

# Rural-Urban Inequality in Pollution Control in China\*

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## Abstract

Previous literature documents environmental inequality in the US. This study provides evidence of inequality in pollution control within China's regionally-decentralized authoritarian (RDA) system. A major air pollution regulation implemented in 2006 successfully lowered sulfur dioxide emissions, but less so in rural than urban counties, an important dimension of inequality in China. For every one percent reduction required for a prefecture, rural counties experienced a 0.71% lower emissions reduction than urban and a 0.35% higher incidence of illness, with no evidence of increased output or employment. Within the RDA hierarchy, inequality is not reflected in pollution goals set by the central government or sub-goals set by provincial governments, but rather emerges in prefecture-level implementation. Cost-benefit of pollution control, incentive/monitoring problems, and economic-pollution tradeoffs play some role in the goals, but do not explain rural inequality in emissions outcomes.

**Keywords:** Rural-urban divide; Environmental inequality; Local governance; Pollution control; Distributional effect

**JEL Codes:** Q52; H79; Q58; R58; P28

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# 1 Introduction

Previous studies document inequality in environmental outcomes along the dimensions of income, race, and age (Banzhaf, Ma and Timmins, 2019). Given pollution's impact on economic and health outcomes, these disparities play a crucial role in evaluating environmental policies. This work has focused almost exclusively on the US and dimensions of inequality that are important there. In this paper, we examine the equity of environmental outcomes under China's regionally decentralized authoritarian system (RDA) (Xu, 2011a), in which the central government controls personnel and sets policies, but lower levels of government implement them. This is important to determine whether environmental inequality is unique to a federalist system. We explore this within the unique aspects of China's system and focus on an important dimension of inequality in China and other emerging economies.

We provide evidence of rural-urban inequality in pollution control in China. A major air pollution regulation implemented in 2006 reduced rural emissions by less than urban. Inequality between rural and urban regions in China has long been of concern (Benjamin et al., 2008) and is a focus of government policy (State Council, 2010, 2019) because rural counties are disadvantaged relative to urban in economic (Zhao, 1999), health (Meng et al., 2015; Yip, 2010), and education (Park, 2008) outcomes, and the gap is much wider than in other developing countries (Knight, Shi and Song, 2006). These disparities arose, in large part, due to the legacy of China's centrally-planned economy, which controlled prices and directed investment to subsidize industrialization at the expense of rural areas (Park, 2008). Even since China's market reforms began in 1978, this inequality has widened (Park, 2008).<sup>1</sup> The legacy of these differential policies means that a divide between urban and rural regions may extend beyond demographic differences such as age, income, or

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<sup>1</sup>It has persisted primarily because of China's hukou policy, which impedes migration from rural to urban areas as reflected in suboptimal city sizes (Au and Henderson, 2006) and spatial disequilibrium in housing prices (Zheng et al., 2014).

education.

We confirm that the regulation reduced sulfur dioxide (SO<sub>2</sub>) emissions on average across counties in line with its goals; but rural counties experienced lower reductions than urban. This differential change in emissions had tangible effects on health, increasing the incidence of illnesses in rural relative to urban counties. These effects are conditional on a host of demographic controls that proxy for other dimensions of inequality. In this sense, it is analogous to determining the cause rather than the existence of environmental racial inequality in the US (Banzhaf, Ma and Timmins, 2019, p. 190).

We then examine the institutional origin of the regulatory inequality within China's RDA system, which is characterized by centralized political decisions but regionally decentralized administrative and economic decisions. Unlike a federalist system in which they would be elected, lower-level officials are appointed and promoted by the central government, making them accountable to the central government rather than to local constituents that elect them.<sup>2</sup> This provides the central government powerful, but indirect, control over lower-level decisions. This is reflected in the regulation we analyze. The central government set the guidelines for the regulation and issued province-level goals. The provincial governments then set prefecture-level goals, but left implementation of these goals to the prefectures. We find no evidence of rural-urban inequality in either the province- or prefecture-level goals, but the prefecture-level implementation led to disparate outcomes in rural versus urban counties within them.

We cannot say whether the inequality introduced by the policy narrowed or exacerbated pre-existing differences in ambient air pollution concentrations between urban and rural counties. As far as we know, data on SO<sub>2</sub> concentrations at a geographic level specific enough to distinguish counties is not available during the sample period. Urban-county emissions exceeded those in rural before the policy (Lin et al., 2012; Su et al., 2011); however, the effect on concentrations depends on weather and location of emission sources.

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<sup>2</sup>Each level of the government handles personnel decisions for the level just below it, but the central government maintains significant influence at the lower levels by virtue of control cascading downward.

Regardless, the central government's goals did not address pre-existing differences as they imposed more relaxed goals on higher-emissions regions.

Finally, we examine possible explanations for how the rural-urban inequality arose. These include targeting areas with high pre-policy emissions or "dirtier" output, differences in cost-benefits of pollution reduction, monitoring and enforcement costs, a pollution-haven effect, and a multi-tasking incentive problem favoring economic output over emissions reductions. Some of these factors are reflected in province- and prefecture-level goals; however, the goals are orthogonal to ruralness even after controlling for these. Moreover, none of these factors play a significant role in explaining differential effects of the regulation across counties within prefectures, and the residual role of ruralness remains almost the same after controlling for them. This suggests that there are important unobserved factors that affect administration of the regulation at the prefecture level. These could be goals besides environmental and economic performance that are correlated with ruralness or costs not correlated with emissions levels but with ruralness. There may also be deeper political or institutional practices that differ between rural and urban counties within a prefecture.

We focus on the *Eleventh Five-Year Plan for Environmental Protection (Plan)*, implemented in 2006, which required reductions in SO<sub>2</sub> from 2006 to 2010. Under the *Plan*, the central government (the first level of government) set a pollution reduction goal for each province (the second level). Provincial governments then set goals for each prefecture (the third level). Each prefectural government was then responsible for implementing policies to reach these goals across counties (the fourth level) within their prefecture. This provides a rare opportunity to evaluate inequality under China's RDA system because we can observe or estimate the relevant goals and outcomes at all levels. We observe numeric goals set by the top two levels (central and provincial) for the levels just below them, and we observe the actual outcomes at all three levels.

To assess inequality introduced by the central government's province-level goals, we

relate the goals to each province's rural composition. We assess the inequality introduced by the provincial governments' prefecture-level goals similarly, by relating the prefecture-level goals to each prefecture's rural composition. For inequality introduced in implementing the prefecture-level goals, we cannot observe the county-level implementation within prefectures. We instead rely on econometric estimation. We employ difference-in-difference-in-differences (DDD) estimation to identify the causal effect on emissions of implementing the prefecture-level goals in rural versus urban counties within prefectures. This utilizes three dimensions of variation. First, we observe counties before versus after the policy. Second, counties within the same prefecture differed in their classification (rural versus urban), but faced the same prefecture-level goal. Third, counties faced different prefecture-level emissions goals. Subject to identification conditions, the triple difference causally identifies the stringency of goal implementation in rural versus urban counties within the same prefecture.

In aggregate, the *Plan's* goals were met: SO<sub>2</sub> emissions were reduced by the targeted amount on average. However, rural areas experienced substantially lower emissions reductions than urban. For every 1% reduction required for a prefecture, rural counties experienced a 0.71% lower emissions reduction than urban after the policy is implemented. At the same time, the *Plan* led to an increase in reported incidences of illnesses in rural relative to urban counties. For a 1% increase in the stringency of a prefecture-level goal, rural residents were 0.35% more likely than urban to report having been recently sick. Despite the lower emissions reductions and worse health outcomes in rural counties, we present evidence that the *Plan* did not increase output or employment more in rural counties.

We identify the sources of this increased inequality within China's decentralized political system by examining the degree of inequality introduced at each level of political decision-making or implementation. The province-level goals set by the central government are observable, and we do not find evidence of rural-urban inequality in them,

conditioning on province-level demographics. We check robustness to conditioning on demographics for two reasons. First, we provide evidence that the central government considered demographic differences when setting the goals. Second, we wish to control for other dimensions of inequality that rural status may be correlated with, to isolate ruralness as the underlying source of the bias. The prefecture-level goals set by the provincial governments are also observable. They are consistent with the goals set by the central government and we do not find evidence of rural-urban inequality conditioning on prefecture-level demographics.

