

**Greening the Career Incentive Structure for Local Officials in China:
Does Less Pollution Increase the Chances of Promotion for Chinese Local Leaders?**

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Abstract: Does it pay to be “greener” as a local official in China? In this paper, we examine the effect of local environment regulation outcomes, i.e., local pollution, on leaders’ chances of promotion. This is an important question because only when the Chinese cadre evaluation system rewards local officials’ green behaviors, these officials would move away from their past priority in promoting economic growth at all costs, so that the environmental crisis in China might be addressed. We collect party secretary data for Chinese counties between 2001 and 2014 to measure promotion patterns. We construct county-year SO₂ and PM_{2.5} pollution measures using NASA satellite data. We adopt an instrumental variable approach to deal with potential endogeneity issues of the pollution variables: for both PM 2.5 and SO₂, we use ventilation coefficient, i.e., the product of wind speed and mixing layer height, as the instrument. Our empirical analysis shows that for county party secretaries, those who are able to reduce air pollution are more likely to be promoted. We find similar results for county magistrates. However, we do not find evidence for this pollution-promotion link for prefecture and provincial party secretaries.

1. Introduction

The emerging environmental crisis in China has attracted much attention from practitioners and academics (Economy 2004; Shapiro 2012). Environmental challenges pose considerable threats to China's long-term development (Tilt 2013). In addition to the detrimental effects on its own environment, Chinese environmental crisis has profound global implications. For instance, with its increasing economic size and energy consumption, China is now the largest emitter of carbon dioxide in the world. In 2018, Chinese emissions of roughly 13.5 Gt CO₂ were approximately 25% of the global total (Olivier and Peters 2018).

The environmental crisis in China is not only a natural outcome of economic growth in a typical developing country going through industrialization. Rather, there are deep political reasons, one of which has to do with the incentive structure for local officials who have long been prioritizing economic development at the expense of the environment. Chinese cadre evaluation system promotes those who deliver high priority targets. Local leaders are motivated to develop local economy because upper-level governments make promotion decisions by evaluating the relative economic growth of jurisdictions (Maskin et al. 2000). To generate better economic growth, local governments often sacrifice the environment by, for instance, lessening or non-compliance with existing regulations to lower local firms' production costs.

The public and the central government have become acutely aware of such a built-in "environmentally unfriendly" incentive in the cadre evaluation system. The central government has implemented various policies to address severe environmental issues. For instance, in 2013, the State Council approved the *Action Plan for Air Pollution Prevention and Control*, which outlines specific PM_{2.5} air pollution targets for local governments. In recent years, new targets including environmental protection have been added as high priority targets for local officials. The central government expects that such changes would incentivize local officials to reduce pollution.¹ However, for many scholars, when it comes to performance evaluation, promoting economic growth is still considered by most local officials as the safest bet for career advancement (Li and Zhou 2005; Heberer and Senz 2011).

This paper tests whether local officials' green efforts, reflected by better local environmental outcomes, are rewarded by the cadre evaluation system since the early 2000s. This is an important question, because only when the system rewards green behaviors, local officials might move away from their past priority in promoting economic growth, so that the environmental crisis in China might be addressed. We first collect county party secretary data for over 2000 Chinese counties between 2001 and 2014 to measure their promotion patterns. We construct county-year level SO₂ and PM_{2.5} air pollution measures, using fine-grained NASA satellite data. We adopt an instrumental variable approach to deal with potential endogeneity issues of the pollution variables: for both PM_{2.5} and SO₂, we use ventilation coefficient, i.e., the product of wind speed and mixing layer height, as the instrument. Our empirical analysis shows that for county party secretaries, those who were able to reduce air

¹ Yin et al. (2019) consider integrating environmental performance into the cadre evaluation system one of the two future mechanisms to strengthen traditional command and control regulations; the other involves leveraging the power of financial sectors.

pollution were much more likely to be promoted. We extend our analysis to county magistrates and find similar results. However, when we further extend our study to prefecture and provincial party secretaries, we do not find any evidence for the pollution-promotion link.

We are not the first to empirically test the connection between pollution and cadre promotion in the Chinese context. A few recent studies have started to tackle this pollution-promotion question. Using data on energy intensity, air pollution treatment spending, and air pollution from 86 major Chinese cities, Zheng et al. (2014) find that better environmental performances are associated with a higher chance of city mayor promotion.² Chen et al. (2016) show a positive connection between energy productivity and provincial governors' promotion in 31 provinces. Using data from 100 Chinese cities, Pu and Fu (2018) show that pollution decreases the chances of promotion for city mayors, with the effect varying cross regions and by pollutants. Feng et al. (2018), however, find that environmental performance does not significantly impact political turnovers of municipal party secretaries during 2002-2013. Most recently, Wang and Lei (2020) show that local officials' efforts towards environmental protection contribute to their political promotion for a panel of prefecture-level party secretaries and governors during 1996-2013.³

How is our paper different? Firstly, unlike past studies that either use data from the provincial level or from Chinese prefectural cities, we extend this empirical literature to a lower administrative level. This county-level focus has several advantages. For instance, county-level pollution data is much more fine-grained. In China, prefectures are often very large: e.g., the Daxing'anling Prefecture (46,755 km²) in Heilongjiang, not even a top 20 prefecture by size, is roughly the size of Estonia and is larger than Denmark. There is often significant within-prefecture variation in air pollution. Using prefecture or province pollution averages often washes out pollution hotspots in the data. Moreover, counties are historically the most basic units of administration reached by the central government in China.⁴ Most day-to-day functions of the government, including environmental protection, ultimately are being implemented by county governments. The county-level bureau of environmental protection is the last layer of the environmental protection branch of the government: there is no office or bureau below the county level. Indeed, the importance of the county economy has become even more pronounced after the tax reform in 1994. After this reform, local governments' economic growth strategy changed from industrialization based on corporate profits to urbanization based on land finance (Kung et al. 2013). County governments have been granted land transfer rights so that they can promote economic growth through low-cost land transfers for investment, real estate development, and establishing financing platforms

² Though the statistical significance level of such an association varies by model specification and energy/pollution indicators used.

³ Relatedly, adopting a database of cadre promotion and pollution discharge for Chinese prefecture-level cities from 2003 to 2016, Wang and Lei (Forthcoming) find that environmental protection tournaments have contributed to cadres' promotion since 2007.

⁴ Historically, the Chinese central government could not research below the county level of administration. At levels below county (i.e., townships and villages), public goods and other government functions were historically delegated to local elites.

for infrastructure construction. More recently, county governments have been continuously given greater importance, a trend that is embodied in a series of reforms such as an “expansion of power to create strong counties” (Kuo Quan Qiang Xian) and “provincial directly managed counties” (Sheng Zhi Guan Xian).

Secondly, we use the same instrumental variable strategy to explain promotion of county magistrates and prefecture and provincial party secretaries. We find a similar causal effect of pollution on promotion for county magistrates. But there is no evidence for the pollution-promotion link at the prefecture and provincial levels. This is a significant contribution as it reveals that for party secretaries – those who are in real charge at every level of the government, the causal effect of pollution on promotion only works at the county level. Analyzing promotion of provincial, prefectural, and county party secretaries and government executives between 1999 and 2007, Landry et al. (2018) also only find evidence for performance-based promotion at the county level. Their performance measure is economic growth; our performance measure is based on pollution; both reflect local leaders’ competence, which is often contrasted with loyalty as two competing forces for promotion.⁵ Why the performance-based promotion only works at the county level? We share a similar explanation as in Landry et al. (2018): local officials who are distant in hierarchy from central rulers have no direct influence on central leader selection, therefore posing little threat even if they are not loyal; they are therefore evaluated based on competence as central leaders need to incentivize them for economic growth and pollution reduction. Higher ranked officials, on the other hand, are within the selectorate that is key to the survival of the central rulers: their loyalty matters much more than competence.

Thirdly, unlike past studies that test statistical associations between pollution and promotion, we adopt an instrumental variable estimation that enables us to make a causal claim. We use ventilation coefficient as the instrument for PM_{2.5} and SO₂. Ventilation coefficient is the product of wind speed and mixing layer height, with the former determining horizontal dispersion of pollution while the latter the height within which pollutants disperse. The higher the wind speed and the mixing height, the faster the dispersion of pollutants, therefore the lower the level of air pollution (Arya 1998). Our instrumental variable approach also helps to address a reverse causality concern that high promotability leaders were

⁵ Our finding that county officials were promoted for pollution reduction would not suggest that economic growth was not rewarded at the county level. Pollution reduction and economic growth are both targets to evaluate local officials. Indeed, as a recent paper’s title vividly illustrates – “Career concerns and multitasking local bureaucrats: Evidence of a target-based performance evaluation system in China” (Chen et al. 2018), with environmental targets added to the cadre evaluation system, local officials are subject to a double pressure to both grow the economy and reduce pollution. Economic growth can be achieved without sacrificing the environment. Local governments can encourage cleaner industries through industrial policies. They can also strengthen the enforcement of environmental regulations. Indeed, growth has become less pollution-intensive in China. Figure B-1 in online appendix shows the annual correlations between county PM_{2.5} and GDP per capita between 2001 and 2014: since 2004, the correlations start to drop, suggesting that Chinese counties have been moving into a stage of development in which GDP correlates less with pollution.

assigned to jurisdictions with a better potential in pollution reduction. For instance, local ventilation coefficients often exhibit significant year-by-year changes. Such temporal changes are a function of meteorological conditions that are often difficult to predict for the medium and long terms. It is unlikely that leaders self-select or are appointed in and out of counties depending on (often poorly predicted) expected year-to-year changes in local ventilation coefficients.⁶

Finally, our paper makes general contributions to the literature on environmental outcomes in developing countries and to the literature on the political foundations of pollution. One of the most fundamental questions for environmental and developmental economics is to explain environmental outcomes in developing countries, i.e., “why environmental quality is so poor in developing countries?”⁷ Greenstone and Jack (2015) synthesize four potential explanations: low marginal willingness to pay for environmental goods, high marginal costs of investments in environmental quality improvements, political economy of rent-seeking behaviors, and market failures (e.g., under-provisions of public goods and negative externalities) and imperfections (e.g., missing land, capital, and labor markets). Our paper speaks directly to the third explanation which often focuses on the role of incentive structure. Firms respond to the incentive structure set up by regulators (McRae 2015). So do government officials. Recent studies present new evidence that improving incentives can improve monitoring and enforcement outcomes. For instance, experimental evidence from Duflo et al. (2013) shows that altering market structure incentivized accurate reporting by third-party auditors in India. In Kahn et al. (2015), interjurisdictional water pollution was reduced significantly in China after a new local cadre promotion rule was established to reward pollution reductions along administrative boundaries. Our paper contributes to this emergent literature at the intersection of developmental and environmental economics by focusing on one of the most important incentive structure changes – a shift away from a growth-at-all-cost incentive structure to one that emphasizes environmental protection – in the largest developing country in the world, China.

In addition, there is a literature in economics and political science that study the political foundations of pollution. The focus here is whether and how political regime types affect environmental performances. The literature often contrasts democracies with autocracies. Overwhelming theoretical propositions favor the former as the better system. For instance, democracy is said to be associated with more citizen influence on policies through the ballot box, pressure groups, and a free media (Payne 1995). However, no clear pattern has emerged from the empirical studies (Grafton and Knowles 2004; Binder and Neumayer 2005; Fredriksson et al. 2005; Bernauer and Kuobi 2009). Such mixed empirical findings have motivated the field to move beyond a simple democracy-autocracy dichotomy and to focus on detailed causal mechanisms connecting political dynamics to environmental outcomes. For instance, recent studies examined variations within democracies regarding institutional differences such as proportional vs. majoritarian electoral rules and presidentialism vs.

⁶ See robustness checks, section “Addressing potential reverse causalities,” for our empirical strategies further to rule out this selection effect.

⁷ See also a special issue on this topic in the *Journal of Environmental Economics and Management*: e.g., Jack (2017) for the introduction.

parliamentarianism (Fredriksson and Millimet 2004; Fredriksson and Wollscheid 2007). Our paper contributes to this much more nuanced view of political regimes' environmental impacts. We show that even in the absence of electoral competition, an incentive structure that rewards better environmental performances can be established so that local officials who are able to reduce pollution are more likely to be promoted. This top-down approach serves as a substitutive institution to reward green local leaders, therefore increasing environmental quality in countries without an established democratic rule.

2. Literature and Theoretical Expectation

The alarming level of environmental degradation in China is not simply a natural outcome of economic growth and industrialization in a typical developing country. Rather, there are deep political reasons, one of which has to do with the incentive structure for local officials who, many believe, have long been prioritizing economic development at the expense of the environment (Economy 2004; Shapiro 2012).

Career Incentive Structure and its Environmental Implications

Chinese local leaders' behaviors are driven by a cadre evaluation system in which those who deliver high priority targets are more likely to be promoted. This political tournament theory posits that local cadres engage in a tournament-style competition with their peers in neighboring jurisdictions over promotions to the next level (Chen et al. 2005; Li and Zhou 2005; Wu and Chen 2016). To maximize the chances of promotion, they are motivated to develop local economies because the upper-level government makes promotion decisions by evaluating their performances based on the relative economic growth of jurisdictions (Maskin et al. 2000).

This political tournament theory has received criticisms. For instance, the economic performance of local leaders itself can be endogenous: officials with close ties to central leaders are more likely to be assigned to places with better growth potential (Oppor and Brehm 2007). As a result, many argue that factors such as loyalty or faction decide promotion (Shih et al. 2012.).⁸ Despite the aforementioned criticism, this career incentive approach has been broadly applied in recent studies of Chinese politics and economics, including topics such as leaders and factions within the Chinese Communist Party (Shih et al. 2010), the effects of faction ties and competence on promotion (Choi 2012), judicial cadre evaluation and court leader performances (Kinkel and Hurst 2015), local cadres' responses to changes in target-based cadre evaluation system (Gao 2015), and the changing priorities of local leaders from economic development to social welfare (Zuo 2015).

What are the environmental implications of such a career incentive structure? To generate better economic growth, local governments often sacrifice the environment. In the Chinese context, many environmental laws and regulations are designed at the central level. Their implementation, on the other hand, is largely in the hands of local leaders. It is the implementation of existing laws and regulations that can be manipulated by local officials. Lessening implementation or non-compliance lowers firms' production costs. Dasgupta et al. (2001) show that for a small paper factory in China that on average discharges 327,800 tons

⁸ Jia et al. (2013) find that connection and performance are complements in promotion.

of wastewater yearly, the cost of reducing 90% suspended solids alone is \$452,364 in 1994. Moreover, if firms are mobile, jurisdictions with less stringent de facto environmental regulations attract pollution intensive firms. This is the pollution haven hypothesis, which has received empirical support in the Chinese context (Dean et al. 2009). For instance, Zhu et al. (2014) find that Chinese pollution-intensive firms have relocated from the coastal province Zhejiang to inland China, where enforcement of environmental regulation is laxer.

Indeed, legal scholars have pointed out that the Chinese national environmental legislation on paper is plentiful and powerful; the problem is local enforcement. For instance, despite central government's efforts to clean up, the Huai River remains one of the most polluted in China, because polluting factories along the river contribute significantly to local economy. Local officials had strong incentives not to (fully) enforce environmental regulations (Economy 2004). More recently, Cai et al. (2016) show that local governments can affect the stringency of enforcement via the collection of pollution fees and the inspection of violations. Cao et al. (2019) show that Chinese prefecture leaders' selective enforcement of environmental regulations creates an environmental political business cycle in which pollution increases in years leading to the year of leader turnover.

Unprecedented Environmental Crisis and A Changed Incentive Structure?

The public and the central government have become acutely aware of such a built-in "environmentally unfriendly" incentive in the traditional cadre evaluation system. Indeed, the central government has implemented various policy schemes to address severe environmental issues. Recent studies focus on the effectiveness of such policy initiatives (Kahn et al. 2015; Chen et al. 2018). For instance, since 1996, the central government has identified "three rivers and three lakes basins" (3Rs3Ls) as key regions for water pollution control. Wang et al. (2018) evaluate the effects of the water quality regulations in the 3Rs3Ls basins. They find that such regulations forced out small, heavily polluting firms, but had no effect on surviving firms' productivity. In 1998, a Two Control Zones (TCZ) policy was implemented by the central government in which tougher environmental regulations were imposed in TCZ cities. Cai et al. (2016) find that environmental regulations in the TCZ cities indeed affects patterns of foreign direct investment, especially for those from countries with better environmental protections. In 2006, the 11th Five-year Plan from the central government assigned different pollution reduction quota to provincial governments. Shi and Xu (2018) reveal a heterogeneous effect of cross-province variations in policy intensity (in reducing pollution) on the content and volume of Chinese firm exports: interestingly, state-owned enterprises (SOEs) and firms in the central and western part of China are much less affected.

Other policy instruments have also been applied by the government. Zhang et al. (2018) study the National Specially Monitored Firms (NSMF) program in which central supervision is applied to firms that are listed as NSMF. They find that central supervision significantly reduces industrial COD emissions by at least 26.8%. Focusing on another policy innovation – government environmental interviews with firms (Huan Bo Yue Tan), Shen and Zhou (2017) find that the environmental performances of companies in the interviewed areas have improved significantly. Karplus and Wu (2019) and van der Kamp (Forthcoming) study the effect of central government top-down inspection campaigns. The former shows that such crackdowns result in a large reduction in SO₂ emissions in short periods before pollution

reverts to prior levels after crackdowns end. The latter finds that such a police patrol instrument does not even have a significant short-term effect.

In recent years, environmental protection has been added as a high priority target for local officials' evaluation. The motivation is that such changes would incentivize local officials to be "green." However, many scholars still believe that when it comes to maximize the chances of promotion, economic growth is still considered the safest bet for most local officials (Li and Zhou 2005; Heberer and Senz 2011). Whether local officials in China would respond to this "greener" incentive structure largely depends on whether their green efforts, as reflected by better local environmental outcomes, would be rewarded by the cadre evaluation system. This is the focus of our study, that is, all else equal, *does less local pollution increase the chances of promotion for Chinese local leaders?*

3. Data

Measuring Local Officials' Promotion

In this paper, we examine the effect of local environment regulation outcomes – local pollution – on local leaders' chances of promotion to a higher-level post. China has 334 prefecture-level administrative units that are further divided into 2,862 county-level units. We first focus on county party secretaries because they are higher in rank than county magistrates and are the primary decision-makers when it comes to salient policies.⁹ The dependent variable, *political turnover*, is binary and is defined as follows:

$$political\ turnover = \begin{cases} 1: promoted & \left(\begin{array}{l} \text{move from county to district; from county and} \\ \text{district to higher position at prefecture and above} \end{array} \right); \\ 0: same\ job\ or\ job\ move\ at\ the\ same\ level; \end{cases}$$

This binary "promotion" variable equals to 1 if an official gets a promotion; 0 if moving between different counties or staying at the same level of departments. Demoted, retired, and punished officials are not included. This is because demotion, punishment, and retirement reflect special circumstances that often have little to do with a cadre's economic and environmental performances. For instance, a cadre is retired due to his/her age; he/she is punished for his/her crime. To construct this *political turnover* variable, we obtain county party secretary names from province yearbooks and search biographies from Baidu Encyclopedia to get information regarding age, gender, education, place of birth, and working experiences. All years are included in the sample, not just the years with a turnover event. In the online appendix, we include robustness checks that use a *political turnover* variable that treats demotion, retirement, and punishment also as 0. We obtain similar results using this alternative measure of promotion outcome (Table A3 and A4).

