ term, leaving only GDP per capita and population density as basic control variables.

Finally before settling on final models, we must first look carefully at the potential for reverse causality. This paper provides a specific test for endogeneity problem in the section entitled "Robustness Checks". The test results imply that reverse causality is indeed a problem in our model. In order to solve this problem, both models assign each observation its own time trend by using an interaction term between id and time to control the different rate of change in SO_2 emissions between the treatment and control groups. After accounting for reverse causality problems, the two baseline models are as following:

Models with Time Trend for Each Unit

Model I:

$$SO_2\,PC_{it} = \beta_0 + \beta_1 GDPPC_{it} + \beta_2 GDPPC^2_{it} + \beta_3 pop\_density_{it} + \beta_3\, Treatment_{it} + \sum_{1991}^{t} \delta\,(\text{id*time})_{it} + a_i + \mu_{it}$$

Model II:

$$SO_2\,PGDP_{it} = \beta_0 + \beta_1 GDPPC_{it} + \beta_2 pop\_density_{it} + \beta_3\, Treatment_{it} + \sum_{1991}^{t} \delta\,(\text{id*time})_{it} + a_i + \mu_{it}$$

Results Discussion

Model I: Before running the baseline model, a simple two-way fixed effects model without time dummies was conducted first. The results shown in Table 3 in Appendix 4 shows that the TCZ policy has not had a significant effect on SO_2 per capita emissions. After adding time dummies to knock down the overall time trend of SO_2 emissions, the treatment variable for Model I becomes significant (Table 4) at 10% significant level. However the sign of the coefficient on the policy dummy is positive, which indicates that SO_2 emissions per capita of provinces in two control zones failed to reduce but rather increased, compared to the emissions of provinces outside the zones. Moreover, after making an adjustment for time trends within each unit, Table 5 illustrates that the treatment variable is not significant at either the 5% or 10% significant level in Model I. Interestingly, the significant GDPPC-squared term shows that the Environmental Kuznets Curve hypothesis does hold in this model, which suggests that we were correct to control for empirical variables of the EKC hypothesis.

Model II: Table 6 in Appendix 5 gives the regression outcome for the baseline model without time dummies, which suggests that SO_2 emissions reduction in the control zones is 32.61 kg per 10 thousand Yuan (approximately $1,500 USD) more than provinces outside of control zones. After applying the id*time interaction term in the model, the marginal effect of the treatment dummy remains highly significant, but the scale of coefficient drops from 32.61 kg per 10 thousand Yuan to 14.35 kg per 10 thousand Yuan.

Results from above regression indicate that the TCZ policy has no significant effect on the reduction of the absolute industrial SO_2 per capita. Nonetheless, we can see that the policy makes production greener, since the ratio of SO_2 emissions against GDP drops. However, it is not surprising to see a declining ratio of SO_2 emissions against GDP, since China witnessed huge economic development and achieved striking GDP growth over the last two decades. Because GDP is the denominator of the dependent variable, the ratio of SO_2 emissions against GDP would definitely have declined rapidly over the past ten years. Graph 2 presents mean regional GDP increased much faster than mean regional SO_2 emissions. Thus, even though it is possible that the TCZ policy perhaps did not reduce SO_2 emissions, as long as China had high GDP growth, the ratio of SO_2 emissions to GDP would have fallen. Hence, it is too soon to make the conclusion that the TCZ policy contributed to making production greener.

In fact, Chinese environmental reports claim that the TCZ policy did not fundamentally prevent the growth of SO_2 pollution in China, especially during 2000-2005. According to the governmental report on environmental policy, specific requirement of the TCZ policy did not come to practice until after 2000. The main reason is that energy efficiency was seriously underfunded[5], and the Chinese government emphasized economic growth over improving energy efficiency and environmental protection. In China, an electricity shortage emerged in 2002 and even worsened in 2004. In the summer of 2004, 24 provinces experienced a brownout, which caused widespread disruption of industrial production and huge economic losses. Because of power shortages, the plan to shut down small coal-fired power units was not carried out. On the contrary, some small units that had been shut down resumed operation and many new small coal-fired power units were built in a short period of time. As a result, SO_2 emissions from coal-fired power plants increased by 70%, from 6.54 million tons in 2001 to 11.12 million tons in 2005 (SEPA 2002, 2006). Rather than cutting national SO_2 emissions in 2000–2005 by 10%, to 18 million tons as planned, by 2005 emissions actually rose to 21 million tons, almost 40% above the goal.