Finally, the county-level analysis reveals that rural-urban disparities are introduced by prefecture-level governments' implementing the policy across counties. In the DDD estimates, rural-urban inequality is increasing in the prefecture-level goals with an elasticity of 0.71. That is, a more stringent prefecture-level goal led to stricter implementation of pollution control in urban vis-à-vis rural counties within a prefecture. The DD effect (comparing rural to urban counties before versus after the policy) is insignificant after conditioning on the DDD effect, suggesting that most of the inequality introduced is due to the *Plan* rather than other coincident factors.

We verify that the identification requirements for the DDD estimation are met. These include, first, that prefecture-level goals are random with respect to county classification. This is met because rural and urban counties within a prefecture face the same prefecture-level goal, and we include prefecture fixed effects in estimation. Second, the policy does not affect a county's classification as rural or urban. We verify that characteristics of rural and urban counties are balanced once we control for the variables that the government used to classify them as such. We also include these classification variables interacted with a flexible time trend in estimation. Third, we confirm that the pre-policy emissions trends for rural and urban counties are parallel.

The remainder of the paper proceeds as follows. Section 2 summarizes related literature. Section 3 provides background information on the regulation, and Section 4

describes the data. Section 5 presents our empirical strategy including identification, Section 6 summarizes the main empirical results, and Section 7 provides evidence on possible explanations. Section 8 concludes.

## 2 Related Literature

Our paper is related to three areas of literature. First, we provide empirical evidence on the functioning of China's RDA system. There are a few papers providing such empirical evidence. [Han and Kung \(2015\)](#) verify that local governments respond to explicit fiscal incentives set by the central government. [Yang et al. \(2024\)](#) demonstrate the central government's influence over lower levels of government via promotions: an increased emphasis on environmental goals results in lower promotion prospects for officials with worse environmental records. [Luo, Wang and Yang \(2025\)](#) document the decentralized nature of China's policymaking, with local officials playing a crucial role in formulating and implementing policies. We complement these papers by demonstrating quantitatively that local-level implementation can deviate from central-level goals due to the regionally decentralized nature of China's governance system. As [Xu \(2011a\)](#) points out, allowing for such discretion at the lower levels is crucial to the functioning of China's RDA system since it facilitates experimentation.

For the functioning of China's RDA system as it relates to environmental management, [Zheng and Kahn \(2013\)](#) note that China's central government plays a crucial role in environmental quality; but that its goals sometimes conflict with local governments' priorities, consistent with our empirical findings. [Zheng and Kahn \(2013\)](#) also note that local governments may not internalize spillovers, but this does not account for our results since we find that rural counties bear a greater environmental cost than urban counties even though their prefecture-level government is subject to the same goal for both. In an RDA system there is a principal-agent and an information problem that work in oppo-

site directions, similar to that under fiscal federalism (Oates, 1972).<sup>3</sup> Our results suggest that the principal-agent problem predominates: disparity is not specified by the central or provincial governments but rather is introduced in implementation at the local level. Although we cannot completely rule out an information explanation, we control for many observable factors. The information explanation would apply only if there is some unobservable reason at the prefecture, but not national or provincial, level that rural areas should be disadvantaged relative to urban.

Second, it relates to the environmental justice literature (Banzhaf, Ma and Timmins, 2019). While many studies focus on contributing factors, such as location decisions made by households and polluting firms, others explore whether the stringency of government regulations varies between different communities (Viscusi and Hamilton, 1999; Gray and Shadbegian, 2004; Luo et al., 2025). In the US context, research frequently examines disparities related to income, ethnicity, and age (Bento, Freedman and Lang, 2015; Mansur and Sheriff, 2019; Shapiro and Walker, 2021; Timmins and Vissing, 2022; Currie, Voorheis and Walker, 2023; Hernandez-Cortes and Meng, 2023; Colmer et al., 2024; Drupp et al., 2025). We instead provide evidence of inequality along a dimension more relevant to developing economies, and under a different form of government. The paper sheds light on the distributional consequences of environmental regulation by revealing a significant disparity in pollution control between rural and urban areas in China.

The closest papers to this one are the few that examine environmental inequality related to China's rural-urban divide, all of which find that health effects from air pollution are greater in rural than urban areas. As these papers note, rural areas have been understudied due to lack of data. Zhou et al. (2015) finds that severe episodes of fine particulate pollution in China lead to significantly higher mortality in rural than urban areas. Fan, He and Zhou (2020) shows that activation of China's winter heating policy increases air pollution by more in urban than in rural areas but that mortality increases

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<sup>3</sup>As Xu (2011a) describes, China's system differs from a federalist system in more complicated ways than just fiscal responsibility.

more in rural. [He, Liu and Zhou \(2020\)](#) finds that agricultural straw burning in China has greater mortality effects on middle-aged and old people in rural areas relative to other sub-populations. We complement these papers by examining inequality emerging from a regulation and how it arises within China's RDA system.

Third, our paper enriches the literature on rural-urban disparities in China. Most studies focus on how the rural-urban gap contributes to China's income inequality ([Wu and Perloff, 2005](#); [Li, Luo and Sinclair, 2013](#); [Xie and Zhou, 2014](#)) and disparities in health outcomes ([Huang et al., 2013](#); [Han et al., 2023](#)). Our research specifically investigates rural-urban inequality in pollution regulation to understand how government policies in developing economies might lead to such disparities.

From a policy perspective, China has launched many initiatives to reduce pollution. While existing literature provides an understanding of the impact of environmental regulations on economic activity and environmental quality in China ([Hering and Poncet, 2014](#); [Cai et al., 2016](#); [Chen et al., 2018](#); [He, Wang and Zhang, 2020](#); [Liu, Tan and Zhang, 2021](#)), it has paid less attention to its distributional consequences. Our study provides the first analysis that reveals a significant disparity in the regulation of pollutant emissions between rural and urban counties, which is important for formulating equitable pollution outcomes. It also suggests the potential downside of setting a "hard" target at higher levels of government but leaving implementation subjective within an RDA system.

## **3 Institutional background**

### **3.1 China's governmental system and environmental regulation**

The Chinese government operates within a multilevel hierarchical system. Under the central government, there are four tiers of local government: province, prefecture, county, and township. Despite not being a federal state, China grants significant power to local governments, particularly in areas like economic development ([Xu, 2011a](#)). China established a decentralized system for pollution control beginning in 1978. Under this system,

the central government sets environmental goals, while the lower levels of government formulate and implement detailed regulations (Van Rooij and Lo, 2010). Specifically, the central government's Ministry of Ecology and Environment formulates national policies and oversees their enforcement through personnel decisions for local environmental protection bureaus. Local bureaus enforce regulations within their jurisdictions and operate under the control of local governments.

The central government's Five-Year Plans (FYPs) play a crucial role in shaping public policy. In these plans, the central government defines priorities and goals, including for environmental protection, to be achieved within specific timeframes (Karplus, Zhang and Zhao, 2021). During our sample period, the central government's State Environmental Protection Administration<sup>4</sup> and National Development and Reform Commission developed the *Five-Year Plans for Environmental Protection* within the framework of the FYPs. It is widely argued that regulations before 2006 were poorly enforced (Vennemo et al., 2009). To strengthen regulation and improve compliance, the Eleventh FYP (covering 2006 through 2010) introduced environmental protection as a criterion for assessing local leaders' performance. Government leaders' promotions partially depended on their region's environmental quality (Xu, 2011b). This shift has led local governments to place greater importance on environmental outcomes (Wang, 2013).