Later in this paper, we extend our analysis to county magistrates and prefecture and provincial party secretaries. We define the political turnover variable for a county magistrate as 1 if he/she is promoted to be a county party secretary or any position that would be considered a promotion for county party secretaries (i.e., a move from county to district; from county and district to higher position at prefecture and above); and 0 otherwise. Similarly,

⁹ Eaton and Kostka (2014), for instance, argue that "Within the leadership group, party secretaries usually hold the pre-eminent position and are seen as the first hand."

county magistrates who are retried, demoted, or punished are not included in the analysis presented in the main text. In the online appendix (Table A5 and A6), we present results (which are similar) using an alternative promotion outcome variable that treats demotion, punishment, and retirement also as 0. At the prefecture level, we define a prefecture party secretary as promoted if he/she is promoted to key positions at the province level or above (Jiang 2018). At the province level, we define a province party secretary as promoted if he/she is promoted to be a member of the Politburo, a standing member of the Politburo, the premier of state council, a vice premier of state council, or a member of the state council.

Measuring Local Air Pollution

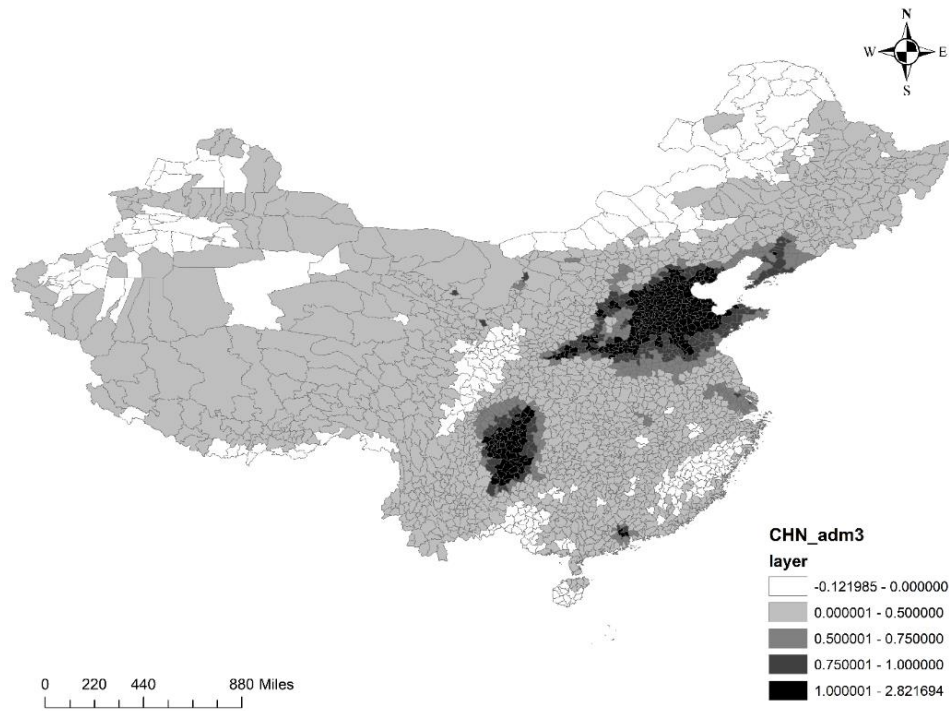
Our empirical analysis uses satellite data from the National Aeronautics and Space Administration (NASA). We use two types of air pollutant data: PM2.5 and SO2.¹⁰ The PM2.5 data has been used in recent articles such as Cao et al. (2019). These are annual average concentration data, covering 1998-2016, and are provided in grid-cells with 0.1×0.1 decimal degree resolution (about 11km by 11km). We re-sampled the grid data in ArcMap so that each grid is evenly divided into 100 smaller grids. We calculated the county-year annual average concentration levels by overlaying the resampled PM2.5 grids over Chinese county polygons and taking the average PM2.5 annual concentration levels of all grids falling within a county polygon.

The SO2 data is much more recent. They are provided by 0.125×0.125 decimal degree global grids, about 13km by 13km at the equator. One complication is that these are daily data from 2005 to 2018.¹¹ We processed all data between 2005 and 2018, took annual averages based on daily data, re-sampled the data so that each grid is evenly divided into 100 smaller grids, and we overlaid them to polygons of Chinese counties: the end results are annual averages of SO2 concentration levels at the county level. Figure 1 shows county annual averages of SO2 concentration for 2005 and 2015: note that 2005 is the last year before the 11th Five-year Plan which formally added environmental performances into the cadre evaluation system. It seems that China has significantly reduced its SO2 air pollution since 2005.

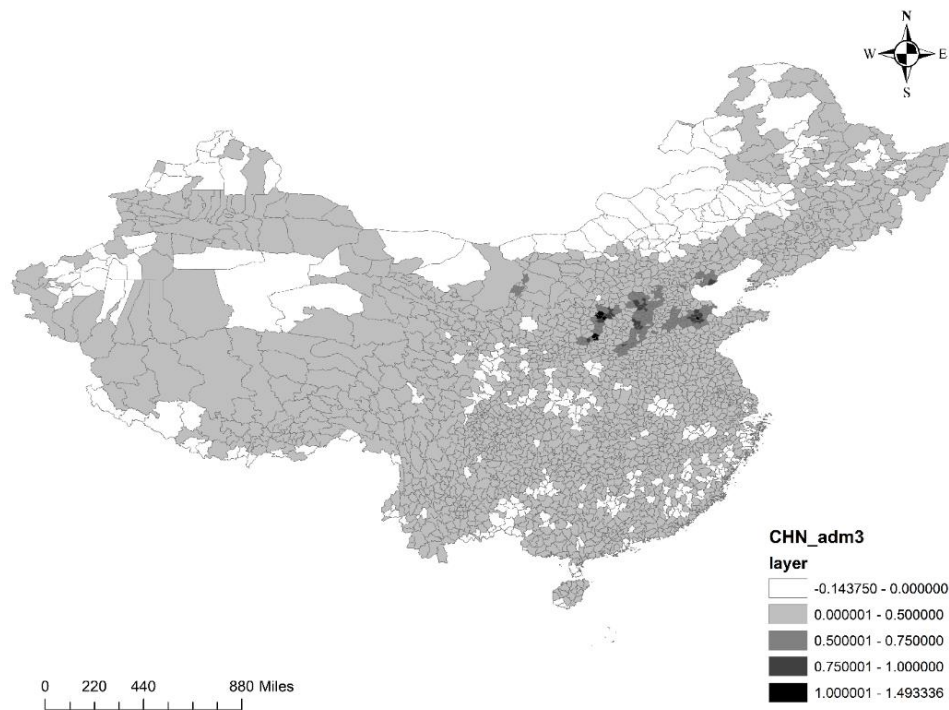
¹⁰ PM2.5 data is from: <http://sedac.ciesin.columbia.edu/data/set/sdei-global-annual-gwr-pm2-5-modis-misr-seawifs-aod>. SO2 is from OMI/Aura Sulphur Dioxide (SO2) Global Gridded V3: https://disc.gsfc.nasa.gov/datasets/OMSO2G_V003/summary?keywords=so2. Both last accessed in January 2019.

¹¹ Daily data for 2004 are available but do not cover all days for most of the grids. Therefore, we do not use data from 2004.

Figure 1: County-level annual averages of SO₂ concentration, 2005 and 2015.



(a): 2005



(b): 2015

PM2.5 and SO2 are highly correlated in our data. The correlations are higher than 0.6 when looking at the data yearly. Indeed, SO2 is a precursor to PM2.5 formation, which makes PM2.5 a good proxy for SO2. There are a few advantages to use both air pollutants. PM2.5 data has a much longer temporal coverage (starting 1998). However, PM2.5 often can travel over long distances. SO2 is much less subject to this concern, therefore often considered a better indicator of local air pollution.

There are a few justifications for our choice of satellite air pollution data. First, there is no systematic official air pollution data at the county level in China. Even at the prefecture-city level, official air pollution data from monitoring stations is only available for very recent years.¹² In the absence of official county level data, satellite data have been used in many studies as a good measure for local air pollution (Li et al. 2011; Streets et al. 2013). Second, we checked the correlations between satellite and monitor station data for prefecture/cities.¹³ The correlation between monitoring station SO2 data and the satellite SO2 data used in this study, for prefecture cities and years covered by both data sources (326 prefecture cities and for 2014-2017), is 0.714. We conducted the same exercise for PM2.5: the correlation is 0.681. Both correlations are very high, indicating that satellite data is a very good proxy for government monitoring station data.

Finally, one might question whether the use of satellite data is appropriate when a county leader's superiors only have official pollution data that can suffer from data manipulation. Chen et al. (2012) and Ghanem and Zhang (2014) suggest that data manipulation happens often in the form of local governments changing pollution statistics downward from above to below the warning line to avoid punishment. In our online appendix, we show that with such a downward manipulation in the official pollution data, the use of satellite data would be biased *against* us finding our main result, that is, a negative relationship between pollution and a local leader's chances of promotion.¹⁴

Control Variables

We include a battery of county characteristic variables, including per capita GDP, fiscal revenue, total population, infrastructure expenditures, and industry production in each county-year as well as county leader characteristics such as gender, education, age, age

¹² According to Freeman et al. (2019): "Existing studies of air pollution in China typically use the Air Pollution Index (API) and PM10 data from the Ministry of Environmental Protection of China. However, API and PM10 data can only be obtained in large and medium-sized cities in China, and PM2.5 data were not published until 2014." The Chinese City Statistical Yearbooks have data on the volume of SO2 exhausted (ton) since 2003 for many prefecture cities: but these are industrial sources of SO2 only.

¹³ The only open source monitoring station data that we are aware of is from the Chinese Air Quality Historical Database: <https://www.aqistudy.cn/historydata>. It provides daily data for air pollutants such as AQI, PM2.5, PM10, SO2, CO, NO2, and O3.

¹⁴ See Section C of the online appendix ("Satellite vs. Government Data and Potential Biases for Our Analysis") for more details.

square, tenure length, and political connection.¹⁵ The data of county characteristics comes from Provincial Yearbooks and National County (Prefecture) Social Economic Statistical Yearbooks. We also control for PM2.5/SO2 in each prefecture-year in most model specifications. Table 1 presents the basic summary statistics for variables included in the main analysis: note in our sample, we exclude Beijing, Tianjin, Shanghai, Chongqing because they are municipalities directly under the central government; we also exclude Tibet, Qinghai, and Hainan due to the data availability.

¹⁵ Regarding the political connection variable, for county party secretaries and county magistrates, it is 1 if the county leader was born at the same county or same prefecture with the prefecture governor or prefecture party secretary; and 0 otherwise. For a prefecture party secretary, we define connection as 1 if he/she and his/her provincial party secretary share the same birth province. For a province party secretary, we define connection to be 1 if he/she has working experiences in central government, which allow him/her to maintain a stronger connection with the centre and a better knowledge of the workings of central appointment procedures (Li and Zhou 2005).

Table 1. Summary statistics for the key variables.

Variables	Definition	Mean	S.td.	Obs.
Variables for county party secretary				
<i>Dependent variable:</i>				
Political turnover	Promotion=1, no promotion=0	0.159	0.366	16,362
<i>Independent variables:</i>				
VC	Ventilation coefficient (log)	7.340	0.277	16,362
PM2.5	Moving average PM2.5 during the tenure	33.362	17.171	16,362
SO2	Moving average So2 during the tenure	0.479	0.451	9,206
PM2.5 growth rate	The growth rate of PM2.5	0.054	0.261	16302
SO2 growth rate	The growth rate of SO2	0.037	0.629	7938
<i>Control variables:</i>				
Gender	Female=0, male=1	0.967	0.178	16,362
Education	Associate degree or below=0; Bachelor's degree or above=1	0.948	0.222	16,362
Age	Age of official in each year	46.788	3.852	16,362
Tenure	The number of years spent at current tenure	4.214	1.723	16,362
Connection	=1 if the leader was born in the same county or prefecture with prefecture leaders, 0 otherwise	0.145	0.352	16,362
PPM2.5	The average PM2.5 of the predecessor's tenure	32.537	16.501	12,618
APM2.5	The mean PM2.5 in each city-year	33.840	17.157	16,362
SSO2	The average SO2 of the predecessor's tenure	0.510	0.471	4,230
ASO2	The mean SO2 in each city-year	0.458	0.448	9,206
GDP	GDP per capita in each county-year, yuan (log)	9.439	0.928	16,362
Fisrev	Fiscal revenue in each county-year, 10000 yuan (log)	9.949	1.381	16,362
Pop	Population in each county-year, 10000 persons (log)	3.680	0.763	16,362
Infraexp	Infrastructure expenditures in each county-year, 10000 yuan (log)	12.006	1.699	16,362
lnIndus	Industry production in each county-year, 10000 yuan (log)	12.187	1.505	16,362
Any major thermal plant	The dummy for whether there is any major thermal power plant (installed capacity ≥ 1 million KW) in the upper winder direction	0.631	0.483	16,362
Coal consumption upwind (log)	total annual coal consumption of all major thermal power plants	10.423	8.025	16,362
Ratio of polluting industry	The value of sales in polluting industry divided by the value of total industrial sales in each county-year	0.404	0.294	12,599
Variables for county magistrate				
<i>Dependent variable:</i>				
Political turnover	Promotion=1, no promotion=0	0.215	0.411	13,122
Variables for prefecture party secretary				
<i>Dependent variable:</i>				
Political turnover	Promotion=1, no promotion=0	0.086	0.281	3,388
<i>Independent variables:</i>				
Pref_PM2.5	Moving average PM2.5 during the tenure	35.447	15.328	3,388
Pref_SO2	Moving average So2 during the tenure	0.323	0.392	2,448

<i>Control variables:</i>				
Gender	Female=0, male=1	0.966	0.182	3,388
Education	Associate degree or below=0; Bachelor's degree or above=1	0.997	0.054	3,388
Age	Age of official in each year	52.012	3.748	3,388
Tenure	The number of years spent at current tenure	4.359	1.813	3,388
Connection	=1 if the leader was born in the same province with province leaders, 0 otherwise	0.102	0.303	3,388
PrefAPM2.5	the mean PM2.5 in each province-year	0.356	0.139	3,388
PreflnRGDP	GDP per capita in each city-year, yuan (log)	9.753	0.854	3,388
PreflnFisrev	Fiscal revenue in each city -year, 10000 yuan (log)	12.736	1.216	3,388
PreflnPop	Population in each city -year, 10000 persons (log)	5.880	0.630	3,388
PreflnInfraexp	Infrastructure expenditures in each city -year, 10000 yuan (log)	14.938	1.246	3,388
PreflnIndus	Industry production in each city -year, 10000 yuan (log)	15.638	1.445	3,388

Variables for provincial party secretary

Dependent variable:

Political turnover	Promotion=1, no promotion=0	0.031	0.173	358
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Independent variables:

Prov_PM2.5	Moving average PM2.5 during the tenure	29.965	14.545	358
Prov_SO2	Moving average So2 during the tenure	0.356	0.337	237

Control variables:

Gender	Female=0, male=1	0.992	0.091	358
Education	Associate degree or even below=0, bachelor's degree or above=1	0.950	0.219	358
Age	Age of official in each year	58.922	4.169	358
Tenure	The number of years spent at current tenure	4.260	2.451	358
Connection	=1 if the leader has central working experiences, 0 otherwise	0.464	0.499	358
ProvlnRGDP	GDP per capita in each province-year, yuan (log)	9.810	0.742	358
ProvlnFisrev	Fiscal revenue in each province-year, 10000 yuan (log)	14.872	0.891	358
ProvlnInfraexp	Infrastructure expenditures in each province-year, 100 million yuan (log)	8.247	1.217	358
ProvlnIndus	Industry production in each province-year, 100 million yuan (log)	8.918	1.380	358

4. Empirical Strategy

To investigate the effect of environmental performance on local officials' promotion, we use the following benchmark model for PM 2.5:

$$\text{political turnover}_{ict} = \alpha_1 \text{PM2.5}_{ict} + \alpha_2 X'_{ct} + \alpha_3 Z'_{ict} + \eta_c + \theta_t + \varepsilon_{ict} \quad (1)$$

And the benchmark model for SO2 is:

$$\text{political turnover}_{ict} = \beta_1 \text{SO2}_{ict} + \beta_2 X'_{ct} + \beta_3 Z'_{ict} + \eta_c + \theta_t + \varepsilon_{ict} \quad (2)$$

Where the dependent variable $\text{political turnover}_{ict}$ is the turnover of local official i in county c in year t . PM2.5_{ict} is the moving average of PM2.5 during the tenure for local official i in county c in year t , and SO2_{ict} is the moving average of SO2 during the tenure for local official i in county c in year t . X_{ct} is a vector of time-varying county characteristics, such as

per capita GDP, fiscal revenue, total population, infrastructure expenditures, and industry production. Z_{ict} is a vector of time varying characteristics of local officials, such as gender, education, age, age square, tenure length, and connection. η_c is county fixed effect,

capturing all time-invariant differences across counties. θ_t is year fixed effect, capturing all yearly factors that are common to counties such as macro-level shocks. ε_{ict} and ϵ_{ict} are error terms. Following Bertrand, Duflo, and Mullainathan (2004), we address the potential serial correlation and heteroskedasticity issues by clustering the standard errors at the city level.

A key assumption for obtaining an unbiased estimation for α_1 or β_1 is that conditional on all the control variables, the variable of interest, $PM2.5_{ict}$ or $SO2_{ict}$, is uncorrelated with the error term. However, it is possible that $PM2.5_{ict}$ and $SO2_{ict}$ are endogenous. For instance, cadres with higher probability for promotion are appointed to counties with better potentials in environment protection and economic growth. This reverse causality issue can generate a biased estimation. In addition, omitted variables, such as the ability of local officials, which often cannot be measured directly and accurately, could also cause a biased estimation of key explanatory variables.

To deal with these endogeneity issues, in addition to the benchmark models, we adopt an instrumental variable approach.¹⁶ We use ventilation coefficient, which is the product of wind speed and mixing layer height, as the instrument for both $PM2.5$ and $SO2$.¹⁷ Wind speed determines horizontal dispersion of pollution while mixing height determines the height within which pollutants disperse. These two elements are key meteorological determinants for pollution concentration: the higher the wind speed/mixing height, the faster the dispersion of pollutants, the lower the level of local air pollution (Arya 1998). Indeed, we find that counties with higher ventilation coefficients are associated with lower $PM2.5/SO2$ (the first stage regressions, Column (3) of Table 2 and 3), confirming the relevance condition of this instrument. Ventilation coefficient is determined by meteorological and geographical

¹⁶ In the online appendix, Section D (“An alternative DID estimation”), we present results from an earlier version of this paper which adopts a difference-in-differences (DID) approach. We decided to present DID results only in an online appendix because first, our key explanatory variables ($PM2.5$ and $SO2$) might be endogenous. Second, we observe a pre-trend when testing the parallel trend assumption using the full sample. However, we have an explanation on why we observe this pre-trend. Following this explanation, we limit our sample to non-TCZ counties: this pre-trend disappears (Figure D-1, online appendix).