Robustness Checks

1) Endogeneity: It is important to point out that the TCZ policy is not a randomized trial and those provinces with high SO_2 emissions and serious acid rain problems would have been

[5] Cailing Gao. *Historical Analysis of SO2 Pollution Control Policies in China*. Environmental Management (2009) 43:447–457

likely policy targets. If reverse causality is an issue, I would expect the rate of change of SO2PC and SO2PGDP between the treatment group and the control group to be quite different before the implementation of TCZ policy. In order to test this assumption, the dataset was collapsed by group and year, and pre-treatment T-Tests were conducted for the means of change of both SO2PC and SO2PGDP variables between the control group and treatment group. In Appendix 6, Tables 9 and 10 demonstrate that there is no significant difference between control group and treatment group before policy implementation for either SO2PC SO2PGDP. However, the T-Tests have only weak power due to the low degrees of freedom. As shown in the two tables, the means of change of SO2PC and SO2PGDP in the treatment group are almost three times the mean of change in the control group. Graphs 3 and 4 also give us visual evidence that, before the execution of the TCZ policy, SO2PC started at a higher level with a faster growth rate in the treatment group, while SO2PGDP started at a higher level with a faster reduction rate in the treatment group than in the control group.

Additionally, by applying a Probit model, we can investigate the common features among observations in the treatment group. Regression outcomes shown in Table 11 demonstrate that all independent variables are key factors in determining which provinces participate in the TCZ policy. In other words, provinces within control zones are characterized by high existing SO_2 pollution, high GDP per capita and high population density. Actually, these characteristics exactly reflect the selection criteria identified by the Plan on Identifying the Acid Rain Control Zone and Sulfur Dioxide Pollution Control Zone issued by the State Environmental Protection Administration in 1996. In this plan, selection criteria for areas to be included in the acid rain control zone present as followings: (1) current PH level of precipitation is less than 4.5; (2) sulfur deposition exceeds critical loads; (3) and there is a large amount of sulfur dioxide emissions. Also, the selection criteria for the sulfur dioxide pollution control zone was specified as followings: (1) the annual average concentration of sulfur dioxide in recent years exceeds the level II of the national standard; (2) daily average concentration of sulfur dioxide exceeds the level III of the national standard; (3) has a large amount of sulfur dioxide emissions. For the detailed information of national ambient air quality standards, please refer to Table 12 in Appendix 6. Apparently, the policy specifically targeted to areas where obtained more sulfur dioxide emissions and acid rain precipitation. As a result, the policy analysis would be affected by selection bias, leading to reverse causality problems.

Moreover, the third items for both selection criteria of these two control zones are very vague. Without a specific quantity restriction, it is hard to clearly identity how much of sulfur dioxide emissions could be “a large amount”. Thus, some scholars have cast doubts on the effectiveness of the TCZ policy and some even argued that the control standards were just used to prioritize sulfur dioxide control efforts by which the cities and regions could receive extra attention and resources.

2) Autocorrelation: Another problem that must be considered is autocorrelation in the error term for both Model I and Model II. Autocorrelation, if it exists, would not result in the “wrong” answers for coefficient estimates, but would blow up the standard error and generate an incorrect confidence interval. After running a regression of the residuals of both SO2PC and SO2PGDP on their lags, I find that there are three lags with a significant impact on the

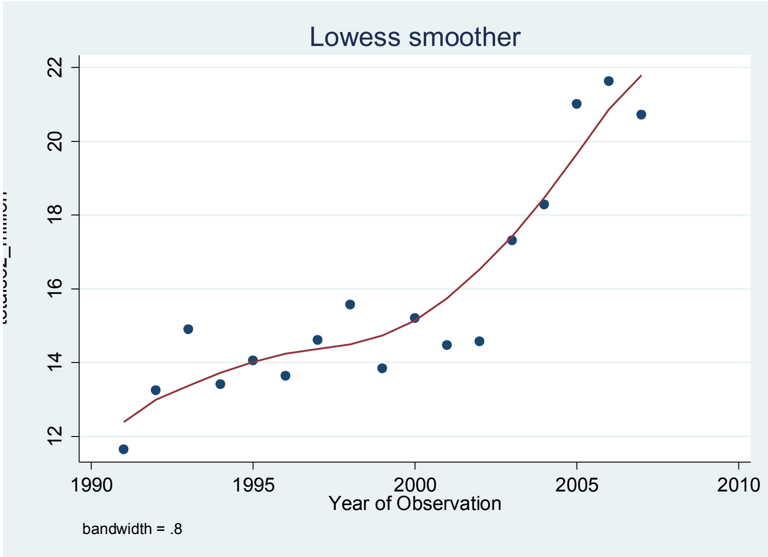
SO2PC's residual (See Table 13 in Appendix 6), while two lags have a significant impact on SO2GDP's residual (See Table 14). To correct this, Newey-West standard errors were applied to account for the autocorrelation (Table 15). As stated earlier, the estimates of treatment dummy are still not significant in Model I but continued to show strong significance in Model II.