In the Eleventh FYP, the central government set an SO<sub>2</sub> reduction goal. The central government's *Plan* decomposed the national goal into province-level goals, for which the provincial governments were responsible, but was otherwise purposely vague about implementation, consistent with China's RDA system. The province-level governments, in turn, specified goals for their prefecture-level governments, but left implementation details to them. As a result, prefecture-level governments possessed a high degree of autonomy within their jurisdictions. In contrast to many previous environmental efforts, the *Plan* was largely successful. By the end of the five-year period, SO<sub>2</sub> emissions had

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<sup>4</sup>Renamed Ministry of Environmental Protection in 2008 and then renamed again the Ministry of Ecology and Environment in 2018.

declined by 14.3% in 2010 compared to 2005.<sup>5</sup>

### 3.2 Urban and rural counties

County designations as rural or urban are specified in the National Bureau of Statistics' Administrative Division Code. This code, set out in the *China County Statistical Yearbook*, consists of six digits. The first two digits denote the province, the next two the prefecture, and the last two the county. In 2005, there were 31 provinces, 333 prefectures, and 2,862 counties.<sup>6</sup> The county-level code is divided into three categories: traditional counties ("xiàn" in Chinese), county-level cities ("xiàn jí shì"), and municipal districts that are part of a prefecture-level city ("shì xiá qū").<sup>7</sup> We classify traditional counties as rural and county-level cities and municipal districts as urban, in accordance with the central government's designations.

Significant social and economic differences exist among the three types of counties, particularly in agriculture and "rural development".<sup>8</sup> Municipal districts and county-level cities focus on developing their industrial and tertiary sectors, while traditional counties emphasize agriculture, resulting in higher shares of GDP from, and employment in, agriculture. While both county-level cities and traditional counties can be on the periphery of prefecture-level cities, they differ in population density, GDP, population, and industrial development (Ministry of Civil Affairs, 1993). Importantly, these designations correspond to their administrative treatment in China's political system.

A traditional county can transition to a municipal district or a county-level city if it meets GDP, secondary industry GDP share, non-agricultural population, population density, and fiscal budget revenue criteria (Ministry of Civil Affairs, 1993) (details in Appendix Table A1). China's population has urbanized over time. In 2005, the year

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<sup>5</sup>This average differs from that in Appendix A2 because this is a nationwide average while the appendix is an average of prefecture-level reductions.

<sup>6</sup>Due to administrative restructuring, the number of counties decreased to 2,846 by 2024.

<sup>7</sup>For the last two digits, a value below 20 denotes a municipal district, a value above 80 a county-level city, and a value from 20 to 80 a traditional county.

<sup>8</sup>"Rural development" is a term used in Chinese policy documents that refers to emphasizing development in rural relative to urban regions.

before the *Plan* was implemented, 57% of China's population lived in rural counties. This declined to 50% by 2010, the last year of our sample (National Bureau of Statistics of China, 2010). In our sample period, there were forty transitions from rural into urban counties between 2000 and 2005 (pre-policy) and one transition between 2006 and 2010 (post-policy).<sup>9</sup>

## 4 Data

We employ data at three levels of analysis: province, prefecture, and county.

### 4.1 Province-level data

For the province-level analysis, we require data on emissions goals, actual emissions, and demographics. We compile the emissions goals set by the central government from its official website.<sup>10</sup> The goals specify an emissions-reduction goal – the expected decrease in SO<sub>2</sub> emissions in 2010 relative to 2005 – for each province. Data on actual SO<sub>2</sub> emissions is also from the central government's official website.<sup>11</sup>

To control for demographic factors that may affect the setting of emissions goals, actual emissions reductions, or other dimensions of regulatory inequality besides rural status, we obtain data from the *China Statistical Yearbook*. We include the province's per-capita GDP since emissions may vary with income; value added by the secondary sector as a fraction of GDP since emissions may vary with manufacturing intensity; population density as emissions may scale with population; fiscal revenue as emissions may depend on infrastructure; and number of industrial enterprises above scale<sup>12</sup> as emissions may increase with the number of manufacturing firms. These also control for other potential dimensions of regulatory inequality, such as income levels and degree of industrialization.

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<sup>9</sup>Our data includes seventeen of the pre-policy transitions. The *China County Statistical Yearbook* (CCSY) was more likely to have missing data for counties after a change in status.

<sup>10</sup>See [https://www.gov.cn/gongbao/content/2006/content\\_394866.htm](https://www.gov.cn/gongbao/content/2006/content_394866.htm) (in Chinese).

<sup>11</sup>See [https://www.ndrc.gov.cn/xxgk/zcfb/gg/201106/t20110610\\_960984.html](https://www.ndrc.gov.cn/xxgk/zcfb/gg/201106/t20110610_960984.html) (in Chinese).

<sup>12</sup>The data contain information on all state-owned enterprises, and non-state-owned firms with annual revenues exceeding RMB 5 million.

Appendix Table A2 provides summary statistics. Province-level goals ranged from a reduction of 25.9% to no required reduction, with an average of 9.7%. The mean actual reduction (9.1%) is roughly consistent with the goals being met overall. The average fraction of rural population within provinces is 53% and it varies from 5% to 80%.

## 4.2 Prefecture-level data

For the prefecture-level analysis, we require data on emissions goals, actual emissions, and demographics. We assembled the goals from each province's official documents, which specified the percentage reduction in SO<sub>2</sub> to be achieved by each of their prefectures by 2010 relative to 2005. Since there is no central repository for these documents, we hand-collected them from different websites.<sup>13</sup> For actual SO<sub>2</sub> emissions, we collected data from each prefecture's FYP published after the policy ended in 2010 (their Twelfth FYP).<sup>14</sup> We gathered data on the same demographic variables used in the province-level analysis from the *China City Statistical Yearbook*. Appendix Table A3 provides summary statistics. The average goal and actual emissions reduction is positive due to outliers (e.g., one prefecture has a goal of 900% increase in emissions and an actual increase of 780%).<sup>15</sup> If we remove twelve outliers (with a goal of 150% or more) the averages are -6.9% and -11.3%, respectively, consistent with the goals being more than met. This average goal is somewhat more lax than the average province-level goal, while the average actual reduction is somewhat greater than the average province-level reduction (compare to Appendix Table A2).

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<sup>13</sup>For prefectures in most provinces we relied on <https://www.pkulaw.com> (in Chinese), a database that provides coverage of local regulations in China. For prefectures in other provinces (Jilin, Henan, Hunan, Shaanxi), we used the legal database ([www.law-star.com](http://www.law-star.com)) (in Chinese).

<sup>14</sup>For details of each prefecture's Twelfth FYP, we use its official website. For example, the website of the People's Government of Hangzhou (<https://www.hangzhou.gov.cn>) (in Chinese). For those prefectures that did not publish their Twelfth FYP on their website, we used the legal database ([www.law-star.com](http://www.law-star.com)) (in Chinese).

<sup>15</sup>We do not know why these prefectures have such lax goals but it may be that emissions in the base year were comparatively low or there were pre-existing industrial projects that were grandfathered in.

### 4.3 County-level data

At the county-level, we require data for three separate analyses of the *Plan*: effect on emissions, health, and economic outcomes. For the effect on emissions, we require data on actual emissions and demographics. Unlike at the province and prefecture levels, the government does not provide data on county-level emissions. Instead, we compute county-level SO<sub>2</sub> emissions by combining two sources. The first is the Environmental Survey and Reporting (ESR) program, conducted annually by the Ministry of Ecology and Environment. For each county, the program includes firm pollution sources that together contribute at least 85% of total SO<sub>2</sub> emissions. Since this threshold is applied at the county level and we estimate log specifications, this cutoff should not bias our estimates. The ESR contains a firm’s unique identifier, emissions output, and Administrative Division code for the firm’s location which allows us to aggregate all reported firms to the county level.<sup>16</sup>

The ESR data includes all firms (manufacturing, mining, and power plants) before 2005. However, after 2005 it no longer includes power plants. Since power plants contribute about 50% of total SO<sub>2</sub> emissions in China, we combine the ESR data, excluding power plants, with power plant emissions from the Multi-Resolution Emission Inventory for Climate and Air Pollution (MEIC) data.<sup>17</sup> This inventory lists emissions from all sources in  $0.25^\circ \times 0.25^\circ$  grids, where each grid covers an area of approximately 460 to 740 square kilometers, depending on latitude. As some counties have areas smaller than a single grid, we perform high-precision resampling to refine the spatial resolution to  $0.025^\circ \times 0.025^\circ$ . We then aggregate the power plant emissions for each grid to the county level by assigning each to the county containing its centroid, using a 2005 county-border map of Chinese administrative divisions.