¹⁷ In Section E (“An alternative IV approach for $PM2.5$ regressions”) of the online appendix, we present results using another instrument for the $PM2.5$ variable: this is a difference-in-differences (DID) based instrument, exploring differential effects of provincial pollution reduction targets by the 11th Five-year plan (2006-2010), before and after such targets were imposed (Lu et al. 2017). Results using this different instrument are consistent with what we find using ventilation coefficient. The reason why we did not use this DID based instrument in our main analysis is because we can only use it for $PM2.5$: we cannot use it for $SO2$ because we only have one year for the pre-treatment period (i.e., 2005) in the $SO2$ data (only available from 2005 to 2014).

conditions, therefore also meeting the exogeneity requirement/exclusion restriction of an instrument.

Since Broner et al. (2012), several studies use ventilation coefficient as an instrument for air pollution and environmental regulation stringency (Hering and Poncet 2014; Cai et al. 2016; Bagayev and Lochard 2017; Shi and Xu 2018; Li et al. 2020). We obtain the wind speed information at the 10-m height and the boundary layer height, which is used to measure mixing height, from the European Center for Medium-Term Weather Forecasting ERA-interim dataset. We match the ERA-interim dataset with the seat of each county by latitude and longitude. Ventilation coefficients are calculated as annual averages for each county, 2005 to 2014.¹⁸ The first stage of the instrumental variable estimation for PM2.5 and SO2 is:

$$PM2.5_{ict}/SO2_{ict} = \delta_1 VC_{ct} + \delta_2 X'_{ct} + \delta_3 Z'_{ict} + \eta_c + \theta_t + \mu_{ict} \quad (3)$$

VC_{ct} is the ventilation coefficient for county c in year t , X_{ct} is the vector of time-varying county characteristics, Z_{ict} is a vector of time varying characteristics of local officials, η_c county fixed effect, and θ_t year fixed effect.

5. Empirical Results

Main results

Empirical results regarding the effect of PM 2.5 on county party secretaries' promotion are reported in Table 2. In Column (1), we report findings from an OLS estimation where we do not address potential endogeneity issues for PM 2.5: here we find that PM2.5 is negative associated with promotion; this association is statistically significant.

Results using ventilation coefficient as the instrument are in Column (3): Panel B has the first stage result; here, the instrument, *Ventilation coefficient*, has a negative and statistically significant effect on PM 2.5, suggesting that a higher level of ventilation coefficient reduces pollution level and therefore proving the relevance condition for the instrument. Panel A in Column (3) has the second stage result: after being instrumented, the key explanatory variable, PM 2.5, imposes a negative and statistically significant effect on county party secretaries' promotion. This confirms our argument that a better environmental performance is helpful for local officials' promotion.

Moreover, PM2.5 has a large substantive effect on promotion. The coefficient from Panel A, Column (3) is -0.022. The standard deviation of the PM2.5 variable is 17.17 (Table 1). Therefore, one standard deviation reduction in PM2.5 results in 0.377 (37.7%) increase in promotion probability: this is a large effect given that the average promotion probability is only 0.159 (Table 1). Furthermore, comparing the coefficient estimations in Column (1): OLS and (3): IV, the much smaller magnitude in the OLS estimation may suggest the issue of omitted variables and reverse causality in the estimation.

We also report the reduced form estimation result in Column (2) where we regress political turnover directly on the instrumental variable (*Ventilation coefficient*) together with other control variables. The estimated coefficient is also significant, showing that in counties

¹⁸ We removed observations with extreme values in annual average ventilation coefficients so that our results would not be affected by outliers.

with higher annual average ventilation coefficients (therefore lower pollution), local officials are more likely to get promotion.

In Table 3, we report the results for the effect of SO₂. Column (1) has the results from an OLS estimation, and the coefficient of SO₂ is positive. As we have discussed earlier, SO₂ can be endogenous due to the issues of omitted variables or reverse causality, thus the estimation can be biased. Once we use ventilation coefficient to instrument SO₂ in Column (3), the variable SO₂ imposes a negative and statistically significant effect on county party secretary promotion. This is consistent with the results from PM 2.5 regressions. Also note that the first stage result, in Panel B, shows that the instrument, *Ventilation coefficient*, has a negative and statistically significant effect on SO₂, suggesting that higher wind speed and higher mixing height reduce pollution levels, proving the relevance condition of the instrument. With regards to SO₂ variable's substantive effect, the coefficient from Panel A, Column (3) is -1.099. The standard deviation of the SO₂ variable is 0.451 (Table 1). Therefore, one standard deviation reduction in SO₂ results in 0.495 (49.5%) increase in promotion probability: this is an even larger effect than that of PM_{2.5}.¹⁹

Finally, we also report the reduced form estimation result in Column (2), where we regress political turnover directly on the ventilation coefficient together with other control variables. Similar to the case of PM_{2.5} (Table 2), the estimated coefficient is positive and statistically significant, showing that in the counties with a larger ventilation coefficient (therefore lower pollution all else equal), local officials are more likely to be promoted.

¹⁹ However, we need to interpret these large substantive effects with caution. The standard deviations of the pollution variables in Table 1 includes both the temporal and the cross-section variations. For any county, however, it is extremely difficult to reduce PM_{2.5} or SO₂ by one standard deviation in a year, partly because a larger proportion of the standard deviation of the PM_{2.5} and SO₂ variables is caused by cross-county differences. For instance, to get a sense of the variation in the within-county temporal changes in SO₂, we first calculate the year-by-year temporal changes in SO₂ for each county. We then calculate the standard deviation of these yearly changes: this temporal component-based standard deviation is about 0.180, much smaller than the overall standard deviation of the SO₂ variable, which is 0.451.

Table 2. Main results for the effect of PM2.5 on promotion of county party secretaries.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation		Dependent variable: Political Turnover	
PM 2.5	-0.006*** (0.001)		-0.022** (0.009)
Ventilation coefficient		0.061*** (0.023)	
Panel B: First stage estimation			Dependent variable: PM 2.5
Ventilation coefficient			-2.748*** (0.628)
Underidentification test			14.731***
Weak identification test			224.373***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	16,362	16,362	16,362

Notes: (1): Robust standard errors, clustered at city level, are in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2): Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level of departments. Demoted, retired, and punished officials are not included. (3): Control variables include PM2.5 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2001 to 2014.

Table 3. Results for the effect of SO2 on promotion of county party secretaries.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation		Dependent variable: Political Turnover	
SO2	0.083* (0.043)		-1.099** (0.548)
Ventilation coefficient		0.094** (0.043)	
Panel B: First stage estimation			Dependent variable: SO2
Ventilation coefficient			-0.086*** (0.018)
Underidentification test			24.989***
Weak identification test			62.629***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	9,206	9,206	9,206

Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is the Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demoted, retired, and punished officials are not included. (3): Control variables include SO2 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2005 to 2014.

6. Robustness Checks

In this section, we present robustness checks to see if our main results hold when we consider alternative operationalization of pollution measures, control for peer and predecessor pollution levels together, account for promotion outcomes in other counties in the same prefecture, control for potential pollution spill-over effects, limit our analysis to sub-samples of our data, and use simultaneous equations to model promotion alongside local GDP. We further control for the pollution-intensiveness of the county economy to address the possibility of change in local economic structure as an alternative explanation. We discuss possible endogenous cadre selection issues – favored cadres are assigned to high ventilation coefficients (low pollution) areas and less favored cadres to low ventilation coefficients (high pollution) areas – and our strategy to address selection effects by excluding suspect cases, i.e., observations having the highest 10% and lowest 10% of ventilation coefficient values. Column (10) in Table 4 and 5 are results from simultaneous equation estimation. All other columns in Table 4 and 5 are instrumental variable estimation results.

Capturing relative performance in pollution reduction

In Column (1) of Table 4, we examine the effect of PM2.5 on political turnovers without controlling city peer performance (PM2.5 in each prefecture/city-year) and predecessor performance (average PM2.5 during the predecessor's tenure). In Column (2), we control for both city peer performance and predecessor performance. The estimates of the instrumented PM2.5 variable in Column (1) and (2) are similar to the baseline estimation in Table 2.

In Column (3), we consider using one pollution variable to test the relative performance of local officials. This alternative measure is operationalized as follows:

$$\text{Diff_PM2.5}_{ict} = (\text{PM2.5}_{ct} - \overline{\text{PM2.5}_{c,T-1}}) - (\text{PM2.5}_{pt} - \overline{\text{PM2.5}_{p,T-1}}) \quad (4)$$

On the right hand side, the first term, $\text{PM2.5}_{ct} - \overline{\text{PM2.5}_{c,T-1}}$, is the difference between a county(c)-year(t)'s PM2.5 concentration (PM2.5_{ct}) and the average of PM2.5 concentrations during a county party secretary's predecessor's term ($\overline{\text{PM2.5}_{c,T-1}}$). The idea is to measure

how much more air pollution a county has emitted compared to the average level of its party secretary's predecessor. The second term, $\text{PM2.5}_{pt} - \overline{\text{PM2.5}_{p,T-1}}$, is the prefecture version of the first term, i.e., the difference between a prefecture(p)-year(t)'s PM2.5 concentration (PM2.5_{pt}) and the average of PM2.5 annual concentrations during a prefecture party

secretary's predecessor's term ($\overline{\text{PM2.5}_{p,T-1}}$): it measures how much more air pollution a

prefecture has emitted compared to the average level its prefecture party secretary's predecessor. The difference between the two terms on the right-hand side of equation (4) captures a county party secretary's relative yearly PM2.5 air pollution performance compared to his/her predecessor and compared to the relative growth at the prefecture level. The higher the value, the worse a county party secretary's environmental performance compared to his/her predecessor and peers in the same prefecture. Column (3) of Table 4 shows our result holds when we use this relative performance variable.

In Column (5) of Table 4, we use the annual growth rate of PM2.5 as the measure for PM2.5 pollution. *PM2.5 growth rate*, instrumented by ventilation coefficient, also has a

negative and statistically significant effect on promotion.²⁰ In Column (1), (2), (3), and (5) of Table 5, we repeat the same robust checks for the effect of SO₂: in all four columns, the effect of SO₂ on promotion is always negative and significant.²¹

Results using sub-samples

We exclude observations from Hebei province for the Summer Olympic Games venue cities, the observations for officials whose turnover happened during 2008 or 2009 for global financial crisis, and counties in provincial capital cities. The estimation results are reported in Column (6), (7), and (8) in Table 4 and 5. The main results stay, indicating that our results are not driven by specific subsamples.

A Two Control Zones (TCZ) policy was implemented by the central government in 1998, with tougher regulations imposed in TCZ cities. This might introduce a further cross-sectional difference in the effect of pollution on promotion. We therefore exclude TCZ counties. Results are reported in Column (9) in Table 4 and 5. Our results hold. Interestingly, the magnitudes of mean coefficient estimates of the pollution variables in Column (9) of Table 4 (effect of PM_{2.5} in non-TCZ counties) and in Column (9) of Table 5 (effect of SO₂ in non-TCZ counties) are larger than those from the full samples (Column (3) in Table 2 and 3). This suggests that the pollution-promotion effect is stronger in non-TCZ than in TCZ counties: for the same amount of pollution reduction, party secretaries in TCZ counties were rewarded less than those in non-TCZ counties.

If an upper-level government requires an environmental improvement relative to past performance (e.g., in percentage terms), leaders in counties with past tougher environmental regulations (e.g., TCZ counties) might face a disadvantage because their pollution levels might have already been pushed down to a low level and any further reduction would be very costly; if the upper level government takes this into consideration, the same amount pollution reduction in TCZ counties should be rewarded more: we should see a stronger pollution-promotion effect in TCZ counties and a weaker effect in non-TCZ counties – this is the opposite from what we find in Column (9) of Table 4 and 5.

However, other mechanisms might also be at play here. First, TCZ counties might have already made the required investment in pollution reduction equipment, therefore are better equipped to reduce pollution. Second, their local officials and civil servants might be more experienced and better trained. Finally, they might have not pushed down their pollution to a level beyond which any further reduction would be very costly: this is consistent with recent studies suggesting that the TCZ policy had a limited effect on curbing SO₂ emissions, especially during the 10th Five-year Plan (2001-2005) (Chen et al. 2018). Under these possibilities, the upper level government might hold a higher standard for local leaders in the

²⁰ Among the control variables used in Column (5) of Table 4 (and Table 5), we also used tan annual growth rate measure for per capital GDP.

²¹ The sample size drops in Column (2) and (3) of Table 5 because of missing information of predecessors, especially for the officials in the early 2000s. In Column (3), we measure a party secretary's relative air pollution growth the same way as in the case of PM_{2.5}:

$$\text{Diff_SO}_2 = (\text{SO}_{2ct} - \overline{\text{SO}_{2c,T-1}}) - (\text{SO}_{2pt} - \overline{\text{SO}_{2p,T-1}}).$$

TCZ counties: the same amount pollution reduction in TCZ counties should be rewarded less – this is consistent with what we find, that is, a weaker pollution-promotion effect in TCZ counties.

Simultaneous equation model estimation

It is possible that industrial activities in some dirty industries will produce higher GDP, thus GDP can be an outcome of pollution. In this section, as one more robust check, we use a simultaneous equation model taking both GDP per capita and political turnovers as endogenous outcomes. The details for the estimation of simultaneous equations can be found in the online appendix, Section F (“Simultaneous equation estimation”).

Column (10) in Table 4 has the result from simultaneous equation estimation for PM_{2.5}, which is comprised by two equations that describe the relationships among turnover and GDP per capita. To identify and estimate the simultaneous equations, in estimation for GDP per capita, we control for ventilation coefficient and fiscal expenditures of each county together with officials’ characteristics, and in estimation for political turnovers, we control for industrial output in each county-year and local officials’ characteristics. The standard errors are bootstrapped 50 times. The estimated coefficient of PM_{2.5} is still significant and negative. We also examine the effect of SO₂ using a similar simultaneous equation model. The result is reported in Column (10), Table 5: the coefficient is not statistically significant.

Spatial spill-over of pollutants

Air pollution can travel cross county boundaries. One might question whether such a spatial spill-over of air pollutants from neighbouring jurisdictions would affect our results. Note that often, air pollution data available to upper-level governments to evaluate county environmental performance comes from monitoring stations. Such data measure local air quality that is a function of *both* locally emitted air pollution and pollution coming from other counties when spatial spill-over occurs.²² Governments do not have a separate measure for locally emitted air pollutants and another measure for the quantity of air pollutants coming from neighbouring counties because the latter is often difficult to estimate given that wind direction and speed often change on a daily or even hourly basis.

This raises a very interesting question of whether upper-level governments would consider the effect of air pollution spill-over when making promotion decisions. As far as we know, there is no empirical study testing this. In this section, we provide some preliminary answers by testing, for a county party secretary, whether having at least one major thermal power plant in his/her county’s upper wind direction affects his/her chances of promotion: major thermal power plants are a major source of air pollution in China; indeed, a few recent studies have used this as an instrumental variable for local air pollution (Freeman et al 2019; Khanna et al 2020). Following these studies, we define major thermal power plants as those

²² The satellite data used in this paper captures the same county air quality. Therefore, air pollution data used by upper-level government officials measures the same county-year air quality as our satellite PM_{2.5}/SO₂ data.

with an installed capacity equal or larger than 1 million KW.²³ We created two variables: first, we calculate the total annual coal consumption of all major thermal power plants located upwind of a county-year and within 500km of the county²⁴ – this is the *Coal consumption upwind* variable; second, we create a dummy variable to indicate whether there is any major thermal power plant located upwind of a county-year and within 500km of the county – this is the *Any major thermal plant* variable.

To test whether upper-level governments consider the effect of air pollution spill-over when making promotion decisions, we first interact our instrumented air pollution measure (PM2.5/SO2) with the *Coal consumption upwind* variable. If upper-level governments take into account of pollution from outside a county, a county with more coal consumption by major thermal power plants in its up wind direction – therefore subject to higher yearlong air pollution spill-over from outside its jurisdiction – should be punished less with the same increase in air pollution. This would result in a positive and statistically significant interaction term between PM2.5/SO2 (instrumented) and *Coal consumption upwind*. However, Table A7 of the online appendix shows that the interaction terms ($PM2.5 \times Coal\ consumption\ upwind$ and $SO2 \times Coal\ consumption\ upwind$) are far from being statistically significant, suggesting that upper-level governments do not consider the effect of upwind major thermal power plants. At the same time, the PM2.5/SO2 (instrumented) variables outside the interaction terms are negative and statistically significant.

Second, we add in the *Any major thermal plant* variable as an additional control variable in our baseline instrumental variable analysis to test whether our pollution variables are still statistically significant once we control for the existence of any major thermal power plant located upwind and within 500km of a county-year. The results are reported in Column (11) in Table 4 and 5: the estimated coefficients of PM2.5/SO2 and their significance levels are very similar to our main results in Table 2 and Table 3.

One potential explanation for why upper-level governments do not consider pollutants coming from neighbouring jurisdictions is that often counties within the same prefecture compete with each other for promotion; given these counties' spatial proximity to each other – they are in the same prefecture – they are likely to suffer from the same outside pollution sources from upper wind directions. In other words, the amount of pollution from upper wind sources suffered by counties within the same prefecture is more or less the same. Therefore, what makes the difference to separate counties within the same prefecture by their environmental performances is locally generated pollution.

Potential promotion spill-over effect

One county party secretary's chances of promotion might also depend on promotion outcomes in other counties in the same prefecture given the total positions for promotion are

²³ Data of major thermal power plants is from various issues of Chinese Electric Power Yearbooks.

²⁴ To identify the area defined as “upwind of a county,” we take a section of a circular buffer drawn at a distance of 500 km from the county center: the angle between the left/right side of the section and the annual dominant wind direction of the county is 45 degrees. Freeman et al. (2019) have a nice illustration and a detailed discussion of this operationalization.

often relatively stable in the same prefecture. In other words, it is possible that a promotion spillover effect across counties within the same prefecture would occur. We conduct a robustness check by adding a spatial lag of the dependent variable: this is a temporally lagged (by a year, to avoid the simultaneity bias in spatial lag models) average dependent variable value of all other counties in the same prefecture. For PM2.5, the result is reported in Column (12) of Table 4. We find that the coefficient of the instrumented PM 2.5 is still significant and negative.²⁵

In Column (12) of Table 5, we examine the spillover effect for SO2 regressions. The coefficient of instrumented SO2 is still negative but it is not significant, with a p-value around 0.20. This lack of statistical significance is likely to be firstly a function of a smaller sample size compared with the PM2.5 case (Column (12) of Table 4); and secondly because of the nature of spatial lag models. In an extreme case, if county party secretaries can only be promoted within the same prefecture and the number of promotions is fixed during a time period, for a given county c , the spatial lag variable – which measures promotion outcomes in ALL other counties – can almost perfectly predict its promotion outcome, making other explanatory variables (including pollution variables) almost irrelevant. However, in the real world, upper-level government officials certainly would not decide promotion for county c by only counting promotion outcomes in other counties. In other words, a spatial lag model like ours is a very demanding model for non-spatial-lag explanatory variables.²⁶

Change in local economic structure as an alternative explanation

It is possible that well-off industrialized counties have experienced a cleaner composition change in local economy that lowers pollution intensity. Growth in these counties increases chances of promotion while at the same time is associated with lower pollution (intensity), therefore creating a negative relationship between pollution and promotion. If this is the case, we might have omitted an important confounding factor, the “greenness” of local economy or the composition of local economy in general.