Conclusion

It appears that the TCZ policy does not have an effect on SO_2 per capita emissions, but that the policy does have a significant effect on reducing SO_2 emissions per unit of GDP. However, due to limitations in the dataset, it is still difficult to quantify the true impact. The regression outcomes seem to support the theory that the TCZ policy has made production cleaner, which means that each unit of GDP growth causes less SO_2 emissions. However, the first important question is whether or not provinces selected into the Two Control Zones emit more SO_2 and have more serious acid rain problems than provinces not selected. If this is true, the control group is an invalid counter factual and an analysis of the TCZ policy based on comparisons between these two groups is not quite reliable. Although models incorporate time trends for each unit to solve the selection bias problem in Model II, another important question is if SO_2 emissions decreased relative to GDP, do these emissions have less negative effect on the environment? Unfortunately, based only on Model II, we cannot truly answer yes to this question. SO_2 emissions grow more slowly than GDP, but as long as SO_2 emissions continually rise, the environmental challenge of SO_2 pollution will exist forever. In other words, decreasing the ratio of SO_2 emissions against GDP does not give us any optimistic expectation concerning the future of SO_2 pollution problem. To be conservative, due to the imperfect counterfactual and dependent variable design, we cannot say that the Two Control Zone policy has had a significant effect on China's industrial SO_2 emissions control.

Appendix 1: Introduction

Graph 1 –Total Chinese SO2 Emissions, 1991-2007



Appendix 2: Summary Statistics and Variable Descriptions

Table 1 – Variable descriptions

Dependent Variable	**Description**	**Unit**
SO2 per capita	China's industrial SO2 emissions per person. Calculating form total SO2 emissions divided by total population	Kg/person
SO2 per GDP	China's industrial SO2 emissions per GDP. Calculating from total SO2 emissions divided by total GDP	kg/10 thousand Yuan
Independent Variable	**Description**	**Unit**
GDP per capita	China's GDP per person. Calculating form total GDP divided by total population	10 thousand Yuan/person
GDP per capita Square	Square term of GDP per capita	$(10\text{ thousand Yuan/person})^2$
Population Density	Numbers of people per km^2	People/ km^2
Treatment	Dummy variable of TCZ policy.	

Table 2 – Data Set Statistics (1991-2007)

Variable	# Observations	Mean	Std Dev.	Min	Max
SO2 per capita	510	13.82916	9.573403	0	60.25645
SO2 per GDP	510	27.48502	32.51312	0	343.3522
GDP per capita	510	.9211395	.9186862	.0874088	6.560199
GDP per capita Square	510	1.690828	4.255604	.0076403	43.03621
Population Density	510	365.104	461.2879	3.88647	2996.774
Treatment	510	.4509804	.4980798	0	1

Appendix 3: Methodology

Hausman Test of Models I & II

For Model I:

```
             ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |      fe            .          Difference          S.E.
-------------+----------------------------------------------------------------
       GDPPC |    6.680926     7.071294       -.3903678        .1907793
GDPPC_square |   -.8814021    -1.182948        .3015461        .1127847
 pop_density |   -.0202859    -.0024479       -.017838         .0061733
   treatment |   -.8026344    -1.055372        .2527377        .1735761
------------------------------------------------------------------------------
                          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(4) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =     2154.02
                Prob>chi2 =      0.0000
                (V_b-V_B is not positive definite)
```

