Electronic Supplementary Material

Efficiency evaluation of government investment for air pollution control in city clusters: A case from the Beijing–Tianjin–Hebei areas in China

Siqi YANG, Li ZHANG (✉), Zhaoxu CHEN

School of Information Management, Beijing Information Science and Technology University, Beijing 100096, China

E-mail: zhangli@bistu.edu.cn

Nan LI

Key Laboratory of Urban Environment and Health, Institute of Urban Environment Chinese Academy of Sciences, Xiamen 361021, China; Xiamen Key Laboratory of Urban Metabolism, Institute of Urban Environment Chinese Academy of Sciences, Xiamen 361021, China; University of the Chinese Academy of Sciences, Beijing 100049, China

Appendix A

Twenty similar SFA regression equations are available, where all *t*-tests were passed. The one-sided generalized LR test results for the input slack variables show that only the slack variables of centralized heating investment in 2014 do not significantly reject the existence of a management inefficiency term. Therefore, we used OLS regression to separate the environmental factors and statistical noise in 2014. The centralized heating variable in the 2014 regression table was obtained from the OLS regression.

Table A1 Regression results of a similar SFA model in the second stage in 2018

Slack variables	Gas investment			Central heating investment		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−85113	1.000	−85113***	−111499	1.000	−111499***
GDP per capita	0.556	0.001	512.966**	0.728	0.329	2.215*
σ^2	8.54E+09	1.000	8.54E+09***	1.35E+10	1.000	1.35E+10***
γ	1.000	0.000	757468.13***	1.000	0.000	43660.949***
Log likelihood		−230.086***			−234.253***	
LR test		10.912***			11.517***	
Slack variables	Landscaping investment			Investment in the treatment of waste gas		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−19802	9.307	−2128***	−195042	1.000	−195042***
GDP per capita	0.129	0.010	12.364**	1.273	0.410	3.102**
σ^2	4.43E+08	1.000	4.43E+08***	8.56E+10	1.000	8.56E+10***
γ	1.000	0.000	1230404.900***	1.000	0.000	103846***
Log likelihood		−202.722***			−250.122***	
LR test		9.108***			15.218***	

Note: *, **, ***, and **** in all the tables indicate significance at the 0.25, 0.05, 0.01, and 0.005 levels, respectively.

Table A2 Regression results of the similar SFA model in the second stage in 2017

Slack variables	Gas investment			Central heating investment		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−14430	1.000	−14430	−30055	1.009	−29802
GDP per capita	0.104	0.023	4.598***	0.218	0.001	171.919*
σ^2	9.38E+08	1.000	9.38E+08	1.79E+09	1.000	1.79E+09
γ	1.000	0.000	2800.398	1.000	0.000	3656701.100
Log likelihood		−208.574****			−215.220****	
LR test		11.661****			10.680****	
Slack variables	Landscaping investment			Investment in the treatment of waste gas		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−42338	1.000	−42338	−214418	1.000	−214418
GDP per capita	0.308	0.014	21.537***	1.547	1.199	1.290***
σ^2	2.28E+09	1.000	2.28E+09	1.56E+11	1.000	1.56E+11
γ	1.000	0.000	92218.814	1.000	0.000	10238.945
Log likelihood		−219.365****			−256.735****	
LR test		6.930****			12.530****	

Table A3 Regression results of a similar SFA model in the second stage in 2016

Slack variables	Gas investment			Central heating investment		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−150226	1.000	−150226	−243417	1.000	−243417
GDP per capita	1.206	0.229	5.274**	1.953	0.239	8.174**
σ^2	2.24E+10	1.000	2.24E+10	5.96E+10	1.000	5.96E+10
γ	1.000	0.000	78349.051	1.000	0.000	92547.143
Log likelihood		−238.986***			−247.898***	
LR test		11.738***			12.496****	
Slack variables	Landscaping investment			Investment in the treatment of waste gas		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−20566	1.534	−13406	−380186	1.000	−380186
GDP per capita	0.165	0.060	2.750**	3.046	0.510	5.970**
σ^2	3.43E+08	1.000	3.43E+08	1.51E+11	1.000	1.51E+11
γ	1.000	0.000	16578.051	1.000	0.000	2317.869
Log likelihood		−200.416***			−257.685***	
LR test		8.874***			9.973***	