However, we think this alternative explanation is unlikely to present a threat to our empirical analysis because first, our main analysis adopts an instrumental variable approach which avoids potential omitted variable biases. Our choice of ventilation coefficient as the instrument means that we only use the part of the variation in air pollution that is explained by variations in ventilation coefficient to explain chances of promotion. In other words, we do not use the part of variation in air pollution caused by the change in local economic composition to explain promotion. One potential concern here is whether ventilation coefficient correlates with local economic composition. We have checked this in the data: after controlling for fixed county and fixed year effects, the correlation between ventilation

²⁵ The coefficient of spatial lag itself is -1.678 and statistically significant, suggesting that in the same prefecture, one county party secretary’s promotion at year t reduces the chances of promotion for other county party secretaries at year $t + 1$.

²⁶ We have controlled for a very large number of fixed unit effects at the same time.

coefficient and the ratio of polluting industries in local industries is 0.036, suggesting very low level of correlation between these two variables.²⁷

Moreover, we have further controlled for the ratio of polluting industries in local industries in Column (13) of Table 4 and 5: in addition to other control variables used in our main regression (Column (3) of Table 2 and 3), we have added a variable measuring the ratio of polluting industries in local industries – this operationalized as the value of sales in polluting industries divided by the value of total industrial sales in a county-year.²⁸ Following Greenstone et al. (2002 and 2012), we define polluting industries as heavy emitters of industrial SO₂, which can be found from China Environment Yearbook.²⁹ Note that including this variable reduces the number of observations by about 20%, because the Chinese industrial data that we use to calculate the ratio of polluting industries is only available for 2001-2007. In the PM_{2.5} case (Column (13), Table 4), the coefficient of the instrumented PM_{2.5} variable is negative and statistically significant; in the SO₂ case (Column (13), Table 5), the coefficient of the instrumented SO₂ variable is still negative and its p-value is 0.105: we think the reduced statistical significance level has a lot to do with the reduced sample size.³⁰

Addressing potential reverse causalities

A reverse causality threat to our analysis is that higher promotability cadres are appointed to counties with better potentials in environment protection and economic growth. Note that GDP growth has always been important for promotion. Yet before the 11th Five-year Plan (2006-2010), pollution was not a major consideration: starting in December 2005, local government leaders would be held accountable for reaching the environmental protection goals set by the central government in their administrative region (Chen et al. 2018; Shi and Xu 2018). If there is such a reverse causality, before 2006, higher promotability cadres were more likely to be assigned to counties with better potential for economic growth, regardless of the potential for environmental protection; after the implementation of the 11th Five-year Plan, environmental protection became an important factor, high promotability cadres who

²⁷ Ventilation coefficient also does not correlate with local economic growth: after controlling for fixed county and fixed year effects, the correlation between the two variables is 0.049.

²⁸ We have also experimented with using an output ratio measure, which is the value of output in polluting industries divided by total industrial output: the results are similar.

²⁹ Based on the industrial SO₂ emissions data in China Environment Yearbook of 2002 (which reports the statistics of 2001), we use two-digits industrial code and define the following as pollution-intensive industries: 22: paper and paper products industry, 26: chemical raw materials and chemical product manufacturing, 31: non-metallic mineral products industry, 32: ferrous metal smelting and rolling processing industry, and 33: non-ferrous metal smelting and rolling processing industry. These are the top five industries by SO₂ emissions.

³⁰ The coefficient for the ratio of polluting industries variable itself is -0.036, and it is not significant in Column (13) of Table 4 for the PM_{2.5} regression; the coefficient is -0.067 in Column (13) of Table 5 for SO₂ regression, and it is statistically significant at 0.10 level.

were assigned to counties with high economic growth potential but low pollution reduction potential should have been re-assigned to counties with high potentials for both economic growth and pollution reduction. When we checked our data regarding cadre job transfers, we do not observe this pattern. First, in our data, for county party secretaries, about 18% of job changes are transfers to other counties (still) as party secretaries – there is no significant year-by-year variation in the percentage of such same-level transfers during our study period. Second, we test whether there is any significant difference in air pollution between transfer-source counties and transfer-target counties of these same-level party secretary job transfers; t-test results show that there is indeed no significant difference in the means of air pollution between these two groups of counties (p-value = 0.40 for PM2.5 and p-value = 0.15 for SO₂).

A second reversal causality concern is the possibility that given the variation in the ventilation coefficient is not entirely random (wind speeds and mixing dynamics could be predictable for at least some regions and for some time), county officials may have self-selected or been assigned to counties based on predicted county ventilation coefficients. To rule out this possible selection effect, first, we test whether there is any significant difference in ventilation coefficient between the transfer-source counties and the transfer-target counties of same-level county party secretary job transfers: t-test results show that there is no significant difference in ventilation coefficients between these two groups of counties (p-value = 0.90 for t-test).

Second, following Landry et al. (2018), we ran our main instrumental variable analysis (same model specification as in Column (3) of Table 2 and 3) after removing the observations with the highest and lowest 10% of ventilation coefficient values. The idea here is that if indeed there are county officials selecting in and out of counties based on ventilation coefficients, it is more likely that they leave counties with very low ventilation coefficients (therefore high pollution, all else equal) and enter counties with very high ventilation coefficients (low pollution). In other words, we address this potential selection bias problem by excluding suspect cases of endogenous selection in which favored cadres are assigned to high ventilation coefficients (low pollution) areas and less favored cadres to low ventilation coefficients (high pollution) areas. Column (14) in Table 4 and 5 show that after removing these suspect cases, the coefficient estimates of PM_{2.5}/SO₂ are similar, both in statistical significance levels and the size of the substantive effects, to those of our main analysis in Column (3) of Table 2 and 3.

Other robustness checks

We have controlled for county-year economic performance using per capita GDP in our regression analysis. Other studies on local cadre promotion such as Landry et al. (2018) also consider testing or controlling for the effect of economic growth rate. Therefore, in Column (4) of Table 4 and 5, we replace per capita GDP with growth rate in per capita GDP: the results do not change.³¹

³¹ We chose not to show coefficient estimates of control variables in regression tables because of space constraints. For readers who are interested in the effect of county economic performance, we have added two tables in the online appendix (Table A1/A2 for PM_{2.5}/SO₂ regressions): in Column (1), we show the estimated coefficients of the *per capita GDP*

Finally, we replace fixed year effects with fixed province-year effects to further control for province-year shocks that could be correlated with province law and regulation changes and other related outcomes.³² The results are reported in Column (15) of Table 4 and 5: both coefficients of the instrumented SO₂ and PM_{2.5} variables are still negative and statistically significant.

variable on promotion; in Column (2), we replaced *per capita GDP* with *GDP measured by satellite data*, which is county-year average nightlight index per km². In both tables, all coefficients for GDP measures are positive. Their statistical significance levels, however, vary. Only in Column (1) of Table A2, the coefficient is statistically significant. One reason why we cannot establish a statistically significant relationship between GDP measures and promotion is because GDP measures are endogenous, and we have not applied any causal identification strategy for the GDP measures (which are control variables in our analysis).

³² County fixed effects are also included as in other columns.

Table 4. Robust checks for the effect of PM2.5 on promotion of county party secretaries.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Dependent variable: Political Turnover	No peer and predecessor	Peer and predecessor	Relative performance	Control GDP rate	Growth rate	Exclude Hebei	Exclude 2008 & 2009	Exclude capital city	Exclude TCZ	Simultane ous equation	Spatial spillover	Promotion spillover	Pollution structure	Selection bias	Change FE
PM 2.5	-0.022** (0.009)	-0.050** (0.022)		-0.022** (0.009)		-0.022** (0.009)	-0.027** (0.010)	-0.023** (0.009)	-0.038** (0.018)	-0.001*** (0.000)	-0.023** (0.009)	-0.022* (0.012)	-0.031** (0.015)	-0.033** (0.016)	-0.057* (0.033)
Relative performance			-0.065** (0.029)												
PM 2.5 growth rate					-1.076** (0.502)										
County FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	
Province-year FE															YES
County controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Personal controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	16,362	12,618	12,618	16,302	16,302	15,279	14,482	15,246	8,292	16,362	16,362	12,349	12,599	13,035	16,362

Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is the political turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demoted, retired, and punished officials are not included. (3): Control variables include PM2.5 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2001 to 2014. (5): Column (4) and Column (5) replace the control variable of GDP per capita with GDP growth rate. Column (10) is the result from simultaneous equation model, and the standard errors are bootstrapped for 50 times. Column (11) control for the dummy whether there is any major thermal power plant (installed capacity ≥ 1 million KW) located upwind of a county and within 500km of the county. Column (13) control for the ratio of pollution industries. Column (15) controls for the county fixed and province-year fixed effects, and the standard errors are clustered at county level. (6): Other than in Column (10), instrument variable is ventilation coefficient in all the regressions.

Table 5. Robust checks for the effect of SO2 on promotion of county party secretaries.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)
Dependent variable: Political Turnover	No peer and predecessor	Peer and predecessor or	Relative performance	Control GDP rate	Growth rate	Exclude Hebei	Exclude 2008 & 2009	Exclude capital city	Exclude TCZ	Simultaneous equation	Spatial spillover	Promotion spillover	Pollution structure	Selection bias	Change FE
SO2	-1.123** (0.566)	-2.812* (1.619)		-1.123** (0.559)		-1.402** (0.691)	-1.854** (0.881)	-1.085** (0.550)	-1.927** (0.876)	0.024 (0.025)	-1.091** (0.547)	-0.636 (0.573)	-0.988 (0.607)	-1.294** (0.512)	-3.088* (1.822)
Relative performance			-1.151* (0.619)												
SO2 growth rate					-0.270* (0.156)										
County FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Province-year FE															YES
County controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Personal controls	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	9,206	4,230	4,230	9,172	7,938	8,659	8,027	8,488	4,365	9,206	9,206	7,013	7,504	7,315	9,206

Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is the Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demoted, retired, and punished officials are not included. (3): Control variables include SO2 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. Personal control variables include official's gender, education, age, age square, tenure length, connection. (4): The sample period is from 2005 to 2014. (5): Column (4) and Column (5) replace the control variable of GDP per capita with GDP growth rate. Column (10) is the result from simultaneous equation model, and the standard errors are bootstrapped for 50 times. Column (11) control for the dummy whether there is any major thermal power plant (installed capacity ≥ 1 million KW) located upwind of a county and within 500km of the county. Column (13) control for the ratio of pollution industries. Column (15) controls for the county fixed and province-year fixed effect, and the standard errors are clustered at county level. The p-value for the instrumented SO2 variable is 0.105 in Column (13). (6): Other than in Column (10), instrument variable is ventilation coefficient in all the regressions.

7. Testing the Pollution-promotion Link for County Magistrates

Our analysis so far examines political turnovers of county party secretaries. This focus is motivated by the fact that party secretaries are the ones really in charge at every level of the Chinese government. In this section, we extend our analysis to county magistrates who take more responsibility in the day-to-day work of local development. In Table 6, we present the results of OLS, reduced form, and instrumental variable regression regarding the effect of PM2.5: PM2.5 has a negative and statistically significant effect on county magistrates' promotion. The IV estimation for county magistrates is very similar to the coefficient estimate in Column (3) of Table 2.³³

In Table 7, we report the results for the effect of SO2 on political turnovers of county magistrates. Similarly, we find that SO2 has a negative and statistically significant effect. Compared to the coefficient for county party secretaries in Column (3) of Table 3, the estimation for county magistrates is larger. In our online appendix, Table A5 and Table A6 present robustness checks with a different operationalization for political turnover, which treats demotion, retirement, and punishment as also 0. The estimation findings are similar to what we find in Table 6 and Table 7 of this section.

³³ The total number observations for county magistrates is 13,122, smaller than the number in county party secretary regressions due to more missing personal characteristics of county magistrates.

Table 6. Results for the effect of PM2.5 on promotion of county magistrates.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation	Dependent variable: Political Turnover		
PM2.5	-0.006*** (0.001)		-0.020* (0.012)
Ventilation coefficient		0.062* (0.031)	
Panel B: First stage estimation	Dependent variable: PM2.5		
Ventilation coefficient			-3.116*** (0.004)
Underidentification test			17.754***
Weak identification test			168.660***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	13,122	13,122	13,122

Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is the Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demoted, retired, and punished officials are not included. (3) Control variables include PM2.5 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2001 to 2014. (5): Instrument is ventilation coefficient.

Table 7. Results for the effect of SO2 on promotion of county magistrates.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation	Dependent variable: Political Turnover		
SO2	0.164*** (0.046)		-3.950* (2.380)
Ventilation coefficient		0.218*** (0.070)	
Panel B: First stage estimation	Dependent variable: SO2		
Ventilation coefficient			-0.055** (1.091)
Underidentification test			6.570***
Weak identification test			15.657***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	8,436	8,436	8,436

Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2): Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demotion, retirement and punished officials are not included. (3) Control variables include SO2 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2005 to 2014. (5): Instrument is ventilation coefficient.

8. Beyond the County-level: Prefecture and Provincial Party Secretaries

In the hierarchical structure of administrative divisions in China, at the top is the central government, followed by provincial governments, prefecture level governments, and county-level governments. Generally, each level oversees the work carried out by its lower level in the administrative hierarchy. In the introduction, we provided justifications for our focus on county leaders. As far as we know, ours is the first county level study on the pollution-promotion link. One natural question, after we have established a robust causal effect of air pollution on county leaders' promotion, is whether we would find similar results at higher administrative levels. In this section, we examine the effect of environmental performance on prefecture and provincial party secretaries' promotion.

We apply similar estimation strategies. The estimation results for prefecture party secretaries are reported in Table 8 for the effect of PM2.5 and in Table 9 for the effect of SO2. In Column (3) of both Table 8 and Table 9, after we apply instrumental variable estimation, the effect of environment performance on political turnovers is not statistically significant. The estimation results for province party secretaries are reported in Table 10 for PM2.5 and in Table 11 for SO2. In Column (3) of both tables, the instrumented PM2.5 and SO2 also have no effect on political turnovers.³⁴

³⁴ Note that in Column (1) of both Table 8 and Table 10 – when we use OLS to test the relationship between PM2.5 and promotion of prefecture and provincial party secretaries, the coefficients of PM2.5 variables are negative and statistically significant: this is consistent

The effect of environment performance on promotion is statistically significant and robust at the county level. Why don't we find a similar effect at the prefecture and provincial levels? Firstly, a much lower number of observations at the prefecture and provincial level makes it much more difficult to find statistically significant effects, especially given that we include many control variables and fixed effects in the analysis. Secondly, PM2.5's standard deviations at the county, prefecture, and province levels are 17.152, 15.328, 14.54; those for SO2 at the county, prefecture, and province levels are 0.451, 0.392, 0.337. The difference in pollution between counties is relatively large while it is smaller at the province and prefecture levels. It is possible that the effect of pollution on promotion in some counties is large while it is small in some other counties: the results at the province and prefecture levels reflect an averaged effect of those at the county level; after averaging, the effect may not be significant. Finally, as we have discussed in the introduction, county officials are distant in the party hierarchy and pose little threat to central rulers; their loyalty therefore matters less than competence which is needed for local economic growth and pollution reduction. The promotions of prefecture and provincial officials are tied more to loyalty because these positions are key to the survival of the central rulers (Landry et al. 2018).

with past studies that, without using causal identification strategies, often find reducing pollution increases the chances of promotion at the prefecture and provincial levels (Pu and Fu 2018; Wang and Lei 2020 Forthcoming).

Table 8. Results for effect of PM2.5 on promotion of prefecture party secretaries.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation	Dependent variable: Political Turnover		
PM2.5	-0.005* (0.003)		0.027 (0.037)
Ventilation coefficient		-0.050 (0.061)	
Panel B: First stage estimation	Dependent variable: PM2.5		
Ventilation coefficient			- 1.879* (1.104)
Underidentification test			21.914**
Weak identification test			41.518**
City FE	YES	YES	YES
Year FE	YES	YES	YES
City control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	3,388	3,388	3,388

Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is the Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different cities or staying at the same level departments. Demoted, retired and punished officials are not included. (3): City control variables include city-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2001 to 2014. (5): Instrument is ventilation coefficient.

Table 9. Results for effect of SO2 on promotion of prefecture party secretaries.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation		Dependent variable: Political Turnover	
SO2	0.134* (0.073)		0.212 (0.340)
Ventilation coefficient		-0.045 (0.072)	
Panel B: First stage estimation			Dependent variable: SO2
Ventilation coefficient			-0.212*** (0.043)
Underidentification test			23.738***
Weak identification test			49.437***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	2,448	2,448	2,448

Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demotion, retirement and punished officials are not included. (3): City control variables include city-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2005 to 2014. (5): Instrument is ventilation coefficient.

Table 10. Results for effect of PM2.5 on promotion of provincial party secretaries.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation		Dependent variable: Political Turnover	
PM2.5	-0.006* (0.003)		0.003 (0.024)
Ventilation coefficient		-0.015 (0.142)	
Panel B: First stage estimation			Dependent variable: PM2.5
Ventilation coefficient			-5.384** (2.689)
Underidentification test			14.115***
Weak identification test			14.107***
Province FE	YES	YES	YES
Year FE	YES	YES	YES
Province control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	358	358	358

Notes: (1) Robust standard errors, clustered at province level, are reported in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2) Dependent variable is the Political Turnover which equals to 1 if the province official gets the promotion, 0 if moving between different provinces or staying at the same level departments. Demoted and punished officials are not included. (3) Province control variables include province-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length and connection which is measured by the dummy of central working experiences. (4) The sample period is from 2001 to 2014. (5): Instrument is ventilation coefficient.

Table 11. Results for effect of SO2 on promotion of provincial party secretaries.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation	Dependent variable: Political Turnover		
SO2	-0.003 (0.114)		0.442 (0.556)
Ventilation coefficient		-0.135 (0.165)	
Panel B: First stage estimation	Dependent variable: SO2		
Ventilation coefficient			-0.305*** (0.103)
Underidentification test			7.559***
Weak identification test			11.365*
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	237	237	237

Notes: (1): Robust standard errors, clustered at province level, are reported in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2): Dependent variable is Political Turnover which equals to 1 if the province official gets the promotion, 0 if moving between different provinces or staying at the same level departments. Demotion and punished officials are not included. (3): Province control variables include province-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length and connection which is measured by the dummy of central working experiences. (4): The sample period is from 2005 to 2014. (5): Instrument is ventilation coefficient.

9. Conclusion and Discussion

Does it pay to be “greener” as a local official in China? In this paper, we first examine whether local air pollution affects county leaders' chances of promotion. In addition to testing the marginal effect of pollution on promotion, we adopt an instrumental variable approach to deal with potential endogeneity issues of the key independent variables: we use ventilation coefficient as the instrument for PM 2.5 and SO2. Our empirical analysis shows that for county party secretaries, those who were able to reduce air pollution are much more likely to be promoted. We find similar results for county magistrates. Yet when we extend our analysis to prefecture and provincial party secretaries, we do not find any empirical evidence for the pollution-promotion link.