For Model II:

```
             ---- Coefficients ----
             |      (b)          (B)            (b-B)     sqrt(diag(V_b-V_B))
             |      fe            .          Difference          S.E.
-------------+----------------------------------------------------------------
       GDPPC |   -8.923173    -6.347495       -2.575678        1.094601
 pop_density |    .0752424     .0086229        .0666195         .020403
   treatment |   -32.61374    -29.91391       -2.699824              .
------------------------------------------------------------------------------
                          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(3) = (b-B)'[(V_b-V_B)^(-1)](b-B)
                          =  -117.98    chi2<0 ==> model fitted on these
                                        data fails to meet the asymptotic
                                        assumptions of the Hausman test;
                                        see suest for a generalized test
```

Appendix 4: Results and Discussion for Model I

Table 3 – Two-Way Fixed Effects Regression of Baseline Model I (Without Time Dummies)

Independent Variable	Dependent Variable SO2PC
GDPPC	6.681***
	(0.819)
GDPPC_square	-0.881***
	(0.193)
pop_density	-0.0203***
	(0.00687)
treatment	-0.803
	(0.694)
Constant	17.01***
	(2.432)
Observations	510
R-squared	0.187
rmse	4.736
Number of id	30
Standard errors in parentheses	
*** p<0.01, ** p<0.05, * p<0.1	

Table 4 – Two-Way Fixed Effects Regression of Baseline Model I (With Time Dummies but not Report)

Independent Variable	Dependent Variable SO2PC
GDPPC	2.505*
	(1.471)
GDPPC_square	-0.663***
	(0.237)
pop_density	-0.00862
	(0.00708)
treatment	1.829*
	(1.059)
Constant	13.35***
	(2.523)
Observations	510
R-squared	0.273
rmse	4.555
Number of id	30
*** p<0.01, ** p<0.05, * p<0.1	
Standard errors in parentheses	

Table 5 – Two-Way Fixed Effects Adjusted Regression of Model I (With id*time term but not Report)

Independent Variable	Dependent Variable SO2PC
GDPPC	11.36***
	(1.932)
GDPPC_square	-1.042***
	(0.256)
pop_density	-0.00320
	(0.0169)
treatment	-1.099
	(0.821)
Constant	20.28***
	(11.17)
Observations	510
R-squared	-
rmse	4.070
Number of id	30
*** p<0.01, ** p<0.05, * p<0.1	
Standard errors in parentheses	

Appendix 5: Results and Discussion for Model II

Table 6 – Two-Way Fixed Effects Regression of Baseline Model II (Without Time Dummies)

Independent Variable	Dependent Variable SO2PGDP
GDPPC	-8.923***
	(1.978)
pop_density	0.0752***
	(0.022)
treatment	-32.61***
	(2.585)
Constant	25.88*
	(7.066)
Observations	510
Number of id	30
R-squared	0.385
rmse	20.03
Standard errors in parentheses	
*** p<0.01, ** p<0.05, * p<0.1	

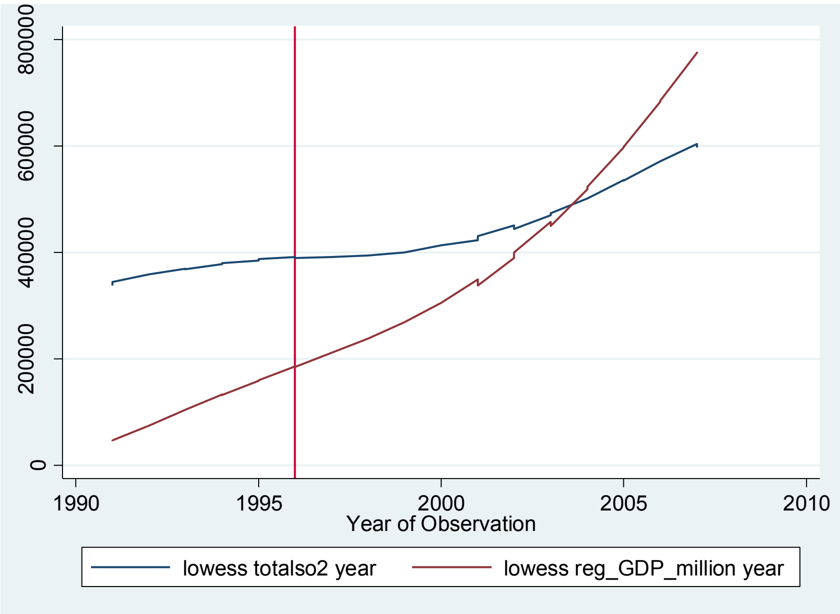
Table 7 – Two-Way Fixed Effects Regression of Baseline Model II (With Time Dummies but not Report)