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<sup>16</sup>Previous studies (e.g., He, Xie and Zhang, 2020) aggregate the firm-level ESR data to obtain county-level emissions similarly.

<sup>17</sup>We use version v1.4 of the data. The MEIC data was developed by a Tsinghua University research team and we thank them for providing us the data quickly after receiving our request. See <http://meicmodel.org.cn> for more details about the methodology and how to obtain the data. Many well-cited papers use this data (Zhang et al. (2017) and Li et al. (2019)). In addition to manufacturing, mining, and power plants, this data also includes transportation and residential emissions.

We test robustness to our preferred measure of emissions in two ways: using the ESR data alone excluding power plants and using the MEIC data alone. Although it is comprehensive, we do not use the MEIC data alone for our baseline results because it is derived by allocating more aggregated emissions measures than the ESR data and appears to introduce more measurement error.<sup>18</sup>

For county-level demographics that may affect emissions or that may reflect inequality, we use the *China County Statistical Yearbook* (CCSY), which compiles information on 2,184 counties.<sup>19</sup> The variables are analogous to those for the province- and prefecture-level analysis: per-capita GDP,<sup>20</sup> population density, fiscal revenue, and share of population engaged in non-agricultural industries. We use data from 2000 to 2010 to include both pre- and post-*Plan* periods. We merge the CCSY characteristics with the county-level emissions data using the county administrative division codes. This gives us data on 1,783 counties.<sup>21</sup> About 80% of counties are rural (the top panel of Appendix Table A4 contains summary statistics). The sample is slightly unbalanced because a few counties have missing emissions or CCSY data.

To analyze the *Plan*'s effect on county economic outcomes, data on per-capita GDP and employment comes from the CCSY. We supplement these with data on firm value added and an alternative employment measure from the Annual Surveys of Industrial Firms (ASIF) collected by China's National Bureau of Statistics. The CCSY employment includes industrial and agricultural workers; while the ASIF measure includes only industrial sectors. ASIF provides data on all state-owned firms and all non-state-owned firms with annual sales exceeding RMB 5 million.<sup>22</sup> To analyze the effect of the *Plan* on health

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<sup>18</sup>The MEIC total emissions data deviates from aggregate official statistics by 26% while the ESR supplemented with MEIC power-plant data deviates by only 1.5%.

<sup>19</sup>Some of the 2,862 counties are not included in the CCSY because it does not cover some municipal districts within prefectures.

<sup>20</sup>We supplement missing GDP data with information from the *China Regional Economic Statistical Yearbook*.

<sup>21</sup>We exclude counties from the four centrally-administered municipalities (Beijing, Tianjin, Shanghai, and Chongqing) because they are classified differently than ordinary provinces. The counties within these municipalities are equivalent to prefectures in the administrative hierarchy. The remaining, few missing observations are small, agricultural counties, especially in Tibet, which have no reported SO<sub>2</sub> emissions.

<sup>22</sup>Approximately USD 610 thousand using the average 2005 exchange rate of 8.20.

outcomes, we use data from the China Health and Nutrition Survey (CHNS).<sup>23</sup> The CHNS collects health and demographic information from fifteen provinces using individual-, household-, and community-level questionnaires. We focus on the question: “Did you become ill in the past four weeks?” The survey has a unique identifier for each participant and reports their county of residence. We use an unbalanced panel of county-level data from 2000, 2004, 2006, and 2009 as no surveys were conducted in other years within our sample period. The survey selected at most one county in each prefecture. The bottom panel of Appendix Table A4 contains summary statistics. Fourteen percent of respondents report being sick at least once in the previous four weeks.

## 5 Estimation approach

The primary objective of this study is to examine whether environmental regulation caused rural-urban inequality in pollution control and, if so, at what level or levels of China’s RDA system it was introduced. Disparities may arise from the central government’s setting of goals for provinces, provincial governments’ setting of goals for prefectures, or prefectural governments’ implementation of the prefecture-level goals across counties within their prefectures. The *Plan* provides an ideal setting for assessing whether and how the RDA system affects inequality of a regulatory policy. At the province and prefecture levels, we observe the numerical goals and outcomes, so that they can be directly compared for any bias. In addition, we observe county-level outcomes within prefectures. Since the prefecture-level governments did not necessarily set county-specific goals, and regardless did not publish them, we rely on DDD estimation to determine whether the prefecture-level governments introduced inequality in the county-level implementation.

We model the policy’s effect on emissions at the three different levels of China’s RDA system. First, the central government sets goals for each province to meet by 2010. Given these goals, each provincial government sets goals for their prefectures to meet by 2010.

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<sup>23</sup>This is administered by the University of North Carolina at Chapel Hill, the National Institute of Nutrition and Food Safety, and the Chinese Center for Disease Control and Prevention.

Finally, given these goals, prefectural governments implement the policies, from 2006 to 2010, in each county within their prefecture. Implementation happens only within prefectures; above this, only goals are set. We now discuss the model and estimation.

## 5.1 A model of county-level emissions

We first model county-level emissions and how these depend on implementation within prefectures and on goals set at higher levels. We then describe the estimation of the *Plan's* effects at the province, prefecture, and county level respectively. We assume log SO<sub>2</sub> emissions ( $E_{ct}$ ) in year  $t = 1, \dots, T$  in county  $c = 1, \dots, C$  contained in prefecture  $p = 1, \dots, P$  and province  $v = 1, \dots, V$  are given by:<sup>24</sup>

$$\log(E_{ct}) = \alpha_c + \alpha_{pt} + D_t \left[ \beta_1^R R_{ct} + \left( \beta_2 + \beta_2^R R_{ct} \right) G_v \mathcal{I}_{c \in v} + \beta_3^R R_{ct} G_p \mathcal{I}_{c \in p} \right] + \alpha_p R_{ct} + \gamma X_{ct} + \epsilon_{ct}, \quad (1)$$

where  $\alpha_c$  are county fixed effects that capture county-specific, time-persistent factors affecting emissions and  $\alpha_{pt}$  are prefecture-by-year fixed effects that capture annual, unobserved shocks to emissions common to all counties in a prefecture.  $D_t$  equals one when the *Plan* is in effect (2006 to 2010) and zero before.  $R_{ct}$  equals one if county  $c$  is a rural county in year  $t$  and zero otherwise.  $G_v$  is the goal set by the central government for province  $v$  and  $G_p$  is the goal set by the provincial government for prefecture  $p$ .  $\mathcal{I}_{c \in v}$  is set equal to one if county  $c$  is in province  $v$  and zero otherwise, and  $\mathcal{I}_{c \in p}$  is set to one if county  $c$  is in prefecture  $p$  and zero otherwise.  $\alpha_p$  is a prefecture fixed effect so that the term  $\alpha_p R_{ct}$  are prefecture-by-rural fixed effects that control for unobserved differences between urban and rural counties within each prefecture.<sup>25</sup>  $X_{ct}$  includes characteristics of county  $c$  in year  $t$  including various fixed effects.  $\epsilon_{ct}$  are county-year unobservables affecting emissions.

<sup>24</sup> $D_t G_p \mathcal{I}_{c \in p}$  cannot be included because it is collinear with  $\alpha_{pt}$ .

<sup>25</sup>Few counties change rural versus urban status over time so that this is very similar to  $\alpha_p R_c$ .

Assuming the identification conditions are met,  $\beta_1^R$  captures the baseline change in emissions for rural versus urban counties, once the *Plan* takes effect. This is a control variable since other factors besides the *Plan* could affect rural versus urban emissions and coincide with its implementation. However, it is useful for detecting whether inequality increases with the advent of the *Plan* due to other coincident factors or due to the *Plan* but in ways not correlated with its goals.  $\beta_2$  captures the baseline effect of province-level goals on county-level emissions once the *Plan* takes effect, while  $\beta_2^R$  captures their differential effect on rural relative to urban counties once the *Plan* takes effect (inequality introduced by the central government's goals).  $\beta_3^R$  captures the differential effect of the prefecture-level goals on rural versus urban counties once the *Plan* takes effect (inequality introduced by the provinces' goals).