Our key empirical findings have important policy implications. First, the Chinese cadre's career incentive structure that was built to promote economic growth has evolved to include other priorities including environmental protection. It has started to reward county leaders who were able to outperform their peers in reducing air pollution. One remaining question is when local officials really must choose between economic development and environmental quality such as in moments during economic crisis, whether they would prioritize development and employment again. The current global pandemic and economic recession seems to present a stern test for local officials in China given Chinese economy's relatively high level of trade-dependence.

Moreover, we find that unlike their county-level counterparts, prefecture and provincial party secretaries' promotions were not based on their environmental performances. We have argued that most day-to-day functions of the government, including environmental protection, are often being implemented by county governments. The fact that county leaders' promotion is tied to environmental performances clearly helps to improved environmental quality in China. However, enforcing the same incentive structure for leaders at the prefecture and provincial levels is also very important. For instance, in China, often the central government sets the environmental policy objectives and assigns provincial targets. In response, provincial governments design their own enforcement plans and allocate the regulatory burdens to cities and counties. A provincial leader may not be the enforcer on the ground, but he/she is the central planner in a province: the extent to which he/she is motivated to improve environmental quality is critical to address the environmental crises in China today.

Finally, there is more research to be done. For instance, more qualitative evidence is needed to shed lights on how county leaders' environmental performances are evaluated. As far as we know, there does not seem to be a nationally unified standard: firm-level emissions, emission concentration measures in waste air and wastewater, blue sky days, and total emissions in a county are all possible targets. Provincial and prefecture governments seem to have some level of flexibility in the choice of specific targets. The nature of targets matters. For instance, targets requiring reduction to a given level of emissions differ from those requiring an improvement relative to past emission levels (e.g., in percentage terms). This is because the latter approach often would be more costly for counties with lower starting levels of emissions: their emissions have been reduced to a low level beyond which any further reduction would be more difficult.³⁵ Assuming upper level governments use a portfolio of environmental targets, how these various indicators are weighed in the promotion process at the county level is even more challenging to find out.³⁶ Future research, most likely through fieldwork and interviews, can better answer these important questions.

This paper focuses on the effects of air pollution, which is often more visible and tends to afflict urban areas (Cao and Prakash 2012). Also, thanks to satellite data, we can measure air quality for small localities when monitoring station data is not available. Future research, however, should also investigate the potential effects of water and other types of pollution on promotion given their severities in China. Past empirical research of environmental regulation has overwhelmingly focused on air pollution, water and other types of pollution remain relatively under-studied. Recent research such as Kahn et al. (2015), Chen et al. (2018), and He et al. (2020), however, have demonstrated the importance of water pollution regulations in China.³⁷ While more research is certainly needed, we hope this paper has provided a solid foundation for this new and exciting area of research.

³⁵ We thank one reviewer for reminding us the implications of different evaluating targets.

³⁶ In fact, even weights assigned to much broader categories of cadre evaluation at the county level, such as GDP growth vs. social stability vs. pollution reduction, are often considered confidential information and not to be revealed to the public.

³⁷ Also see Dasgupta et al. (2001) for an earlier study.

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ONLINE APPENDIX:

Section A: Additional Robustness Checks

Table A-1. Main results for the effect of PM2.5 on the promotion of county party secretaries.

	(1)	(2)
Dependent variable: Political Turnover		
PM 2.5	-0.022** (0.009)	-0.017** (0.008)
GDP	0.000 (0.020)	
GDP measured by Satellite data		0.019 (0.019)
County FE	YES	YES
Year FE	YES	YES
County control variables	YES	YES
Personal control variables	YES	YES
Observations	16,362	15,224

Notes: (1): Robust standard errors, clustered at city level, are in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level of departments. Demoted, retired, and punished officials are not included. (3): Control variables include PM2.5 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2001 to 2014 in Column (1), and 2001 to 2013 in Column (2). (5): instrument variable for PM2.5 is ventilation coefficient.

Table A-2. Main results for the effect of SO2 on the promotion of county party secretaries.

	(1)	(2)
Dependent variable: Political Turnover		
SO2	-1.099** (0.548)	-1.246** (0.613)
GDP	0.090* (0.046)	
GDP measured by Satellite data		0.006 (0.036)
County FE	YES	YES
Year FE	YES	YES
County control variables	YES	YES
Personal control variables	YES	YES
Observations	9,206	8,425

Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is the Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demoted, retired, and punished officials are not included. (3): Control variables include SO2 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is 2005 to 2014 in Column (1) and 2005 to 2013 in Column (2). (5): instrument variable for SO2 is ventilation coefficient.

TableA-3. Results for promotion of county party secretaries using a new political turnover variable: the PM2.5 case.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation	Dependent variable: Political Turnover		
PM 2.5	-0.006*** (0.001)		-0.023** (0.009)
Ventilation coefficient		0.062*** (0.022)	
Panel B: First stage estimation	Dependent variable: PM 2.5		
Ventilation coefficient			-2.727*** (0.625)
Underidentification test			14.657***
Weak identification test			229.955***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	17,200	17,200	17,200

Notes: (1): Robust standard errors, clustered at city level, are in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments, demoted, retired, or punished. (3): Control variables include PM2.5 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2001 to 2014.

Table A-4. Results for promotion of county party secretaries using a new political turnover variable: the SO2 case.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation	Dependent variable: Political Turnover		
SO2	0.091*** (0.033)		-1.136* (0.614)
Ventilation coefficient		0.081** (0.038)	
Panel B: First stage estimation	Dependent variable: SO2		
Ventilation coefficient			-0.071*** (0.019)
Underidentification test			22.255***
Weak identification test			19.686***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	10,609	10,609	10,609

Notes: (1): Robust standard errors, clustered at city level, are in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments, demoted, retired, or punished. (3): Control variables include SO2 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2005 to 2014.

TableA-5. Results for promotion of county magistrates using a new political turnover variable: the PM2.5 case.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation	Dependent variable: Political Turnover		
PM25	-0.006*** (0.001)		-0.021* (0.012)
Ventilation coefficient		0.066** (0.031)	
Panel B: First stage estimation	Dependent variable: PM25		
Ventilation coefficient			-3.130 *** (0.004)
Underidentification test			18.120***
Weak identification test			173.535 ***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	13,361	13,361	13,361

Notes: (1): Robust standard errors, clustered at city level, are in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments, demoted, retired, or punished. (3): Control variables include PM2.5 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4): The sample period is from 2001 to 2014.

Table A-6. Results for promotion of county magistrates using a new political turnover variable: the SO2 case.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation	Dependent variable: Political Turnover		
SO2	0.163*** (0.045)		-3.950* (2.404)
Ventilation coefficient		0.213*** (0.070)	
Panel B: First stage estimation	Dependent variable: SO2		
Ventilation coefficient			-0.055** (1.091)
Underidentification test			6.570***
Weak identification test			15.657***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Observations	8,591	8,591	8,591

Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2): Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments, demoted, retired, or punished. (3): Control variables include SO2 emission at the city-year level, county-year controls such as log of per capita GDP and log total population, and leader-year controls including official's gender, education, age, age square, tenure length, and connection. (4) The sample period is from 2005 to 2014.

Table A-7. Robust checks for the effect of pollution on promotion of county party secretaries.

	(1)	(2)
Dependent variable: Political Turnover		
PM 2.5×Coal consumption upwind	0.001 (0.001)	
Coal consumption upwind	-0.024 (0.030)	
PM 2.5	-0.026*** (0.010)	
SO2×Coal consumption upwind		0.021 (0.020)
Coal consumption upwind		-0.010 (0.008)
SO2		-1.487** (0.705)
County FE	YES	YES
Year FE	YES	YES
County control variables	YES	YES
Personal control variables	YES	YES
Observations	16,362	9,206

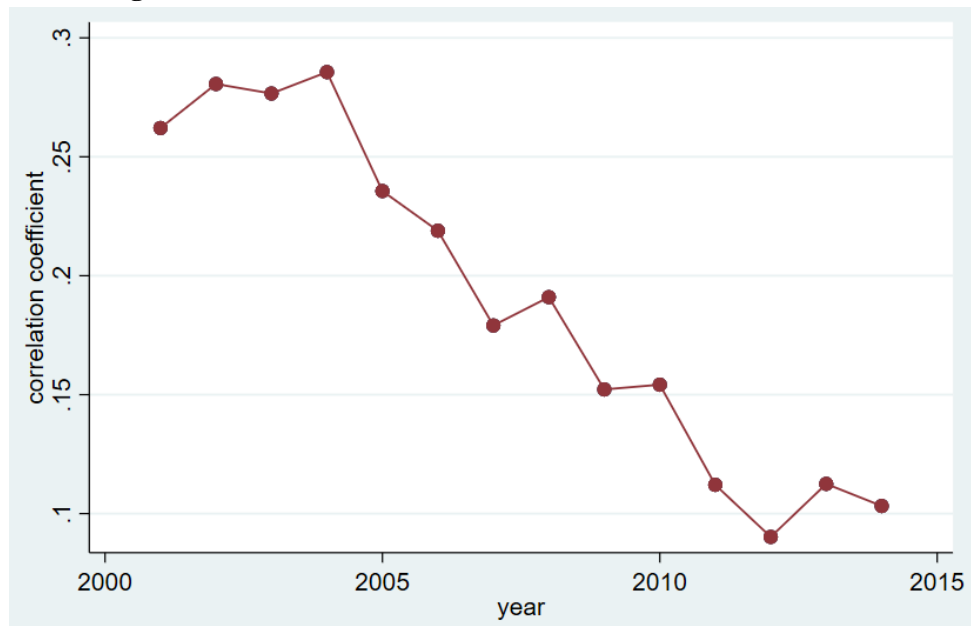
Notes: (1): Robust standard errors, clustered at city level, are reported in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2): Dependent variable is the political turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demoted, retired, and punished officials are not included. (3): Control variables in Column (1) are the same as those used in Table 2 in the main text, and control variables in Column (2) are the same as those used in Table 3 of the main text. (4): The sample period is from 2001 to 2014 in Column (1) and 2005 to 2014 in Column (2). (6): Instrument variable is ventilation coefficient.

Section B: Additional Descriptive Statistics

Table B-1: list of TCZ cities.

Province	TCZ city	Province	TCZ city	Province	TCZ city	Province	TCZ city
Beijing	Beijing		Yangzhou	Henan	Zhengzhou	Guangxi	Nanning
Tianjin	Tianjin				Luoyang		Liuzhou
Hebei	Shijiazhuang		Zhenjiang		Anyang		Guilin
	Tangshan		Taizhou		Jiaozuo		Wuzhou
	Handan	Zhejiang	Hangzhou		Sanmenxia		Guigang
	Xingtai		Ningbo	Hubei	Wuhan		Yulin
	Baoding		Wenzhou		Huangshi		Hezhou
	Zhangjiakou		Jiaxing		Yichang		Hechi
	Chengde		Huzhou		Ezhou	Chongqing	Chongqing
	Hengshui		Shaoxing		Jingmeng	Sichuan	Chengdu
Shanxi	Taiyuan		Jinhua		Jingzhou		Zigong
	Datong		Quzhou		Xianning		Panzhihua
	Yangquan		Taizhou	Hunan	Changsha		Luzhou
	Shuozhou	Anhui	Wuhu		Zhuzhou		Deyang
	Yuncheng		Manshan		Xiangtan		Mianyang
	Xinzhou		Tongling		Hengyang		Suining
	Linfen		Huangshan		Yueyang		Neijiang
Inner Mongolia	Huhehaote		Xuancheng		Changde		Leshan
	Baotou	Fujian	Fuzhou		Zhangjiajie		Nanchong
	Wuhai		Xiamen		Yiyang		Yibin
	Chifeng		Sanming		Chenzhou		Guangan
Liaoning	Shenyang		Quanzhou		Huaihua		Meishan
	Dalian		Zhangzhou		Loudi	Guizhou	Guiyang
	Anshan		Longyan	Guangdong	Guangzhou		Zunyi
	Fushun	Jiangxi	Nanchang		Shaoguan		Anshun
	Benxi		Pingxiang		Shenzhen	Yunnan	Kunming
	Jinzhou		Jiujiang		Zhuhai		Qujing
	Fuxin		Yingtian		Shantou		Yuxi
	Liaoyang		Ganzhou		Foshan		Zhaotong
	Huludao		Ji'an		Jiangmen	Shaanxi	Xian
Jinlin	Jilin	Shandong	Jinan		Zhanjiang		Tongchuan
	Siping		Qingdao		Zhaoqing		Weinan
	Tonghua		Zibo		Huizhou		Shangluo
Shanghai	Shanghai		Zaozhuang		Shanwei	Gansu	Lanzhou
Jiangsu	Nanjing		Yantai		Qingyuan		Jinchang
	Wuxi		Weifang		Dongguan		Baiyin
	Xuzhou		Jining		Zhongshan		Zhangye
	Changzhou		Taian		Chaozhou	Ningxia	Yinchuan
	Suzhou		Laiwu		Jieyang		Shizuishan
	Nantong		Dezhou		Yunfu	Xinjiang	Wulumuqi

Figure B-1: Correlation coefficients between GDP and PM2.5.



Note: This figure plots the correlation coefficient between GDP per capita (log) and PM2.5 for each year.

Section C: Satellite vs. Government Data and Potential Biases for Our Analysis

One might question whether the use of satellite data is appropriate when a county leader's superior only has official pollution data which can suffer from data manipulation. In this section, we justify the use of satellite data by showing 1): there is simply no official-report data on air pollution at the county level; 2): satellite data of air pollution is highly correlated with official monitoring station data when looking at prefecture cities; and probably more importantly 3): with a downward manipulation in the official pollution data, the use of satellite data would be biased against us finding a negative relationship between pollution and a leader's chances of promotion. We explain these three points in turn in the following.

1). No available county level official air pollution data: there is no official air pollution data at the county level. Even at the prefecture-city level, official air pollution data from monitoring stations is only available since very recently. According to Freeman et al. (2019): "Existing studies of air pollution in China typically use the Air Pollution Index (API) and PM10 data from the Ministry of Environmental Protection of China. However, API and PM10 data can only be obtained in large and medium-sized cities in China, and PM2.5 data were not published until 2014."³⁸

In the absence of official county level data, we need air pollution data that can be considered good proxy for the official data. Satellite data have been used in many studies as a good measure for local air pollution. For example, in Freeman et al. (2019): "...We collect city level annual average PM2.5 using Global Annual PM2.5 Grids derived from satellite data by Van Donkelaar et al. (2016). These data provide a reliable and accurate measurement of air quality for all cities in China." As the quote above indicates, satellite data provides a reliable and accurate measurement of air quality in China.

2): High correlations between satellite and monitoring station data: we checked the correlations between satellite and monitor station data. The only open source monitoring station data that we are aware of is from the Chinese Air Quality Historical Database.³⁹ These are daily data for a number of air pollutants such as AQI, PM2.5, PM10, SO2, CO, NO2, and O3, based on government monitoring station data for prefecture/cities in China, 2013-2018 (by the time we scraped the website in 2019). Note that for 2013, there are not enough days covered by the data, so it is problematic to aggregate the 2013 daily data for annual averages. Even for 2014, not all days are available for all prefectures. The PM2.5 satellite data we use are for 1998-2016; the SO2 satellite data we use are for 2004-2018.

We take correlations between SO2 reported by government monitoring station – using annual averages of daily means from the Chinese Air Quality Historical Database – and the SO2 satellite data used in this study, for prefecture cities and years covered by both data sources: these are 326 prefecture cities and for 2014-2017. The correlation is 0.714. We conducted the same exercise for PM2.5: these are the same 326 prefecture cities and for

³⁸ The Chinese city statistical yearbooks have data on the volume of SO2 exhausted (ton) since 2003 for many prefecture cities: but these are industrial sources of SO2 only.

³⁹ 中国空气质量历史数据: <https://www.aqistudy.cn/historydata>.

2014-2016. The correlation is 0.681. Both correlations are very high, indicating that satellite data is indeed a very good proxy for government monitoring station data.

3): Potential biases introduced by data manipulation in the official pollution data: What if some county officials manipulated air pollution data reported to higher level governments? How would it bias our results? Here, it is reasonable to assume data manipulation by local officials is a downward change in the reported data. Moreover, there are two likely scenarios regarding the real relationship between pollution and promotion; we consider each of these two scenarios and show how a downward change in the reported air pollution data by local officials would bias our result.

(Note that there is a third possible but very unlikely scenario in which there is a positive relationship between pollution and promotion: this is highly unlikely as it implies that upper level governments, after controlling for other factors such as economic growth and personal connections, would promote leaders who can generate more pollution. We therefore do not consider this unlikely scenario in the following.)

- a. *In the real world, there is no relationship between pollution and promotion*: we play out this scenario by the top row figures in next page of this memo. The question is that given there is no real relationship between pollution and promotion, whether we would have found a negative relationship if some counties manipulate pollution data. The short answer is no: if there really is no relationship between these two variables, even with data manipulation by county officials, with the satellite air pollution data we use, we won't be able to find a (false) negative relationship. The reason is the following:

Figure a1 from the top row represents the hypothetical real relationship: we only show 8 data points for the sake of simplicity; x-axis represents pollution level, y-axis the probability of promotion. There is a vertical line (in red) that we use to represent a hypothetical warning line set by an upper-level government: this is the threshold of pollution that county governments are not supposed to go over.

Chen et al. (2012) and Ghanem and Zhang (2014) both suggest that data manipulation happens often in the form of local governments changing pollution statistics downward from above the warning line to below the warning line to avoid punishment: this results in the truncation in pollution data, by which scholars can detect data manipulation. This data manipulation is captured by Figure a2 on the top row: two solid points on the far right side of the figure are moved horizontally to the left of the warning line: we indicate this move by two gray arrows in the figure. Because there is no relationship between pollution and promotion, there is no change in the y-axis values for these two data points – this is the reason why these are purely horizontal moves. Note that Figure a2 is the data observed by the upper level government. (We also display the previous positions of these two points by two gray hollow points: they are not observed by the upper level government.)

Because we use satellite data where there is no manipulation, so we cannot observe Figure a2 on the top row; what we observe is Figure a3: here, pollution values are the real values from the satellite – same as in Figure a1; the values for promotion probabilities are the same as in Figure a2, which are also the ones from Figure a1 because manipulating

pollution data has no effect on promotion. Therefore, Figure a1 and Figure a3 are identical. Analyzing Figure a3 is the same as analyzing Figure a1; it introduces no bias because all three figures indicate that there is no relationship between pollution and promotion, which is the real relationship we assumed in this scenario.