Independent Variable	Dependent Variable SO2PGDP
GDPPC	6.720**
	(3.204)
pop_density	0.00674
	(0.024)
treatment	-21.11***
	(4.151)
Constant	61.05***
	(8.030)
Observations	510
Number of id	0.524
R-squared	30
rmse	17.93
*** p<0.01, ** p<0.05, * p<0.1	
Standard errors in parentheses	

Table 8 – Two-Way Fixed Effects Adjusted Regression of Model II (With id*time term but not Report)

Independent Variable	Dependent Variable SO2PGDP
GDPPC	9.461**
	(3.852)
pop_density	-0.0433
	(0.0581)
treatment	-14.35***
	(3.231)
Constant	70.94***
	(18.94)
Observations	510
Number of id	30
R-squared	0.631
rmse	16.04
*** p<0.01, ** p<0.05, * p<0.1	
Standard errors in parentheses	

Graph2- Trend Comparison of Total SO_2 Emissions (tn) and Total GDP (million yuan) from 1991-2007



Appendix 6: Robustness Checks

T-Test: Pre-Treatment Comparison of Mean of Change between Control and Treatment Groups

Table 9- Pre-Treatment T-Test for Change of SO_2 per capita between Two Groups

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
0	5	.0979848	2.385808	5.33483	-6.526081	6.722051
1	5	.3607085	.6338481	1.417327	-1.399136	2.120553
combined	10	.2293466	1.164519	3.682533	-2.404979	2.863672
diff		-.2627237	2.468572		-5.95526	5.429812

```
    diff = mean(0) - mean(1)                                      t =  -0.1064
Ho: diff = 0                                     degrees of freedom =        8

    Ha: diff < 0                 Ha: diff != 0                 Ha: diff > 0
 Pr(T < t) = 0.4589         Pr(|T| > |t|) = 0.9179          Pr(T > t) = 0.5411
```

Table 10- Pre-Treatment T-Test for Change of SO_2 per GDP between Two Groups

Two-sample t test with equal variances

Group	Obs	Mean	Std. Err.	Std. Dev.	[95% Conf.	Interval]
0	5	-3.837704	8.149254	18.22229	-26.46366	18.78825
1	5	-9.117608	4.264096	9.534807	-20.95664	2.721419
combined	10	-6.477656	4.424114	13.99028	-16.4857	3.530385
diff		5.279904	9.197437		-15.92942	26.48923

diff = mean(0) - mean(1)   t = 0.5741

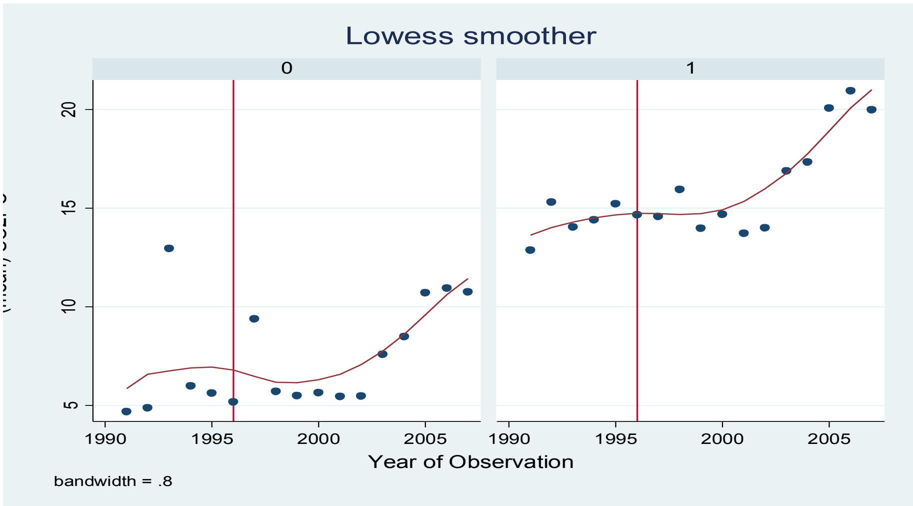
Ho: diff = 0   degrees of freedom = 8

Ha: diff < 0   Pr(T < t) = 0.7091

Ha: diff != 0   Pr(|T| > |t|) = 0.5817

Ha: diff > 0   Pr(T > t) = 0.2909

Graph3- Comparison of Mean of SO_2 per capita between Control Group and Treatment Group (1991-2007)