## 5.2 Province-level goals and rural inequality

If time-series variation in the province-level goals were available, we could aggregate Equation (1) (weighted by fraction of county population ( $w_c$ )) to the province-year level to identify the baseline effect of the province-level goal on province-level emissions ( $\beta_2$ ) and the differential effect on rural relative to urban counties within provinces ( $\beta_2^R$ ):<sup>26</sup>

$$\bar{E}_{vt} = \alpha_{vt} + D_t \left[ \beta_1^R \bar{R}_{vt} + \left( \beta_2 + \beta_2^R \bar{R}_{vt} \right) G_v \right] + \gamma_v \bar{X}_{vt} + \epsilon_{vt}, \quad (2)$$

where  $\bar{E}_{vt} = \sum_c w_c \log(E_{ct}) \mathcal{I}_{c \in v}$  is population-weighted log emissions for province  $v$  in year  $t$ . We define  $w_c$  as a county's fraction of total population measured at the midpoint of the sample period.  $\alpha_{vt}$  is a province-by-year fixed effect,  $\bar{R}_{vt} = \sum_c w_c R_{ct} \mathcal{I}_{c \in v}$  is the share of rural population in province  $v$  in year  $t$ ,  $\bar{X}_{vt} = \sum_c w_c X_{ct} \mathcal{I}_{c \in v}$  is the average demographics of province  $v$  in year  $t$ , and  $\epsilon_{vt}$  are unobserved factors affecting emissions at the province level in year  $t$ .

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<sup>26</sup>For the other terms from Equation (1),  $\alpha_c$  aggregates to  $\alpha_v$  which is collinear with  $\alpha_{vt}$ ,  $\alpha_{pt}$  aggregates to  $\alpha_{vt}$ ,  $D_t R_{ct} G_p \mathcal{I}_{c \in p}$  aggregates to  $D_t \bar{R}_{vt} \alpha_v$  which is subsumed by  $D_t \bar{R}_{vt} G_v$ , and  $\alpha_p R_{ct}$  aggregates to  $\alpha_v \bar{R}_{vt}$  which is subsumed by  $\alpha_{vt}$ .

Since there is no time-series variation in the province-level goals, their effect can only be identified in cross-section.<sup>27</sup> We estimate whether the goals themselves reflect inequality between rural and urban counties:

$$G_v = \alpha + \beta_{2v}^R \bar{R}_v + \gamma_v \bar{X}_v + \epsilon_v. \quad (3)$$

where  $\alpha$  is an intercept,  $\bar{R}_v = \frac{1}{T} \sum_t \bar{R}_{vt}$  is the average fraction of rural population in province  $v$  across all years, and  $\bar{X}_v = \frac{1}{T} \sum_t \bar{X}_{vt}$  is the average demographics in province  $v$  across all years.  $\beta_{2v}^R$  is the key coefficient of interest and captures differences in the goals applied to provinces with different mixes of rural versus urban population, controlling for province-level demographics. This captures the inequality induced by the central government's goals conditional on their being met (we provide evidence in Section 6.1 that they were).  $\epsilon_v$  captures unobserved province-level factors affecting the goals. We allow for heteroskedasticity in  $\epsilon_v$ , since provinces with larger goals may exhibit larger measurement error. Our baseline estimates use a weighted regression with weights equal to province  $v$ 's population as a fraction of total population. We also test robustness to using equal weights.

### 5.3 Prefecture-level goals and rural inequality

If time-series variation in the prefecture-level goals were available, we could aggregate Equation (1), weighted by fraction of county population, to the prefecture level to identify the differential effect of the prefecture-level goals on rural relative to urban counties within prefectures ( $\beta_3^R$ ):<sup>28</sup>

$$\bar{E}_{pt} = \alpha_{pt} + D_t \left[ \beta_1^R \bar{R}_{pt} + \left( \beta_2 + \beta_2^R \bar{R}_{pt} \right) G_v \mathcal{I}_{p \in v} + \beta_3^R \bar{R}_{pt} G_p \right] + \gamma_p \bar{X}_{pt} + \epsilon_{pt}, \quad (4)$$

<sup>27</sup>We cannot combine this or the prefecture-level estimation with the DDD estimation of county-level effects because the latter requires including county fixed effects which would be collinear with both the province- and prefecture-level goals.

<sup>28</sup>For the other terms from Equation (1),  $\alpha_c$  aggregates to  $\alpha_p$  which is collinear with  $\alpha_{pt}$  and  $\alpha_p R_{ct}$  aggregates to  $\alpha_p \bar{R}_{pt}$  which is subsumed by  $\alpha_{pt}$ .

where  $\bar{E}_{pt} = \sum_c w_c \log(E_{ct}) \mathcal{I}_{c \in p}$  is population-weighted log emissions for prefecture  $p$  in year  $t$ ,  $\bar{R}_{pt} = \sum_c w_c R_{ct} \mathcal{I}_{c \in p}$  is the share of rural population in prefecture  $p$  in year  $t$ , and  $\bar{X}_{pt} = \sum_c w_c X_{ct} \mathcal{I}_{c \in p}$  is the average demographics of prefecture  $p$  in year  $t$ .  $\mathcal{I}_{p \in v}$  is an indicator set to one if prefecture  $p$  is in province  $v$  and zero otherwise.  $\epsilon_{pt}$  are unobserved factors affecting emissions at the prefecture level in year  $t$ .

Since there is no time-series variation in the prefecture-level goals, their effect can be identified only in cross-section. We estimate whether the goals themselves reflect inequality between urban and rural counties:

$$G_p = \alpha + \left( \beta_{2p}^R G_v \mathcal{I}_{p \in v} + \beta_{3p}^R \right) \bar{R}_p + \gamma_p \bar{X}_p + \epsilon_p, \quad (5)$$

where  $\alpha$  is an intercept,  $\bar{R}_p = \frac{1}{T} \sum_t \bar{R}_{pt}$  is the average fraction of rural population in prefecture  $p$  across all years, and  $\bar{X}_p = \frac{1}{T} \sum_t \bar{X}_{pt}$  is the average demographics in prefecture  $p$  across all years.  $\epsilon_p$  captures unobserved prefecture-level factors affecting the goals.  $\beta_{2p}^R$  controls for the effect of the province-level goal since the prefecture-level goals must conform to it.  $\beta_{3p}^R$  is the key coefficient of interest and captures differences in prefecture-level goals applied to prefectures with different mixes of rural and urban counties, controlling for prefecture-level characteristics and province-level goal, and conditional on the goals being met (we provide evidence in Section 6.1 that they were). We allow for heteroskedasticity in  $\epsilon_p$ , since prefectures with larger goals may exhibit larger measurement error. Our baseline estimates use a weighted regression with weights equal to the prefecture  $p$ 's population as a fraction of total population. We also test robustness to using equal weights.

## 5.4 County-level implementation and rural inequality

To assess inequality introduced during implementation of the prefecture-level goals, we take advantage of the variation in rural-urban composition of counties, variation in timing of the *Plan*'s implementation, and variation in goals across prefectures to estimate a DDD

model at the county level. This is Equation (1) except that we omit  $D_t (\beta_2 + \beta_2^R R_{ct}) G_v \mathcal{I}_{c \in v}$  because the province-level goals are highly collinear with the prefecture-level goals:

$$\log(E_{ct}) = \alpha_c + \alpha_{pt} + D_t [\beta_1^R R_{ct} + \beta_3^R R_{ct} G_p \mathcal{I}_{c \in p}] + \alpha_p R_{ct} + \gamma X_{ct} + \epsilon_{ct}. \quad (6)$$

$\beta_1^R$  captures the baseline changes in emissions in rural versus urban counties that are coincident with the timing of the policy implementation and is identified from a double difference: before versus after the *Plan* and rural versus urban. This is a control variable, as the effects it captures are not necessarily all due to the policy. It captures any differential change in emissions for rural versus urban counties that coincides with the policy but is uncorrelated with the prefecture-level goals.  $\beta_3^R$  captures the differential impact of these goals on emissions based on counties' designations as rural. It reflects the amplification or diminution of the prefecture-level goals for rural versus urban counties when they are implemented across a prefecture's counties. This is the primary coefficient of interest and is identified from a triple difference: rural versus urban, before versus after the *Plan*, and differences in prefecture-level goals.