- b. *In the real world, there is a negative relationship between pollution and promotion:* we play out this scenario in the three figures of the bottom row of Figure 1. We ask a similar question as in the previous scenario: what kind of bias would be introduced if there is data manipulation by county officials and we use satellite data? The short answer is under this scenario, when there is a downward data manipulation in air pollution data, and if we find a negative relationship between pollution and promotion by analyzing our data, the real relationship should be even more negative between pollution and promotion. In other words, data manipulation by county officials is biased against us finding our key empirical result. The reasoning is the following:

In the bottom row, Figure b1 represents the hypothetical real relationship: note we draw a right-downward dash line to represent the real relationship between pollution and promotion – this is what we want to recover from our analysis. Again, Chen et al. (2012) and Ghanem and Zhang (2014) suggest that data manipulation happens in the form of local governments changing pollution statistics from above to below the warning line. This data manipulation is captured by Figure b2: the two data points at far-right side are moved to the left of the warning line. Because there is a negative relationship between pollution and promotion, such downward manipulation in pollution data creates an upward change in the y-axis values for these two data points: this is the reason why they are moved to their upper left – this is the data observed by the upper level government.

Because we use satellite data where there is no manipulation, we cannot observe Figure b2. What we observe is Figure b3: here, pollution values (x-axis) are the real values from satellite – same as in Figure b1 (real relationship), but different from Figure b2 (data observed by upper level government after manipulation); the values for promotion probabilities are the same as in Figure b2: a downward data manipulation by county officials increases the chances of promotion and we can only observe these promotion outcomes affected by such data manipulation.

Therefore, Figure b3 (data we use) and Figure b1 (real relationship) differs only in the y-axis values for the two observations on the far-right side of the figures: in Figure b3, these two data points are moved upwards vertically, therefore flattening the relationship at the higher value end of x-axis; if we fit linear regression line now based on data in Figure b3 – this is the one we recover from our analysis, indicated by a long dash line in Figure b3 – it is more flattened than the real relationship between pollution and promotion (indicated by a dash line in all three figures). In other words, when the real relationship between pollution and promotion is negative and when there is a downward manipulation in pollution data, and if we find a negative relationship by analyzing our data (Figure b3), the real relationship between pollution and promotion (Figure b1) should be even more negative. Data manipulation by county officials is therefore biased against us finding our key empirical result.

Figure C1: Analyzing potential biases by data manipulation in the official data.



a): in the real world, there is no relationship between pollution and promotion.



b): in the real world, there is a negative relationship between pollution and promotion.

Section D: An alternative DID estimation.

In this section, we present results from an earlier version of the paper in which a difference-in-differences (DID) approach is used instead of the instrumental variable approach currently used in the main text of the paper. We decided to only present this DID approach in an online appendix because first, our key explanatory variables, local PM2.5 and SO2, might be endogenous. Second, we observe a pre-trend when we test the parallel trend assumption using the full sample: we have an explanation on why we observe this pre-trend; following this explanation, we limit our sample to non-TCZ counties and this pre-trend disappears.

Measuring County Party Secretary Promotion

We use two dependent variables to measure promotion patterns. The first has three values defined as follows:

$$TurnOver1 = \begin{cases} 2: \text{promotion (move from county to district; from county and district to prefecture and above);} \\ 1: \text{job move at the same level;} \\ 0: \text{demotion, retirement, punishment.} \end{cases}$$

The second dependent variable is binary and is defined as follows:

$$TurnOver2 = \begin{cases} 1: \text{promotion (from county and district to prefecture and above);} \\ 0: \text{move from county to district; job move at the same level; demotion, retirement, punishment.} \end{cases}$$

$TurnOver1$ is a more detailed operationalization than $TurnOver2$. In the following discussion, we present empirical results and focus our discussion using $TurnOver1$ as the dependent variable even though using $TurnOver2$ gives similar results.⁴⁰ Moreover, whether retirement should be coded as 0 or simply removed from our data is debatable. Removing retired party secretaries from our sample do not change our results though.

Measuring Relative Local Pollution Growth

Using PM2.5 data aggregated at the county-year level, we measure a party secretary's relative yearly environmental performance as follows:

$$Diff_PM2.5_{ict} = (PM2.5_{ct} - \overline{PM2.5_{c,T-1}}) - (PM2.5_{pt} - \overline{PM2.5_{p,T-1}})$$

On the right hand side, the first term, $PM2.5_{ct} - \overline{PM2.5_{c,T-1}}$, is the difference between a county(c)-year(t) PM2.5 concentration ($PM2.5_{ct}$) and the average of PM2.5 annual concentrations during a county party secretary's predecessor's term ($\overline{PM2.5_{c,T-1}}$). The idea here is to measure how much more a county has emitted air pollution, for a given year, compared to the average level of air pollution of a party secretary's predecessor. The second term, $PM2.5_{pt} - \overline{PM2.5_{p,T-1}}$, is the prefecture version of the first term: the difference between a prefecture(p)-year(t) PM2.5 concentration ($PM2.5_{pt}$) and the average of PM2.5 annual concentrations during a prefecture party secretary's predecessor's term ($\overline{PM2.5_{p,T-1}}$); in other words, $PM2.5_{pt} - \overline{PM2.5_{p,T-1}}$ measures how much more a prefecture has emitted air pollution compared to the average level of air pollution of a prefecture party secretary's predecessor.

The difference between these two terms then captures a county party secretary's relative

⁴⁰ Tables and results available upon request from authors.

yearly PM2.5 air pollution growth/performance compared to his/her predecessor and compared to the relative growth (measured in the same way) at the prefecture level. The higher this value, the worse the environmental performance of a county party secretary compared to his/her predecessor and peers in the same prefecture. Finally, using SO2 data at the county-year level, we measure a party secretary's yearly relative air pollution growth the same way as in the case of PM2.5:

$$\text{Diff_SO2} = (\text{SO2}_{ct} - \overline{\text{SO2}_{c,T-1}}) - (\text{SO2}_{pt} - \overline{\text{SO2}_{p,T-1}}).$$

Control Variables

In addition to relative pollution growth variables, we include a battery of county characteristic variables, including log per capita GDP, fiscal revenue, total population, infrastructure expenditures, and industry production in each county-year as well as county party secretary leader characteristics such as gender, education, age, age square and tenure length. We also control for the mean PM2.5 or SO2 in each prefecture-year. Table D1 presents the basic summary statistics for variables included in the main analysis.

Table D1. Summary statistics for the key variables

Variables	Definition	Mean	S.td.	Number of observations
Dependent variables				
Promotion1	Termination or Retirement=0; Same level=1; County to district or Promotion=2	0.3483	0.7161	20597
Promotion2	Promotion=1, all others=0	0.1260	0.3319	20597
Independent variables				
Diff_PM2.5	$=(\text{PM2.5}_{ct} - \overline{\text{PM2.5}_{c,T-1}}) - (\text{PM2.5}_{pt} - \overline{\text{PM2.5}_{p,T-1}})$	-0.3087	0.9067	15012
Diff_SO2	$=(\text{SO2}_{ct} - \overline{\text{SO2}_{c,T-1}}) - (\text{SO2}_{pt} - \overline{\text{SO2}_{p,T-1}})$	0.0177	2.0325	5450
Control variables				
Gender	1=female, 2=male	1.9683	0.1751	19644
Education	0=Associate degree or even below, 1= Bachelor degree, 2=Master degree, 3= Doctor degree.	1.5330	0.6669	18109
Age	Age of official in each year	46.8825	3.9396	18825
Age2	Age's square of official in each year	2213.488	366.7468	18825
Tenure	The years spent at one tenure	4.1394	1.7552	23597
ΔRGDP	The growth rates of GDP per capita in each county-official-year	0.1590	0.2260	13907
MPM2.5	the mean PM2.5 in each prefecture city-year	234.1369	200.367	20597
MSO2	the mean So2 in each prefecture city-year	2.9504	4.3249	11239
lnRGDP	Log of per capita GDP in each county-year	9.3720	0.9297	20184
lnFisrev	Log of fiscal revenue in each county-year	9.7921	1.3294	19168
lnPop	Log of total population in each county-year	3.6804	0.7608	20505
lnIfexp	Log of infrastructure expenditures in each county-year	11.8713	1.7512	20423
lnIndus	Log of industry production in each county-year	12.1247	1.5018	20493

Main Results

To test the marginal effect of relative pollution growth on county party secretary's chances of promotion, we first estimate the following model:

$$TurnOver_{ict} = \alpha Diff_PM2.5_{ict}/Diff_SO2_{ict} + \beta \Delta RGDP_{ct} + \gamma X_{ct} + \lambda Z_{it} + \eta_c + \theta_t + \varepsilon_{ict} \quad (1)$$

Note that we use i to indicate officials, c for county, and t for year. When we use SO2 to measure relative pollution growth ($Diff_SO2_{ict}$), the sample period covered is 2005-2014; when using PM2.5 ($Diff_PM2.5_{ict}$), it is 2001-2014. Again, $TurnOver_{ict}$ captures the county-year level promotion outcome. $\Delta RGDP_{ct}$ is the growth rates of GDP per capita in each county-year, often used to test the competence hypothesis. X_{ct} includes prefecture and county-year level control variables and Z_{it} party secretary(-year) control variables. We include fixed county (η_c) and fixed year (θ_t) effects. We cluster the standard errors at the county level (ε_{ict}).

Table D2: Linear probability model (OLS estimation).

VARIABLES	Political Turnover					
	(Termination or Retirement=0; Same level=1; County to district or Promotion=2)					
	Sample period: 2001-2014			Sample period: 2005-2014		
	(1)	(2)	(3)	(4)	(5)	(6)
Diff_PM2.5	-0.0847*** (0.0085)	-0.1013*** (0.0099)	-0.2358*** (0.0258)			
Diff_SO2				-0.0170** (0.0069)	-0.0210** (0.0010)	-0.1818*** (0.0351)
County variables	NO	NO	YES	NO	NO	YES
Personal variables	NO	YES	YES	NO	YES	YES
County FE	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES
Adj. R-squared	0.0994	0.1365	0.2409	0.1961	0.2132	0.3722
Observations	14990	13106	7791	5319	4731	1948

Notes: (1) Robust standard errors, clustered at county, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2) Dependent variable is the promotion which equals two if the official gets the promotion or move from the county to district, equals one if moving between different county or the same level departments, and equals zero for others. (3) Control variables includes the mean PM2.5 or So2 in each prefecture city-year, the average growth rate of per capital GDP and log of per capita GDP, fiscal revenue, total population, infrastructure expenditures and industry production in each county-year, also includes official's gender, education, age, age square and tenure length.

Table D2 reports the basic findings regarding the marginal effect of relative pollution growth, with model specification 1-3 using the relative PM2.5 pollution growth variable and specification 4-6 the relative SO2 pollution growth variable. All model specifications are estimated with fixed county (County FE) and fixed year (Year FE) effects: the differences are in model 1 and 4, we do not include county and personal control variables; model 2 and 5 add in personal controls; and model 3 and 6 have both county and personal controls. We do have many missing values from the county control variables. Therefore, once county controls are added as in model 3 and 6, the number of observations drop significantly. Here, we find that regardless of the model specifications and types of air pollution, the relative growth in air pollution is always negatively associated with promotion and this association is always statistically significant.

After establishing our baseline result of a negative and statistically significant association between relative growth in air pollution and chances of promotion in Table D2, we conduct a difference-in-differences (DID) regression as specified as follows:

$$TurnOver_{ict} = \alpha' \text{Diff_PM2.5} \times \text{Post}_{2005} + \alpha \text{Diff_PM2.5} + \beta \Delta RGDP_{ct} + \gamma X_{ct} + \lambda Z_{it} + \eta_c + \theta_t + \varepsilon_{ict} \quad (2)$$

Post_{2005} equals to 1 for post 2005 years and 0 otherwise. $\text{Diff_PM2.5} \times \text{Post}_{2005}$ is the DID estimator variable (and the only difference between equation 1 and 2). Post_{2005} only shows up in the DID estimator variable, because it itself is absorbed by the year fixed effects. The coefficient of $\text{Diff_PM2.5} \times \text{Post}_{2005}$, that is, α' , captures the causal effect of relative pollution growth on promotion in this DID set up: this is the difference between the effect of relative pollution growth on promotion since the 11th Five Year Plan and the effect of relative pollution growth on promotion in the pre-11th Five Year Plan period. Note that there is no SO2 data from the pre-11th Five Year Plan period. Therefore, our DID regressions are limited to PM2.5. However, PM2.5 and SO2 are highly correlated: correlations are higher than 0.6 when looking at the data yearly. Therefore, PM2.5 is a good proxy for SO2.

The first model specification of Table D3 reports a statistically significant DID estimator ($\text{Diff_PM2.5} \times \text{I}(\text{year} > 2005)$) coefficient. Model specification 2 of Table D3 further disaggregate the Post_{2005} variable into year dummy variables and interact them with the PM2.5 pollution relative growth variable. Here, the estimates on the coefficients associated with the *lags* – the interactions between year dummies after 2005 and relative pollution growth – are all negative and statistically significant except the one with year 2006: this makes sense because 2006 is the first year for the 11th Five-Year Plan. This might have been the transition year during which policy changes were introduced and implemented.

Importantly, model specification 2 of Table D3 helps us to test the parallel trend assumption in DID. Intuitively, the idea here is that one can include the interactions of the year dummies and the treatment variable (relative pollution growth) for all the periods except one (due to the dummy variable trap). If the outcome trends between treatment and control group before the treatment are the same, that is, the parallel trend assumption holds, the coefficients associated with the *leads* – the interactions between year dummies before 2006 and relative pollution growth – should all be statistically insignificant, i.e., the difference in differences is not significantly different in the pre-treatment periods.

In model specification 2 of Table D3, the coefficient estimates for the leads show signs of a pre-trend. First, the coefficient for the 2002 lead ($\text{Diff_PM2.5} \times \text{I}(\text{year} = 2002)$) is statistically significant at the 0.10 level. Moreover, the slowly declining mean coefficient estimates of the leads of 2002, 2003, and 2004 – 0.184, 0.090, 0.068 – also suggest a pre-trend. It seems that the effects of pollution on promotion has been trending down since 2002 before the treatment of the 11th Five-year Plan kicked in 2006.

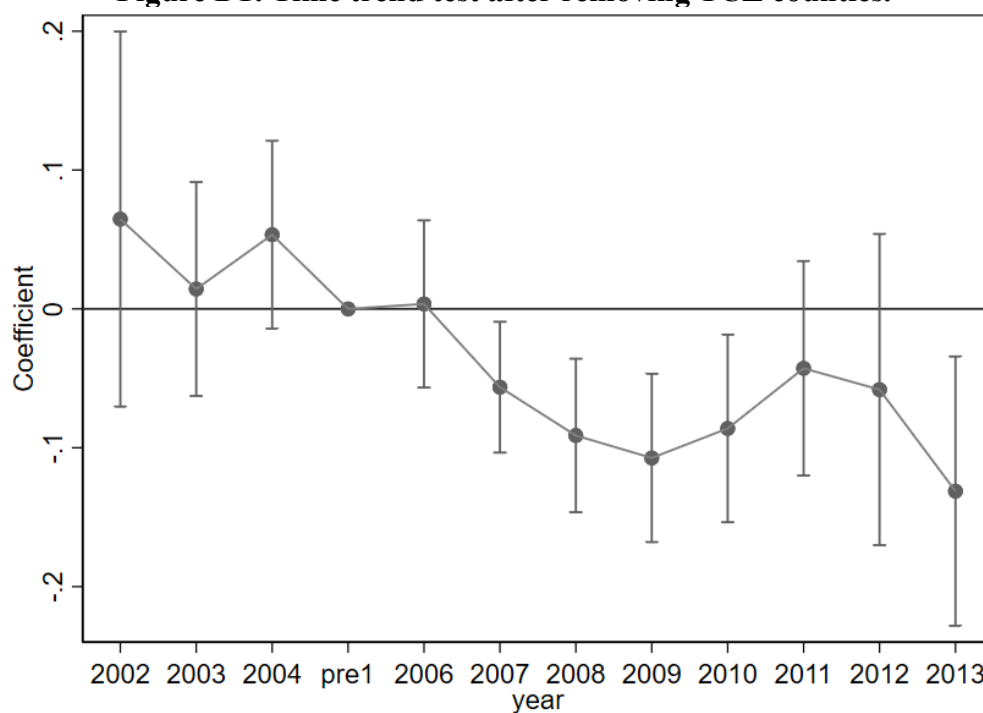
A potential reason for the pre-trend is that before the 11th Five-year Plan, the central government had implemented policy schemes such as the TCZ to address pollution issues in certain areas: local leaders in those areas were subject to performance evaluation based on their environmental performances before 2006; in other words, long before the beginning of the 11th Five-year Plan, certain regions of the country (e.g., the TCZ counties) were already moving towards a cadre evaluation system that incorporates environmental quality; this can result in a pre-trend. If this explanation is valid, once we remove the TCZ counties – again, those that were subject to higher environmental standards and whose leaders were subject to pollution-based promotion before 2006 – the pre-trend should be weakened. Figure D1 shows the results after we remove TCZ counties from the analysis: we observe a much-weakened pre-trend.

Table D3: Difference-in-differences estimation and pre-trend test.

VARIABLES	Political Turnover	
	(Termination or Retirement=0; Same level=1; County to district or Promotion=2)	
	(1)	(2)
Diff_PM2.5	-0.1439*** (0.0309)	-0.170*** (0.043)
Diff_PM2.5 × I(year>2005)	-0.1214*** (0.0316)	
Diff_PM2.5 × I(year=2002)		0.184* (0.110)
Diff_PM2.5 × I(year=2003)		0.090 (0.066)
Diff_PM2.5 × I(year=2004)		0.068 (0.056)
Diff_PM2.5 × I(year=2006)		0.003 (0.046)
Diff_PM2.5 × I(year=2007)		-0.100** (0.045)
Diff_PM2.5 × I(year=2008)		-0.177*** (0.052)
Diff_PM2.5 × I(year=2009)		-0.206*** (0.050)
Diff_PM2.5 × I(year=2010)		-0.175*** (0.054)
Diff_PM2.5 × I(year=2011)		-0.100* (0.057)
Diff_PM2.5 × I(year=2012)		-0.143** (0.063)
Diff_PM2.5 × I(year=2013)		-0.262*** (0.068)
County variables	YES	YES
Personal variables	YES	YES
County FE	YES	YES
Year FE	YES	YES
R-squared	0.2422	0.2475
Observations	7791	7791

Notes: (1) Robust standard errors, clustered at county, are in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2) Dependent variable is the promotion which equals two if the official gets the promotion or move from the county to district, equals one if moving between different county or the same level departments, and equals zero for others. I(•) is the indicate function equals one if the condition is established in the parentheses and zero otherwise. (3) Control variables includes mean PM2.5 in each prefecture city-year, the average growth rate of per capital GDP and log of per capita GDP, fiscal revenue, total population, infrastructure expenditures and industry production in each county-year, official's gender, education, age, age square and tenure length.

Figure D1: Time trend test after removing TCZ counties.



The waved line captures the coefficients of time dummies interacted with the variable “Diff_PM2.5”. The vertical lines cross each point represent the 95% confidence interval of the estimated effect. Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 otherwise, and officials who are demoted, retired, or punished are excluded. Counties in TCZ region are excluded.

Section E: An alternative IV approach for PM2.5 regressions.

In the main text of the paper, we use ventilation coefficient as the instrument for both PM2.5 and SO2. One advantage is consistency. In an earlier version of this paper, we used another instrumental variable for the PM2.5 variable: this is a difference-in-differences based instrument, exploring differential effects of provincial pollution reduction targets on pollution, before and after such targets were imposed (Lu et al. 2017). In this section of the online appendix, we present this alternative IV approach. We think this might be of interest to readers who are interested in identification strategies other than the one using ventilation coefficient; and this can further serve as a robustness check for the PM2.5 results.