Graph4- Comparison of Mean of SO_2 per GDP between Control Group and Treatment Group (1991-2007)

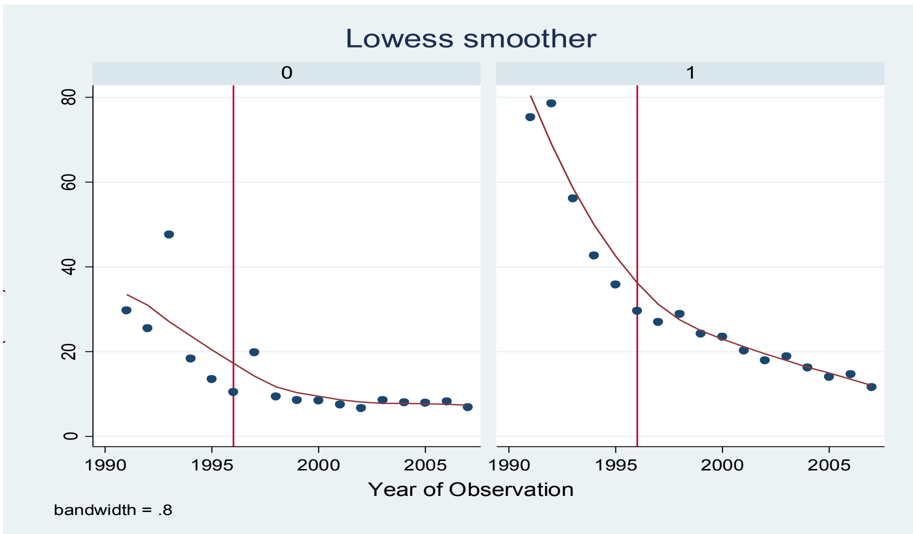


Table 11 – Probit Model for Treatment Dummy Variable

Independent Variable	Dependent Variable Treatment
GDPPC	0.244**
	(0.114)
pop_density	0.000437**
	(0.000186)
SO2PC	0.110***
	(0.0135)
SO2PGDP	-0.0287***
	(0.00456)
Constant	-0.244*
	(0.114)
Observations	510
Number of id	30
R-squared	-
*** p<0.01, ** p<0.05, * p<0.1	
Standard errors in parentheses	

Table 12 - National Standards for the Sulfur Dioxide Concentration[6]

Time Unit	Concentration Limit (μg/m3)		
	Level I	Level II	Level III
Annual Average	0.02	0.06	0.10
Daily Average	0.05	0.15	0.25
Hour Average	0.15	0.50	0.70

[6] State Administration of Environmental Protection of China. *Ambient Air Quality Standard*, January 18, 1996

Table 13 – Test of Autocorrelation for Model I

Independent Varia	Dependent Variable residual of SO2PC
residual_lag1	0.752***
	(0.0443)
residual_lag2	0.152***
	(0.0399)
residual_lag3	0.109***
	(0.0347)
residual_lag4	0.00498
	(0.0336)
Constant	-4.55E-10
	(0.151)
Observations	390.00
R-squared	0.920
rmse	2.988
*** p<0.01, ** p<0.05, * p<0.1	
Standard errors in parentheses	

Table 14 –Test of Autocorrelation for Model II

Independent Variable	Dependent Variable residual of SO2PGDP
residual_lag1	0.739***
	(0.0375)
residual_lag2	0.125***
	(0.0293)
residual_lag3	0.0148
	(0.0196)
residual_lag4	0.0329
	(0.0183)
Constant	-1.29E-08
	(0.330)
Observations	390
R-squared	6.552
rmse	0.925
*** p<0.01, ** p<0.05, * p<0.1	
Standard errors in parentheses	

Table 15 –Two Models with Newey-West Standard Errors
(Time dummies not reported)

Independent Variable	Dependent Variable SO2PC	Dependent Variable SO2GDP
GDPPC	2.505	6.720*
	2.336	(3.143)
GDPPC_square	-0.663**	
	(0.331)	
pop_density	-0.00862	0.00674
	(0.00679)	(0.0219)
treatment	1.829	-21.11***
	(1.621)	(6.375)
Constant	16.04***	35.32***
	(4.833)	(13.18)
Observations	510	510
*** p<0.01, ** p<0.05, * p<0.1		
Standard errors in parentheses		