There is variation to identify  $\beta_3^R$  separately from  $\beta_1^R$ : changes in emissions with the policy for rural versus urban counties that face the same prefecture-level goal. The inclusion of  $\alpha_{pt}$  means that  $\beta_1^R$  and  $\beta_3^R$  are identified from variation within a prefecture-year. It is important to note the difference between  $\beta_3^R$  estimated here and the  $\beta_{3p}^R$  estimated in Equation (5). The latter captures inequality introduced by the prefecture-level goals themselves, while the former captures inequality introduced in their implementation.

We also estimate an alternative, more demanding version of Equation (6) in which we replace  $D_t R_{ct}$  with rural-by-year fixed effects ( $\alpha_t R_{ct}$ ):

$$\log(E_{ct}) = \alpha_c + \alpha_{pt} + \beta_3^R D_t R_{ct} G_p \mathcal{I}_{c \in p} + \alpha_p R_{ct} + \alpha_t R_{ct} + \gamma X_{ct} + \epsilon_{ct}. \quad (7)$$

This specification controls for unobserved factors that affect emissions in rural versus

urban counties year-by-year rather than just pre- versus post-policy.

## 5.5 Identification of county-level effects

Although we include various fixed effects in the baseline models (Equations (6) and (7)), a potential identification concern is that the change of regulatory stringency post-policy is influenced by decisions that local governments made before the *Plan's* implementation. More generally, the policy's causal effect on rural-urban inequality can only be correctly identified if rural and urban counties' emissions exhibit similar trends before the regulation. To verify this parallel trends assumption, we estimate a year-by-year event-study model by replacing  $D_t\beta_1^R$  with yearly coefficients  $\beta_{1t}^R$  and  $D_t\beta_3^R$  with yearly coefficients  $\beta_{3t}^R$  in Equation (6), with 2005 as the reference year:

$$\log(E_{ct}) = \alpha_c + \alpha_{pt} + \beta_{1t}^R R_{ct} + \beta_{3t}^R R_{ct} G_p \mathcal{I}_{c \in p} + \alpha_p R_{ct} + \gamma X_{ct} + \epsilon_{ct}. \quad (8)$$

$\beta_{1t}^R$  measures baseline rural-urban differences in emissions in year  $t$  and  $\beta_{3t}^R$  measures rural-urban inequality in emissions in year  $t$  as it relates to implementation of the prefecture-level goals. We interact the demographics with  $\alpha_t$  (a year fixed effect) and include them in  $X_{ct}$  to control most flexibly for time-varying demographic changes between urban and rural counties. We confirm the results of this estimation when we present our main results, so that we can directly relate the two.

A second identification requirement for the benchmark models to identify the *Plan's* causal effect is that there are no confounding factors that generate a difference in the post-policy trends of emissions in rural versus urban counties. A potential threat to this assumption is that the rural-urban classification is not random, so that the post-2005 outcomes have been caused by inherent differences between rural and urban counties. To address this concern, we follow an approach in [Gentzkow \(2006\)](#) and [Li, Lu and Wang \(2016\)](#) and include the key determinants of the rural-urban classification flexibly in estimation. To identify the classification variables, we rely on government documents

specifying the criteria for “incorporating counties into districts” and “incorporating counties into cities” as described in Appendix Table A1. The variables include per-capita GDP, secondary-industry GDP share, population density, and fiscal revenues.

To verify whether controlling for classification variables could lead to a better balance between urban and rural counties, Appendix Table A5 provides balance statistics. After controlling for the classification variables, there are no statistically significant differences between urban and rural counties. This supports the validity of the classification variables and demonstrates that controlling for them balances the urban and rural counties in the sample. We therefore include these classification variables, interacted with a flexible function of time  $f(t)$ , in  $X_{ct}$  in Equations (6) and (7). In our estimation, we use three different functional forms for  $f(t)$ : a linear time trend, a polynomial expansion of  $t$ , and year-by-year dummies.

## 6 Results

### 6.1 Were the goals consistent and met?

Before conducting our main analysis, we check whether the prefecture-level goals are consistent with the province-level goals and whether they were met on average. At the same time, we determine which control variables to include in estimation by assessing what information the central government appears to have considered in setting the goals. We then confirm that we should use the fraction of rural population rather than the fraction of rural counties in measuring ruralness for the province- and prefecture-level analysis.

Appendix Table A2 shows that the province-level goals were roughly met on average. To determine whether the province-level goals were met province-by-province, we regress the change in province-level emissions on the province-level goals. The dependent variable is 2010 relative to 2005 emissions normalized by 2005 emissions  $\left(\frac{E_{v,2010}-E_{v,2005}}{E_{v,2005}}\right)$  and the independent variable is defined analogously  $\left(\frac{G_{v,2010}-E_{v,2005}}{E_{v,2005}}\right)$ . A coefficient of one would indicate that the goals were met uniformly. If it is less than one, this would indicate

reversion to the mean in actual emissions relative to goals; while if it is greater than one this would indicate that actual emissions are amplified relative to goals. Panel A of Table 1 shows the results. The columns use different control variables that correspond to different information sets that regulators may have used in setting the goals. Column 1 has no controls. This would correspond to the regulators ignoring all demographic information when setting goals. Column 2 controls for demographics in 2005 (the year before the *Plan* started). The variables include per-capita GDP, secondary-industry GDP share, population density, fiscal revenue, and number of above-scale industrial enterprises. This would correspond to regulators using the latest demographic information available at the time the goals were set. Column 3 uses the difference between 2005 demographics and their averages in the prior ten years (1995 to 2005). This would correspond to regulators using forecasted changes in long-run average demographics when setting the goals. The coefficients reveal an amplification of the goals by 1.3 to 2.3 times.

Panel B reveals that removing the five provinces with zero goals (did not have to actively reduce from prevailing levels), yields very similar estimates regardless of controls. Based on the  $R^2$ s, the “2005 controls” model outperforms the “historical controls” model and an F-test reveals that the “2005 controls” model is preferred over the “no controls” model.<sup>29</sup> In this preferred model, the emissions are reduced roughly one-for-one with the goals and 93% of variance is explained consistent with actual reductions in line with goals.<sup>30</sup> Overall, these results indicate that the province-level goals were met fairly uniformly across provinces and that the central government likely used 2005 demographic information in setting them.

For prefectures, Panel C shows that actual outcomes were narrowed relative to

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<sup>29</sup>The  $F$ -statistic is 3.65 which is significant at the 1.6% level.

<sup>30</sup>We also estimated the six regressions in Panels A and B controlling for region fixed effects to account for spillovers among provinces. The results, available upon request, are very similar. The six regions and their provinces are: Northeast (Liaoning, Jilin, Heilongjiang), North (Beijing, Tianjin, Hebei, Shanxi, Inner Mongolia), East (Shanghai, Jiangsu, Zhejiang, Anhui, Fujian, Jiangxi, Shandong), Central South (Henan, Hubei, Hunan, Guangdong, Guangxi, Hainan), Southwest (Chongqing, Sichuan, Yunnan, Tibet), and Northwest (Shaanxi, Gansu, Qinghai, Ningxia, Xinjiang).