Table A4 Regression results of the similar SFA model in the second stage in 2015

Slack variables	Gas investment			Central heating investment		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−47848	1.000	−47848	−86525	1.000	−86525
GDP per capita	0.415	0.007	61.110**	0.754	0.279	2.706**
σ^2	2.53E+09	1.000	2.53E+09	7.32E+09	1.000	7.32E+09
γ	1.000	0.003	334.564	1.000	0.000	20228.378
Log likelihood		−219.210***			−228.632***	
LR test		9.231***			10.883***	
Slack variables	Landscaping investment			Investment in the treatment of waste gas		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−94595	1.000	−94595	−223560	1.000	−223560
GDP per capita	0.825	0.023	35.153**	1.946	0.278	7.000**
σ^2	1.19E+10	1.000	1.19E+10	5.06E+10	1.000	5.06E+10
γ	1.000	0.000	302686.800	1.000	0.001	1173.517
Log likelihood		−232.467***			−247.151***	
LR test		12.386***			10.276***	

Table A5 Regression results of a similar SFA model in the second stage in 2014

Slack variables	Gas investment			Central heating investment		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−389152	1.001	−388937	−55649	36683.916	−2
GDP per capita	3.996	0.494	8.082**	1.781	0.577	3.089**
σ^2	7.29E+10	1.000	7.29E+10	3.61E+09		
γ	0.955	0.055	17.270			
Log likelihood		−253.233***				
LR test		5.950***				
Slack variables	Landscaping investment			Investment in the treatment of waste gas		
	Coefficient	Standard deviation	*t*-statistics	Coefficient	Standard deviation	*t*-statistics
Constant terms	−188803	1.013	−186459	−329096	1.002	−328429
GDP per capita	2.311	0.310	7.454**	3.692	0.703	5.252**
σ^2	1.89E+10	1.000	1.89E+10	1.27E+11	1.000	1.27E+11
γ	0.895	0.084	10.698	0.954	0.047	20.112
Log likelihood		−243.124***			−258.963***	
LR test		2.484***			4.446***	

Appendix B

The BTH region, located in northern China, is one of the most economically developed and densely populated areas in the country. As of 2020, the total population of the BTH region is approximately 110 million, with Beijing and Tianjin being the most populous cities. The cities in Hebei Province and the surrounding areas form large urban agglomerations around these two cities. This region experiences a temperate monsoon climate, with distinct seasons. According to data from the China Meteorological Administration, the average annual temperature in the region is −11–13 °C, with an average annual precipitation of 500–600 mm.

Table B displays demographic, economic, and climatic data for the studied BTH region, including the resident population, gross regional product, average annual temperature, average annual humidity, and average annual precipitation.

Table B BTH background information in 2020

Location	Average annual temperatures (°C)	Average annual humidity (%)	Average annual precipitation (mm)	Resident population (10000 person)	Gross regional product (100 million yuan)
BTH	13.0	57.3	534.5	11010	96356
Beijing	13.8	52	528.0	2189	36103
Tianjin	13.8	59	704.5	1387	14084
Shijiazhuang	14.7	58	658.1	1124	5935
Tangshan	12.6	59	718.2	772	7211
Handan	14.5	64	504.5	941	3637
Baoding	12.9	60	484.3	1155	3954
Taiyuan	11.2	59	547.0	532	4153
Yangquan	11.3	58.6	506.9	132	742
Changzhi	11.2	60	539.0	318	1712
Hohhot	7.0	49	364.2	345	2801
Baotou	7.3	59.4	384.1	271	2787
Chifeng	8.0	49.2	416.8	404	1763
Jinan	14.5	57	661.8	924	10141
Zibo	14.3	60.2	721.4	471	3673
Jining	15.2	64.1	803.5	836	4494
Zhengzhou	16.5	62	679.4	1262	12004
Kaifeng	16.2	64.4	589.3	483	2372
Anyang	15.1	61.7	480.9	548	2300
Jiaozuo	16.9	66.5	659.9	352	2124

Note: Data sources include the *China Statistical Yearbook*, *China City Statistical Yearbook*, *Hebei Statistical Yearbook*, *Inner Mongolia Statistical Yearbook*, *Shandong Statistical Yearbook*, *Yangquan Statistical Yearbook*, and the China Meteorological Administration.