As we discussed in the main text of the paper, the variable of interest, $PM2.5_{ict}$ or $SO2_{ict}$ might be endogenous. For instance, cadres with higher probability for promotion are appointed to counties with better potentials in environment protection and economic growth. This reverse causality issue can generate a biased estimation. In addition, omitted variables, such as the ability of local officials, which often cannot be measured directly and accurately, could also cause a biased estimation of key explanatory variables.

To deal with these endogeneity issues, we adopt an instrumental variable approach. More specifically, when we use PM2.5 to measure local air pollution, we take advantage of cross-province variations in pollution reduction targets imposed by the 11th Five-year Plan to examine the effect of pollution on local officials' promotion. (Table E-1 of the online appendix provides the reduction targets data.) Intuitively, we compare promotion of local officials in provinces with larger pollution reduction targets with promotion in provinces with smaller pollution reduction targets, before and after the beginning of the 11th Five-year Plan (2006-2010). In other words, in this difference-in-differences based instrumental variable estimation (Lu et al. 2017), we use the interaction term between the provincial pollution reduction target ($Treatment_c$) and a post-2005 dummy variable ($post_t$) as the instrument. The first stage of the instrumental variable estimation for PM 2.5 is:

$$PM2.5_{ict} = \gamma_1 Treatment_c \times post_t + \gamma_2 X'_{ct} + \gamma_3 Z'_{ict} + N_c \times f(t) + \eta_c + \theta_t + \vartheta_{ict} \quad (1)$$

$Treatment_c$ is the provincial level pollution reduction target for county c , same for all counties in the same province; $post_t$ is a dummy variable indicating the years during and after the 11th Five-year Plan: it is 0 before 2006; 1 otherwise.

The pollution reduction target is not determined randomly; the difference in political turnovers between high-targets and low-targets counties could be a function of pre-existing differences. To deal with this issue, following Gentzkow (2006) and Lu et al. (2017), we identify the determinants (N_c) of the pollution targets, and control for the different trends in turnovers by interacting these determinants variables (N_c) with a third-order polynomial function of time, $N_c \times f(t)$. After carefully reading central government's main document explaining the allocation of pollution reduction targets – “National Total Pollutant Emission Control Plan during the 11th Five-Year Plan” – we include target determinants such as provincial environment quality, environment capacity, emission base, economic development, pollution reduction capability, and geographical factors. Details of these determinant variables are listed in Table E-2 of the online appendix.

Note that our PM2.5 data has a much longer temporal coverage (starting 1998), which turns out to be necessary for our difference-in-differences based instrumental variable approach that requires pre-treatment periods, i.e., years before the 11th Five-year Plan (2006-2010). SO2 data are only available from 2005 to 2014; we cannot adopt the same difference-in-differences based instrumental variable approach because we only have one year for the

pre-treatment period (i.e., 2005).

Table E-1: Pollution Reduction Targets from the 11th Five-Year Plan (unit: 10,000 tons).

Province	SO2 emissions in 2005	SO2 emission targets in 2010		Reduction Percentage (%)
		Total	In which: Electricity sector	
Beijing	19.1	15.2	5	20.4
Tianjin	26.5	24	13.1	9.4
Hebei	149.6	127.1	48.1	15
Shanxi	151.6	130.4	59.3	14
Neimenggu	145.6	140	68.7	3.8
Liaoning	119.7	105.3	37.2	12
Jilin	38.2	36.4	18.2	4.7
Heilongjiang	50.8	49.8	33.3	2
Shanghai	51.3	38	13.4	25.9
Jiangsu	137.3	112.6	55	18
Zhejiang	86	73.1	41.9	15
Anhui	57.1	54.8	35.7	4
Fujian	46.1	42.4	17.3	8
Jiangxi	61.3	57	19.9	7
Shandong	200.3	160.2	75.7	20
Henan	162.5	139.7	73.8	14
Hubei	71.7	66.1	31	7.8
Hunan	91.9	83.6	19.6	9
Guangdong	129.4	110	55.4	15
Guangxi	102.3	92.2	21	9.9
Hainan	2.2	2.2	1.6	0
Chongqing	83.7	73.7	17.6	11.9
Sichuan	129.9	114.4	39.5	11.9
Guizhou	135.8	115.4	35.8	15
Yunan	52.2	50.1	25.3	4
Tibet	0.2	0.2	0.1	0
Shaanxi	92.2	81.1	31.2	12
Guansu	56.3	56.3	19	0
Qinghai	12.4	12.4	6.2	0
Ningxia	34.3	31.1	16.2	9.3
Xinjiang	51.9	51.9	16.6	0

Source: "Reply to *Pollution Control Plan During the Eleventh Five-Year Plan*," issued by the China State Council in 2006.

Table E-2. Summary statistics for variables of target determination.

Variables	Definition	Mean	S.td.	Obs.
SO2_2005	SO2 concentration in 2005 in each province	0.439	0.457	14,175
PM2.5_05	PM2.5 in 2005 in each province	3.476	0.586	14,175
Capacity	Environment capacity in 2005 measured by SO2 emission in each province, 10000 tons (log)	4.571	0.285	14,175
Dust	Ratio of industrial dust emission up to the standard in 2005 in each province (%)	73.447	18.809	14,175
Soot	Ratio of industrial soot emission up to the standard in 2005 in each province (%)	81.258	13.017	14,175
Industrial SO2	Industrial SO2 emission in 2005 in each province, tons (log)	13.661	0.466	14,175
GDP	Provincial GDP per capita in 2005 in each province, yuan (log)	8.765	0.681	14,175
Population	Provincial population in 2005 in each province, 10000 persons (log)	8.765	0.681	14,175
Waste gas	Operating cost of waste gas treatment in 2005 in each province, 10000 yuan (log)	11.467	0.887	14,175
Investment projects	Investment on environment protection projects in 2005 in each province, 10000 yuan (log)	2.536	0.809	14,175
Waste processing	Expenditures on waste processing in 2005 in each province, 10000 yuan (log)	11.012	0.891	14,175
Desulfurization	Desulfurization capacity of desulfurization facilities in 2005 in each province, tons/hour (log)	5.529	1.216	14,175
Facilities	Number of waste gas treatment facilities in 2005 in each province (log)	8.474	0.646	14,175
Reduction SO2	Reduction of industrial SO2 emission in 2005 in each province, tons (log)	12.793	0.816	14,175
Geographical	It is 1 if in eastern regions, and 0 otherwise	0.284	0.451	14,175
Ventilation	Ventilation coefficient in 2005 in each province (log)	7.355	0.247	14,175

Main Results

Empirical results regarding the effect of PM 2.5 on county party secretaries' promotion are reported in Table E-3. In Column (1), we report findings from an OLS estimation where we do not address potential endogeneity issues for PM 2.5: here we find that PM2.5 is negative associated with promotion; this association is statistically significant.

Results using a difference-in-differences based instrument are in Column (3): Panel B has the first stage result; here, the instrument, $Treatment_c \times post_t$, has a negative and statistically significant effect on PM 2.5, suggesting that a larger pollution reduction target reduces pollution level and therefore proving the relevance condition for the instrument. Panel A in Column (3) has the second stage result: after being instrumented, the key explanatory variable, PM 2.5, imposes a negative and statistically significant effect on county party secretaries' promotion. This confirms our argument that a better environmental performance is helpful for local officials' promotion. Comparing the coefficient estimations in Column (1) and (3), the smaller magnitude in the OLS estimation may suggest the issue of omitted variables and reverse causality in the estimation.

We also report the reduced form estimation result in Column (2) where we regress political turnover directly on the instrumental variable ($Treatment_c \times post_t$) together with other control variables. The estimated coefficient is also significant, showing that in counties with larger provincial pollution reduction targets, local officials are more likely to get promotion after the implementation of the 11th Five-year Plan.

Table E-3. Main results for the effect of PM2.5 on the promotion of county party secretaries.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation		Dependent variable: Political Turnover	
PM 2.5	-0.799*** (0.110)		-3.435*** (1.168)
Treatment \times post		0.048*** (0.015)	
Panel B: First stage estimation			Dependent variable: PM 2.5
Treatment \times post			-0.014*** (0.003)
Underidentification test			22.881***
Weak identification test			27.751***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Target determinants \times T	YES	YES	YES
Target determinants \times T2	YES	YES	YES
Target determinants \times T3	YES	YES	YES
Observations	14,175	14,175	14,175

Notes: (1) Robust standard errors, clustered at city level, are in parentheses, *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$. (2) Dependent variable is Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level of departments. Demoted, retired, and punished officials are not included. (3) County control variables include log of per capita GDP, fiscal revenue, total population, infrastructure expenditures and industry production in each county-year, and PM 2.5 at each city each year. Personal control variables include official's gender, education, age, age square, tenure length, and connection. Target determinants includes environment quality, environment capacity, emission base, economic development, pollution reduction capability and geographical factors. The variables used to measure target determinants are SO2 concentration in 2005, PM 2.5 in 2005, environment capacity in 2005, industrial SO2 emission in 2005, the ratio of industrial dust emission up to the standard in 2005, the ratio of industrial soot emission up to the standard in 2005, provincial GDP in 2005, provincial population in 2005, the operating cost of waste gas treatment in 2005, investment on environment protection projects in 2005, expenditures on waste processing in 2005, desulfurization capacity of desulfurization facilities in 2005, the number of waste gas treatment facilities in 2005, the reduction of industrial SO2 emission in 2005, ventilation coefficient in 2005, and geographical locations. (4) The sample period is from 2001 to 2014.

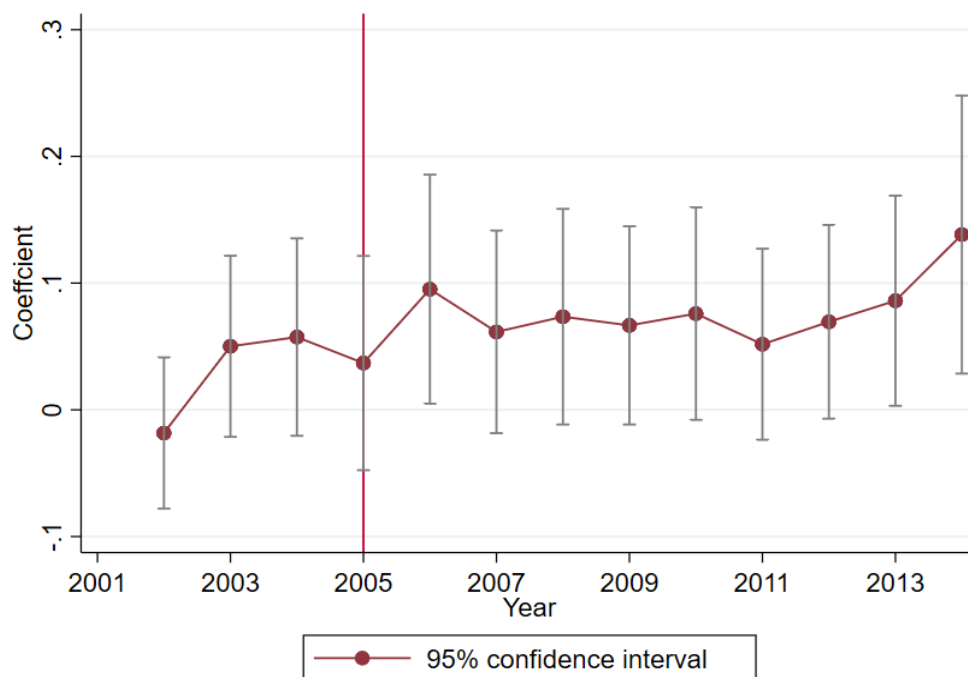
Checking Potential Bias Due to Non-random Selection of the Treatment Group: A major source of bias for this difference-in-differences based IV approach is the non-random selection of the treatment (high target) group. In other words, pollution reduction targets were not assigned randomly across provinces. To alleviate this concern, as we discussed earlier, following Gentzkow (2006) and Lu et al. (2017), we identify and control the determinants of the pollution targets. Note if this strategy works, after controlling these target determinants (and other control variables), the treatment and control groups should display a high level of comparability. One way to test this is to verify that counties in provinces with different pollution reduction targets have similar time trends of political turnovers before 2006,

conditional on the variables included in the analysis (target determinants plus other controls). Therefore, we estimate the following equation:

$$\text{political turnover}_{ict} = \sum_{t=2001}^{2014} \alpha_t \text{Treatment}_c \times \theta_t + \alpha_2 X'_{ct} + \alpha_3 Z'_{ict} + N_c \times f(t) + \eta_c + \theta_t + \vartheta_{ict} \quad (2)$$

α_t is a series of coefficient estimates for year dummies (2001 to 2014) interacted with emission reduction target. This is essentially the reduced form regression from Column (2) of Table 2 but replacing the interaction term between provincial target and a post-2005 dummy with series of interaction terms between provincial target and year dummies.

Figure E-1: Effect of emission target on county party secretaries' turnover over time.



Note: The waved line captures the coefficients of time dummies interacted with emission reduction target. The vertical lines cross each point represent the 95% confidence interval of the estimated effect. The estimation for year of 2001 is the baseline year. The coefficients for year dummies of 2002, 2003, 2004 and 2005 are not significant at 95% confidence interval.

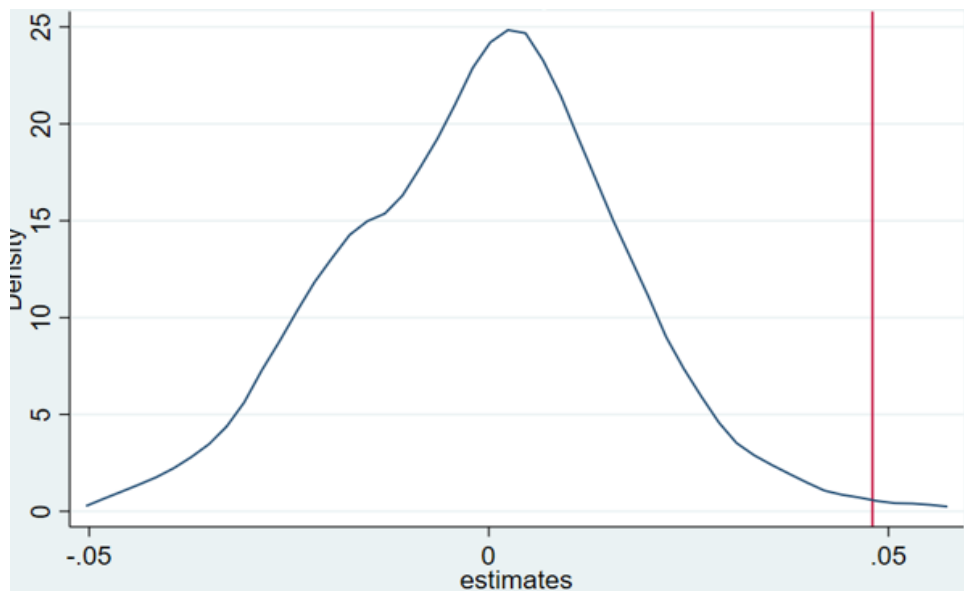
Figure E-1 shows differences in promotion chances between the treatment (high targets) and control (low targets) counties over time by plotting the estimated coefficients of α_t . Note that the estimates for 2002-2005 are far from being statistically significant, suggesting the treatment and control groups were balanced in promotion chances before the 11th Five-year Plan (2006-2010), that is, there is a good comparability between the two groups conditional on target determinant variables and other controls in the reduced form regression. From 2006 to 2014, the α_t estimates gradually increase, indicating that pollution reduction targets have a positive effect on promotion chances.

A Placebo Test with Random Assignment of Treatment (Provincial Target): In this section, to further make sure that our analysis does not suffer from biases from omitted variables, we conduct a placebo test, following Chetty et al. (2009), La Ferrara et al. (2012), and Lu et al. (2017). We randomly assign provincial pollution reduction targets to counties

and construct a new regressor of interest, $Treatment_c^{false \times post}$. Given the data is randomly assigned, $Treatment_c^{false \times post}$ should produce zero effect on pollution, thus regressing political turnover directly on $Treatment_c^{false \times post}$ (i.e., the reduced form regression) should produce zero effect; otherwise, it indicates the existence of omitted variables.

We conduct this data generating process 500 times to avoid contamination by rare events and to improve the power of the test. Figure E-2 shows the distribution of the coefficient estimates of $Treatment_c^{false \times post}$ from the 500 randomized assignments. The estimates are centered around 0, far from our true estimate, 0.048 (from the baseline reduced form regression, i.e., column (2) of Table 2), indicated by a vertical line in the figure. This suggests that the negative and significant effect of pollution on political turnover is unlikely to be driven by unobserved, omitted variables.

Figure E-2: The distribution of estimates in the randomization test.



Note: The figure shows the distribution of the estimates from the 500 times of randomization. In this exercise, we randomly assign the degree of changes in SO2 target reduction to provinces (false Target). We then use the baseline reduced form regression to conduct regression analysis based on the false Target. This is repeated 500 times and the resulting estimated coefficients are plotted. The dependent variable is turnover of county party secretaries and the independent variable is false Target \times post. The vertical line refers to the true estimates in Column (2) of Table 2, i.e., 0.048.

Robustness Checks

In this section, we present robustness checks to see if our main results hold when we consider alternative operationalization of pollution measures, control for peer and predecessor pollution levels together, account for promotion outcomes in other counties in the same prefecture, limit our analysis to sub-samples of our data, and use simultaneous equations to model promotion alongside local GDP. We also discuss how we further address the reverse causality issue by limiting our analysis to a subset of officials who started their county party secretary posts before environmental performance was added to the cadre evaluation system with the 11th Five-year Plan (2006-2010). Column (1) to (9) in Table E-4 and are

instrumental variable estimation results; Column (10) in Table E-4 are results from simultaneous equation estimation.

Capturing relative performance in pollution reduction: In Column (1) of Table E-4, we examine the effect of PM2.5 on political turnovers without controlling city peer performance (PM2.5 in each prefecture/city-year) and predecessor performance (average PM2.5 during the predecessor's tenure). In Column (2) of Table E-4, we control for both city peer performance and predecessor performance regarding PM2.5 pollution. The estimates of the instrumented PM2.5 variable in Column (1) and (2) are very similar to the baseline estimation in Table E-3.