**Table 1:** Relationship between actual emissions reductions and goals for provinces and prefectures under the *Plan*

	Dependent variable: <i>Realization</i>		
	No controls	2005 controls	Historical controls
	(1)	(2)	(3)
<b>Panel A. Province level, all provinces</b>			
<i>Goal</i>	2.001*** (0.354)	1.281*** (0.352)	2.288*** (0.572)
Observations	31	31	31
$R^2$	[0.690]	[0.831]	[0.711]
<b>Panel B. Province level, remove zero goals</b>			
<i>Goal</i>	1.311*** (0.166)	1.111*** (0.129)	1.280*** (0.195)
Observations	26	26	26
$R^2$	[0.853]	[0.925]	[0.903]
<b>Panel C. Prefecture level, all prefectures</b>			
<i>Goal</i>	0.504** (0.203)	0.491** (0.207)	0.492** (0.220)
Province FE	Y	Y	Y
Observations	273	271	271
$R^2$	[0.620]	[0.636]	[0.633]
<b>Panel D. Prefecture level, remove outliers</b>			
<i>Goal</i>	0.978*** (0.142)	0.965*** (0.146)	0.947*** (0.153)
Province FE	Y	Y	Y
Observations	261	260	260
$R^2$	[0.690]	[0.702]	[0.699]
2005 controls		Y	
Historical controls			Y

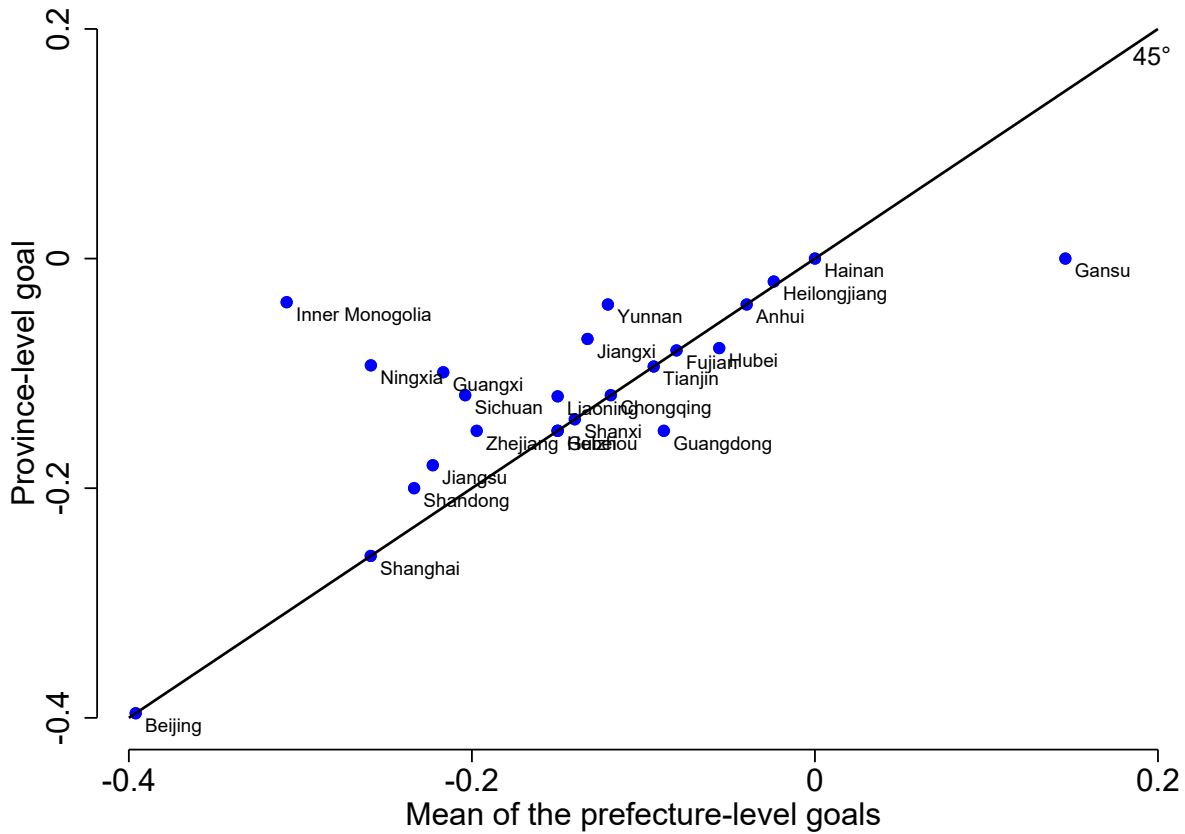
*Notes:* 1. *Realization* is 2010 minus 2005 province- (Panels A and B) and prefecture-level (Panels C and D) emissions divided by 2005 emissions. *Goal* defined same but replacing 2010 emissions with 2010 province- (Panels A and B) and prefecture-level (Panels C and D) goals. In Panel D, we limit the sample to those prefectures with *Goal* smaller than 150%. 2. Column (1) includes no controls, Column (2) 2005 characteristics, and Column (3) deviations of 2005 characteristics from their averages over preceding ten years. Characteristics (described in text) at province (Panels A and B) and prefecture (Panels C and D) level. 3. Robust standard errors in parentheses. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

goals by roughly 0.5, regardless of the demographic controls. These regressions include province-level fixed effects because all prefectures face the same province-level goal, although the results are virtually identical if these are not included<sup>31</sup>. Panel D excludes the twelve prefectures with extremely lax goals (allowed to increase by more than 150% ( $Goal > 1.5$ )) and the estimates are close to one. This implies that the narrowing of outcomes relative to goals in Panel C is due to the prefectures with very lax goals not increasing their emissions commensurately (i.e., the goals were not binding). The “2005 controls” model outperforms the “historical controls” model. Although not directly comparable because they are not nested, performing an *F*-test assuming both models had 260 observations reveals that the “2005 controls” model is preferred to the “no controls” model at the 7.3% level. Overall, these results indicate that the prefecture-level goals were met on average and provide weak evidence that the province-level regulators considered contemporaneous demographic information in setting the goals. The prefecture-level goals are also broadly consistent with the province-level goals as shown in Figure 1, which plots the average of the prefecture-level goals in each province (weighted by pre-policy emissions) against the province-level goal.

To determine the appropriate measure of a province’s or prefecture’s ruralness, we estimate the relationship between emissions and population. Appendix Table A6 shows results from regressing log county emissions on log county population using different combinations of fixed effects. Regardless of fixed effects, the elasticity of emissions with respect to population is close to one, suggesting that the measure should be based on the fraction of rural population rather than the fraction of rural counties. We use 2005 population (midpoint of the sample), since it changes very little over the sample period.

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<sup>31</sup>These results are available upon request.



**Figure 1:** Province-level versus prefecture-level goals

*Notes:* Each dot is the mean of the prefecture-level goals (weighted by pre-policy emissions) for the province on the x-axis plotted against its province-level emissions goal set by the central government on the y-axis. These are plotted relative to the 45° line. A regression of province-level goal and prefecture-level yields a coefficient of 0.56 with a standard error of 0.18. Excluding the three biggest outliers the coefficient is 0.86 with a standard error of 0.11.

## 6.2 Is there a rural bias?

Since the prefecture- and province-level goals are consistent and were met on average, we now see whether there is any rural bias vis-a-vis the prefecture-level goals.<sup>32</sup> Columns (1) to (3) of Table 2 show the results of regressing log county emissions on the policy variable interacted with the prefecture-level goal  $\left(\frac{G_{p,2010}-E_{p,2005}}{E_{p,2005}}\right)$  faced in each county (a DD model) controlling for county fixed effects, year fixed effects, and the demographic

<sup>32</sup>An analogous regression using the province-level goals yields similar magnitudes although they are not significant given the more limited variation.

variables interacted with year dummies. The coefficient on this variable captures the *Plan's* causal effect on emissions. The first column shows that the prefecture-level goals decrease county-level emissions with an elasticity of 0.30. Columns (2) and (3) show the effects separately for rural and urban counties and reflect a larger decline in emissions in urban than rural counties. Column (4) of the table estimates a DDD model by adding an interaction of the policy variable with the prefecture-level goal and a rural county indicator. On average, rural counties experienced a lower decline in emissions than urban with an elasticity of -0.73 evaluated at the mean goal.<sup>33</sup> We now investigate why this bias emerged.