In Column (3), we consider using one pollution variable to test the relative performance of local officials. This alternative measure is operationalized as follows:

$$\text{Diff_PM2.5}_{ict} = (\text{PM2.5}_{ct} - \overline{\text{PM2.5}_{c,T-1}}) - (\text{PM2.5}_{pt} - \overline{\text{PM2.5}_{p,T-1}}) \quad (3)$$

On the right hand side, the first term, $\text{PM2.5}_{ct} - \overline{\text{PM2.5}_{c,T-1}}$, is the difference between a county(c)-year(t)'s PM2.5 concentration (PM2.5_{ct}) and the average of PM2.5 concentrations during a county party secretary's predecessor's term ($\overline{\text{PM2.5}_{c,T-1}}$). The idea is to measure

how much more air pollution a county has emitted compared to the average level of its party secretary's predecessor. The second term, $\text{PM2.5}_{pt} - \overline{\text{PM2.5}_{p,T-1}}$, is the prefecture version of the first term, i.e., the difference between a prefecture(p)-year(t)'s PM2.5 concentration (PM2.5_{pt}) and the average of PM2.5 annual concentrations during a prefecture party

secretary's predecessor's term ($\overline{\text{PM2.5}_{p,T-1}}$): it measures how much more air pollution a

prefecture has emitted compared to the average level its prefecture party secretary's predecessor. The difference between these two terms on the right hand side of equation (3) captures a county party secretary's relative yearly PM2.5 air pollution performance compared to his/her predecessor and compared to the relative growth (measured in the same way) at the prefecture level. The higher this value, the worse the environmental performance of a county party secretary compared to his/her predecessor and peers in the same prefecture. Column (3) of Table E-4 shows our result holds when we use this Diff_PM2.5_{ict} variable to measure relative PM2.5 pollution directly rather than controlling for peer and predecessor performance as additional variables.

Potential spillover effect: One county party secretary's chances of promotion might also depend on promotion outcomes in other counties in the same prefecture given the total positions for promotion are often relatively stable in the same prefecture. In other words, it is possible that a spillover effect across counties within the same prefecture would occur. We conduct a robustness check by adding a spatial lag of the dependent variable: this is a temporally lagged (by a year, to avoid the simultaneity bias in spatial lag models) average dependent variable value of all other counties in the same prefecture. For PM2.5, the result is reported in Column (4) of Table E-4. We find that the coefficient of the instrumented PM 2.5

is still significant and negative; its magnitude is slightly smaller than the baseline result in Column (3) of Table E-3.⁴¹

Results using sub-samples: We exclude observations from Hebei province for the Summer Olympic Games venue cities, the observations for officials whose turnover happened during 2008 or 2009 for financial crisis, and counties in provincial capital cities. The estimation results are reported in Column (5), (6), and (7) for PM2.5 in Table E-4. The main results stay, indicating that our results are not driven by specific subsamples.

In 1998, a Two Control Zones (TCZ) policy was implemented by the central government with tougher regulations imposed in TCZ cities. This might introduce a further cross-sectional difference regarding the effect of pollution on promotion. We exclude TCZ counties and the results are reported in Column (8) in Table E-4. Our results hold. Interestingly, the magnitudes of mean coefficient estimates of the pollution variables in Column (8) in Table E-4 (the effect of PM2.5 in non-TCZ counties) are larger than those from the full samples (Column (3) in Table E-3). This suggests that the pollution-promotion effect is stronger in non-TCZ than in TCZ counties: for the same amount of pollution reduction, party secretaries in TCZ counties were rewarded less than those in non-TCZ counties.

If an upper-level government requires an environmental improvement relative to past performance (e.g., in percentage terms), leaders in counties with past tougher environmental regulations (e.g., TCZ counties) might face a disadvantage because their pollution levels might have already been pushed down to a low level and any further reduction would be very costly; if the upper level government takes this into consideration, the same amount pollution reduction in TCZ counties should be rewarded more: we should see a stronger pollution-promotion effect in TCZ counties.

However, other mechanisms might also be at play here. First, TCZ counties might have already made the required investment in pollution reduction equipment, therefore are better equipped to reduce pollution. Second, their local officials and civil servants might be more experienced and better trained. Finally, they might have not pushed down their pollution to a level beyond which any further reduction would be very costly: this is consistent with recent studies that suggest the TCZ policy had a limited effect on curbing SO₂ emissions, especially during the 10th Five-year Plan (2001-2005) (Chen et al. 2018). Under these possibilities, the upper level government might hold a higher standard for local leaders in the TCZ counties: the same amount pollution reduction in TCZ counties should be rewarded less; this is consistent with what we find regarding a weaker pollution-promotion effect in TCZ counties.

Simultaneous equation model estimation: It is possible that industrial activities in some dirty industries will produce higher GDP, thus GDP can be an outcome variable of pollution levels. We have used instrumental variable estimation to control the endogeneity of pollution in the analysis. In this section, as one more robust check, we use a simultaneous equation model taking both GDP per capita and political turnovers as endogenous outcomes. The

⁴¹ The coefficient of spatial lag itself is -0.448 and significant.

details for the estimation of simultaneous equations can be found in the online appendix, Section F.

Column (10) in Table E-4 is the result from simultaneous equation estimation for PM2.5, which is comprised by two equations that describe the relationships among turnover and GDP per capita. To identify and estimate the simultaneous equations, in estimation for GDP per capita, we control for $Treatment_c \times post_t$ and fiscal expenditures of each county; and in estimation for political turnovers, we control for the average PM2.5 in each city-year. The standard errors are bootstrapped 50 times. The estimated coefficient of PM 2.5 is still significant and negative.

Addressing a potential reverse causality: A reverse causality threat to our analysis is that higher promotability cadres are appointed to counties with better potentials in environment protection and economic growth. Note that GDP growth has always been important for promotion. Yet before the 11th Five-year Plan (2006-2010), pollution was not a major consideration. If there is such a reverse causality, before 2006, higher promotability cadres were more likely to be assigned to counties with better potential for economic growth, regardless of the potential for environmental protection; after the implementation of the 11th Five-year Plan, environmental protection became an important factor, high promotability cadres who were assigned to counties with high economic growth potential but low pollution reduction potential should have been re-assigned to counties with high potentials for both economic growth and pollution reduction. When we checked our data regarding cadre job transfers, we do not observe this pattern. First, in our data, for county party secretaries, about 18% of job changes are transfers to other counties (still) as party secretaries – there is no significant year-by-year variation in the percentage of such same-level transfers during our study period. Second, we test whether there is any significant difference in air pollution between transfer-source counties and transfer-target counties of these same-level party secretary job transfers; t-test results show that there is indeed no significant difference in the means of air pollution between these two groups of counties (p-value = 0.40 for PM2.5).

However, there is still the possibility that cadres who were newly promoted to the county party secretary level after 2005 were assigned to counties based on their promotability, which introduces the reverse causality. As a robustness check, therefore, we limit our analysis to leaders who were already at the county party secretary level before the 11th Five-year Plan. Column (9) of Table E-4 shows that the coefficient of PM2.5 is still statistically significant.

Table E-4. Robust checks for the effect of PM2.5 on promotion of county party secretaries.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dependent variable: Political Turnover	No peer and predecessor	Peer and predecessor	Relative performance	Spatial lag	Exclude Hebei	Exclude 2008 & 2009	Exclude capital city	Exclude TCZ	Confine the sample to leaders who started before 2006	Simultaneous equation
PM 2.5	-3.612*** (1.249)	-3.843** (1.615)		-3.296** (1.532)	-4.472*** (1.504)	-4.130** (1.754)	-4.122*** (1.279)	-4.610*** (1.529)	-5.749* (3.083)	-0.325*** (0.068)
Diff_PM2.5 _{ict}			-2.699** (1.372)							
County FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Year FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
County control variables	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Personal control variables	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Target determinants× T	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Target determinants× T2	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Target determinants× T3	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Observations	14,175	11,054	11,054	11,312	13,405	12,525	13,101	6,846	5,785	14,175

Notes: (1) Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2) Dependent variable is the political turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demoted, retired, and punished officials are not included. (3) County control variables include log of per capita GDP, fiscal revenue, total population, infrastructure expenditures and industry production in each county-year, and PM2.5 at each city each year. Personal control variables include official's gender, education, age, age square, tenure length, connection. Target determinants includes environment quality, environment capacity, emission base, economic development, pollution reduction capability and geographical factors. The variables used to measure target determinants are SO2 concentration in 2005, PM 2.5 in 2005, environment capacity in 2005, industrial SO2 emission in 2005, the ratio of industrial dust emission up to the standard in 2005, the ratio of industrial soot emission up to the standard in 2005, provincial GDP in 2005, provincial population in 2005, the operating cost of waste gas treatment in 2005, investment on environment protection projects in 2005, expenditures on waste processing in 2005, desulfurization capacity of desulfurization facilities in 2005, the number of waste gas treatment facilities in 2005, the reduction of industrial SO2 emission in 2005, ventilation coefficient in 2005, and geographical locations. (4) The sample period is from 2001 to 2014. (5) Column (1) to (9) are results using the DID based instrument. Column (10) is the result from simultaneous equation model, and the standard errors are bootstrapped for 50 times.

Testing the Pollution-promotion Link for County Magistrates

Our analysis so far examines political turnovers of county party secretaries. This focus is motivated by the fact that party secretaries are the ones really in charge at every level of the Chinese government. In this section, we extend our analysis to county magistrates who take more responsibility in the day-to-day work of local development. In Table E-5, we present the results of OLS, reduced form, and instrumental variable regression regarding the effect of PM2.5: PM2.5 has a negative and statistically significant effect on county magistrates' promotion. Compared to the coefficient for party secretaries in Column (3) of Table E-3, the IV estimation for county magistrates is smaller. The total number observations for county magistrates is 11,146, slightly smaller than the number in county party secretary regressions due to more missing personal characteristics of county magistrates.

Table E-5. Results for the effect of PM2.5 on promotion of county magistrates.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation		Dependent variable: Political Turnover	
PM25	-0.732*** (0.128)		-2.660** (1.211)
Treatment × post		0.052** (0.024)	
Panel B: First stage estimation			Dependent variable: PM25
Treatment × post			-0.020*** (0.004)
Underidentification test			27.423***
Weak identification test			29.072***
County FE	YES	YES	YES
Year FE	YES	YES	YES
County control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Target determinants× T	YES	YES	YES
Target determinants× T2	YES	YES	YES
Target determinants× T3	YES	YES	YES
Observations	11,146	11,146	11,146

Notes: (1) Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2) Dependent variable is the Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different counties or staying at the same level departments. Demoted, retired, and punished officials are not included. (3) County control variables include log of per capita GDP, fiscal revenue, total population, infrastructure expenditures and industry production in each county-year, and PM 2.5 at each city each year. Personal control variables include official's gender, education, age, age square, tenure length, connection. Target determinants includes environment quality, environment capacity, emission base, economic development, pollution reduction capability and geographical factors. The variables used to measure target determinants are SO2 concentration in 2005, PM 2.5 in 2005, environment capacity in 2005, industrial SO2 emission in 2005, the ratio of industrial dust emission up to the standard in 2005, the ratio of industrial soot emission up to the standard in 2005, provincial GDP in 2005, provincial population in 2005, the operating cost of waste gas treatment in 2005, investment on environment protection projects in 2005, expenditures on waste processing in 2005, desulfurization capacity of desulfurization facilities in 2005, the number of waste gas treatment facilities in 2005, the reduction of industrial SO2 emission in 2005, ventilation coefficient in 2005, and geographical locations. (4) The sample period is from 2001 to 2014.

Beyond the County-level: Prefecture and Provincial Party Secretaries

In the hierarchical structure of administrative divisions in China, at the top is the central government, followed by provincial governments, prefecture level governments, and county-level governments. Generally, each level oversees the work carried out by its lower level in the administrative hierarchy. In the introduction, we provided justifications for our focus on county leaders. As far as we know, ours is the first county level study on the pollution-promotion link. One natural question, after we have established a robust causal effect of air pollution on county leaders' promotion, is whether we would find similar results at higher administrative levels. In this section, we examine the effect of environmental performance on prefecture and provincial party secretaries' promotion.

We apply similar estimation strategies. The estimation results for prefecture party secretaries are reported in Table E-6 for the effect of PM2.5. Column (3) shows that after we apply instrumental variable estimation, the effect of environment performance on political turnovers is not statistically significant. The estimation results for province party secretaries are reported in Table E-7 for PM2.5. In Column (3), the instrumented PM2.5 also has no effect on political turnovers.

The effect of environment performance on promotion is statistically significant and robust at the county level. Why don't we find a similar effect at the prefecture and provincial levels? Firstly, a much lower number of observations at the prefecture and provincial level makes it much more difficult to find statistically significant effects, especially given that we include many control variables and fixed effects in the analysis. Secondly, as we discussed in the introduction, county officials are distant in hierarchy and pose very little threat to central rulers; their loyalty therefore matters less than competence which is needed for local economic growth and pollution reduction. The promotions of prefecture and provincial officials are tied more to loyalty because these positions are key to the survival of the central rulers (Landry et al. 2018).

Table E-6. Results for effect of PM2.5 on promotion of prefecture party secretaries.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation	Dependent variable: Political Turnover		
PM25	-0.393 (0.333)		-1.383 (2.100)
Treatment × post		0.015 (0.023)	
Panel B: First stage estimation	Dependent variable: PM25		
Treatment × post			-0.013*** (0.003)
Underidentification test			12.238**
Weak identification test			13.956**
City FE	YES	YES	YES
Year FE	YES	YES	YES
City control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Target determinants× T	YES	YES	YES
Target determinants× T2	YES	YES	YES
Target determinants× T3	YES	YES	YES
Observations	3,337	3,337	3,337

Notes: (1) Robust standard errors, clustered at city level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2) Dependent variable is the Political Turnover which equals to 1 if the official gets the promotion, 0 if moving between different cities or staying at the same level departments. Demoted, retired and punished officials are not included. (3) City control variables include log of per capita GDP, fiscal revenue, total population, infrastructure expenditures and industry production in each city-year, and PM 2.5 in each province. Personal control variables include official's gender, education, age, age square, tenure length, and connection. Target determinants includes environment quality, environment capacity, emission base, economic development, pollution reduction capability and geographical factors. The variables used to measure target determinants are SO2 concentration in 2005, PM 2.5 in 2005, environment capacity in 2005, industrial SO2 emission in 2005, the ratio of industrial dust emission up to the standard in 2005, the ratio of industrial soot emission up to the standard in 2005, provincial GDP in 2005, provincial population in 2005, the operating cost of waste gas treatment in 2005, investment on environment protection projects in 2005, expenditures on waste processing in 2005, desulfurization capacity of desulfurization facilities in 2005, the number of waste gas treatment facilities in 2005, the reduction of industrial SO2 emission in 2005, ventilation coefficient in 2005, and geographical locations. (4) The sample period is from 2001 to 2014.

Table E-7. Results for effect of PM2.5 on promotion of provincial party secretaries.

	OLS	Reduced form	IV
	(1)	(2)	(3)
Panel A: Second stage estimation		Dependent variable: Political Turnover	
PM25	-0.659* (0.333)		-0.092 (0.757)
Treatment × post		0.000 (0.021)	
Panel B: First stage estimation			Dependent variable: PM25
Treatment × post			-0.026*** (0.005)
Underidentification test			6.430***
Weak identification test			27.528***
Province FE	YES	YES	YES
Year FE	YES	YES	YES
Province control variables	YES	YES	YES
Personal control variables	YES	YES	YES
Target determinants× T	YES	YES	YES
Target determinants× T2	YES	YES	YES
Target determinants× T3	YES	YES	YES
Observations	331	331	331

Notes: (1) Robust standard errors, clustered at province level, are reported in parentheses, *** p<0.01, ** p<0.05, * p<0.1. (2) Dependent variable is the Political Turnover which equals to 1 if the province official gets the promotion, 0 if moving between different provinces or staying at the same level departments. Demoted and punished officials are not included. (3) Province control variables include log of per capita GDP, fiscal revenue, fiscal expenditure, total population, infrastructure expenditures and industry production in each province-year. Personal control variables include official's gender, education, age, age square, tenure length, connection which is measured by the dummy of central working experiences. The variables to measure target determinants are ventilation coefficient in 2005, desulfurization capacity of desulfurization facilities in 2005, and environment capacity in 2005. (4) The sample period is from 2001 to 2014.

Section F: Simultaneous question estimation.

In this section, we estimate the effect of pollution on political turnovers using simultaneous equation estimation as a robustness check. In our baseline estimation, we include GDP per capita and other variables at county level as control variables. It is possible that industrial activities in some dirty industries will produce higher GDP, thus GDP can be an outcome variable of pollution. Including GDP in the regression will induce a bad-control issue and inconsistency in estimation. However, omitting it will apparently induce omitted variable bias. Therefore, we run a simultaneous equation model taking both GDP and political turnover as endogenous outcomes.

$$\text{political turnover}_{ict} = \alpha_1 \text{PM2.5}_{ict} + \alpha_2 \text{GDP}_{ict} + \alpha_3 X_{1ct}' + \alpha_4 Z_{ict}' + \eta_c + \theta_t + \varepsilon_{ict} \quad (1)$$

$$\text{GDP}_{ict} = \beta_1 \text{PM2.5}_{ict} + \beta_2 \text{political turnover}_{ict} + \beta_3 X_{2ct}' + \beta_4 Z_{ict}' + \eta_c + \theta_t + \vartheta_{ict} \quad (2)$$

In equation (1), the dependent variable, $\text{political turnover}_{ict}$, is the political turnover of county official i in county c in year t . The explanatory variables include environmental performance, PM2.5_{ict} , i.e., PM2.5 of county official i in county c in year t , and GDP_{ict} , i.e., GDP per capita of official i in county c in year t . X_{1ct} is a vector of time-varying county characteristics, such as fiscal revenue, total population, infrastructure expenditures, and industrial production. Z_{ict} is a vector of time varying characteristics of local officials, such as gender, education, age, age square, tenure length, and connection. We also control for the average PM2.5 in each city-year. η_c is county fixed effect, capturing all time-invariant differences across counties, and θ_t is year fixed effect, capturing all yearly factors that are common to counties such as macro-level shocks. ε_{ict} is error term.

In equation (2), the dependent variable, GDP_{ict} , is GDP per capita of county official i in county c in year t . The explanatory variables include PM2.5_{ict} , $\text{political turnover}_{ict}$, and control variables at county level, X_{2ct} , which includes a vector of time-varying county characteristics, such as fiscal revenue, total population, infrastructure expenditures, and industrial production. Fiscal expenditures of each county are also included as control variables. We also control for county fixed effect and year fixed effect. ϑ_{ict} is error term.

To identify and estimate the simultaneous equations, note that X_{1ct} and X_{2ct} are different, in equation (2) we control for fiscal expenditures and ventilation coefficient of each county, while in equation (1), we control for the industrial output in each city-year. The empirical results are shown in Column (10) of Table 4 of the main manuscript.

Similarly, we estimate a simultaneous equation model taking both GDP and promotion as endogenous outcomes when we examine the effect of SO2 on political turnovers.

$$\text{political turnover}_{ict} = \alpha_1 \text{SO2}_{ict} + \alpha_2 \text{GDP}_{ict} + \alpha_3 X_{1ct}' + \alpha_4 Z_{ict}' + \eta_c + \theta_t + \varepsilon_{ict} \quad (3)$$

$$\text{GDP}_{ict} = \beta_1 \text{SO2}_{ict} + \beta_2 \text{political turnover}_{ict} + \beta_3 X_{2ct}' + \beta_4 Z_{ict}' + \eta_c + \theta_t + \vartheta_{ict} \quad (4)$$

To identify and estimate the simultaneous equations, X_{1ct} and X_{2ct} are different; in equation (4) we control for ventilation coefficient and fiscal expenditures of each county, together with fiscal revenue, total population, infrastructure expenditures, and industrial production in X_{2ct} . While in equation (3), we also control for industrial output in each city-year besides X_{1ct} and Z_{ict} . The empirical results are shown in Column (10) of Table 5 of the main manuscript.

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