**Table 2:** Effect of *Plan's* prefecture-level goals on county-level emissions

	Dependent variable: $\text{Log}(\text{emissions})$			
	All	Rural	Urban	All
	(1)	(2)	(3)	(4)
$\text{Goal} \times \text{Post}$	0.302*	0.201*	0.926**	0.922**
	(0.156)	(0.122)	(0.416)	(0.399)
$\text{Goal} \times \text{Rural} \times \text{Post}$				-0.730**
				(0.364)
X × Year dummy	Y	Y	Y	Y
Year FE	Y	Y	Y	
County FE	Y	Y	Y	Y
Rural × Year FE				Y
Rural × Goal				Y
Observations	18,799	14,937	3,859	18,799

*Notes:* 1. Effect of prefecture-level goals on county emissions from estimating DD models in Columns (1) to (3) and DDD model in Column (4). 2. *Goal* defined as 2010 prefecture-level goal minus 2005 emissions normalized by 2005 emissions. Column (1) uses the full sample, Column (2) the rural subsample, and Column (3) the urban subsample. Rural and urban subsamples do not add up to the full sample because we omit three rural counties that switched to urban during the sample period. 3. Standard errors clustered at prefecture level reported in parentheses. Significance: \*\*\*  $p < 0.01$  \*\*  $p < 0.05$ ; \*  $p < 0.10$ .

<sup>33</sup>Using the ESR data excluding power plants, the regression in Column (4) yields a coefficient of -0.542 and a standard error of 0.308 significant at the 7.8% level for the  $\text{Goal} \times \text{Rural} \times \text{Post}$  variable. Using the total emissions reported in the MEIC data yields a coefficient of -0.328 and a standard error of 0.119 significant at the 0.6% level.

### 6.3 Rural bias in province-level goals?

Column (1) of Table 3 examines whether the province-level goals reflect a rural bias by estimating Equation (3). The province-level goal  $\left(\frac{G_{v,2010}-E_{v,2005}}{E_{v,2005}}\right)$  is the dependent variable and fraction of rural population (as established in Section 6.1) is the independent variable. The regression controls for 2005 province-level demographics that regulators appear to have considered in setting the goals (see Section 6.1). These are also included to control for other potential dimensions of inequality. The results show no significant bias in the central government’s goals.

**Table 3:** Relationship between province ruralness and the *Plan’s* province-level goals and outcomes

	Dependent variable:	
	<i>Goal</i>	<i>Realization</i>
	(1)	(2)
<i>Fraction_rural_population</i>	0.095 (0.096)	0.430** (0.177)
X	Y	Y
Observations	31	31

*Notes:* 1. *Goal* is 2010 province-level goal minus 2005 emissions normalized by 2005 emissions and *Realization* is 2010 minus 2005 emissions divided by 2005 emissions. 2. All columns control for 2005 province-level characteristics (per-capita GDP, secondary-industry GDP share, population density, fiscal revenue, and number of above-scale industrial enterprises). 3. Robust standard errors in parentheses. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

Despite the lack of bias in the goals, Column (2) shows that by the end of the five-year period, provinces with more rural populations experienced lower emissions reductions, controlling for province demographics, with an elasticity of 0.43. A one standard deviation increase in province ruralness is associated with 9.1% higher emissions. In the next subsection, we investigate whether the prefecture-level goals set by the provinces introduced this inequality.

## 6.4 Rural bias in prefecture-level goals?

Columns (1) and (2) of Table 4 examine whether the prefecture-level goals reflect a rural bias by estimating Equation (5). The prefecture-level goal  $\left(\frac{G_{p,2010}-E_{p,2005}}{E_{p,2005}}\right)$  is the dependent variable and fraction of rural population (as established in Section 6.1) is the independent variable. Both columns include 2005 prefecture-level demographics to control for characteristics that regulators appear to have considered in setting the goals (see Section 6.1) and to control for other potential dimensions of inequality. Column (1) controls for the province-level goals. Its coefficient is close to one, reflecting that the prefecture-level goals are consistent with them. The coefficient on fraction rural population is small and insignificant. Column (2) replaces the province-level goal with province fixed effects. The point estimate is close to zero and insignificant.

These results show that there is no rural bias in goals set by the province-level governments; however, by the end of the five-year period, more rural prefectures experienced lower emissions reductions. Column (3) shows that, controlling for prefecture demographics and the province-level goal, ruralness leads to lower reductions with an elasticity of 0.20. Column (4) replaces the province-level goal with province fixed effects. The results are similar. A one standard deviation increase in prefecture ruralness is associated with 4.9% higher emissions evaluated at the mean goal. Even though prefecture-level goals exhibited no bias, the actual emissions reductions do so.<sup>34</sup>

The analyses of province- and prefecture-level goal setting imply that the urban-rural inequality in emission reductions arose during the implementation of the policy within prefectures. In the next subsection, we provide causal evidence to confirm this.

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<sup>34</sup>The results in Table 4 exclude prefectures with very lax goals ( $Goal > 1.5$ ). The results are qualitatively similar if these are included, although the standard errors are larger. The coefficients and standard errors for fraction rural population corresponding to the four columns are: 0.299 (0.280), 0.373 (0.354), 0.439\*\* (0.176), and 0.450\*\* (0.202). This would imply more stringent, but statistically insignificant, goals for rural counties and an even greater reduction in actual emissions.

**Table 4:** Relationship between prefecture ruralness and the *Plan's* prefecture-level goals and outcomes

	Dependent variable:			
	<i>Goal</i>		<i>Realization</i>	
	(1)	(2)	(3)	(4)
<i>Fraction_rural_population</i>	-0.003 (0.080)	-0.000 (0.105)	0.200** (0.090)	0.190* (0.114)
<i>Province_goal</i>	0.976* (0.519)		1.142* (0.651)	
X	Y	Y	Y	Y
Province FE		Y		Y
Observations	260	260	260	260

*Notes:* 1. *Goal* is 2010 prefecture-level goal minus 2005 emissions normalized by 2005 emissions and *Realization* is 2010 minus 2005 emissions divided by 2005 emissions. 2. All columns control for 2005 prefecture-level characteristics (per-capita GDP, secondary-industry GDP share, population density, fiscal revenue, and number of above-scale industrial enterprises). 3. Columns (2) and (4) also control for province fixed effects. 4. Robust standard errors in parentheses. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

## 6.5 Rural bias in county-level implementation

Table 5 presents results from various specifications of the DDD models. We set the county demographics in  $X_{ct}$  based on 2005 data given the evidence that regulators used contemporaneous information (see Section 6.1). The  $X_{ct}$  variable is still time-varying because time-dependent fixed effects and interactions of characteristics with time trends are included. All specifications include county fixed effects to control for time-invariant factors affecting emissions.

Panel A shows estimates of Equation (6), which controls for prefecture-by-year and prefecture-by-rural fixed effects so that the variation is within prefecture-year and unobservable factors affecting emissions unique to rural versus urban counties within a prefecture are controlled for. The triple interaction of policy-rural-goal shows that more stringent goals imposed on a prefecture results in greater emissions reductions for urban compared to rural counties within a prefecture. This is the case regardless of whether

**Table 5:** Effect of *Plan* implementation within prefectures on county-level emissions inequality

	Dependent variable: $\text{Log}(\text{emissions})$		
	(1)	(2)	(3)
<b>Panel A: DDD model I</b>			
<i>Rural</i> × <i>Post</i>	-0.104 (0.067)	-0.104 (0.070)	-0.111 (0.074)
<i>Goal</i> × <i>Rural</i> × <i>Post</i>	-0.706** (0.284)	-0.709** (0.285)	-0.709** (0.285)
<b>Panel B: DDD model II</b>			
<i>Goal</i> × <i>Rural</i> × <i>Post</i>	-0.708** (0.283)	-0.711** (0.285)	-0.711** (0.286)
Rural × Year FE	Y	Y	Y
X × T	Y		
X × (T, T <sup>2</sup> , T <sup>3</sup> )		Y	
X × Year dummy			Y
Prefecture × Year FE	Y	Y	Y
Prefecture × Rural FE	Y	Y	Y
County FE	Y	Y	Y
Observations	18,799	18,799	18,799

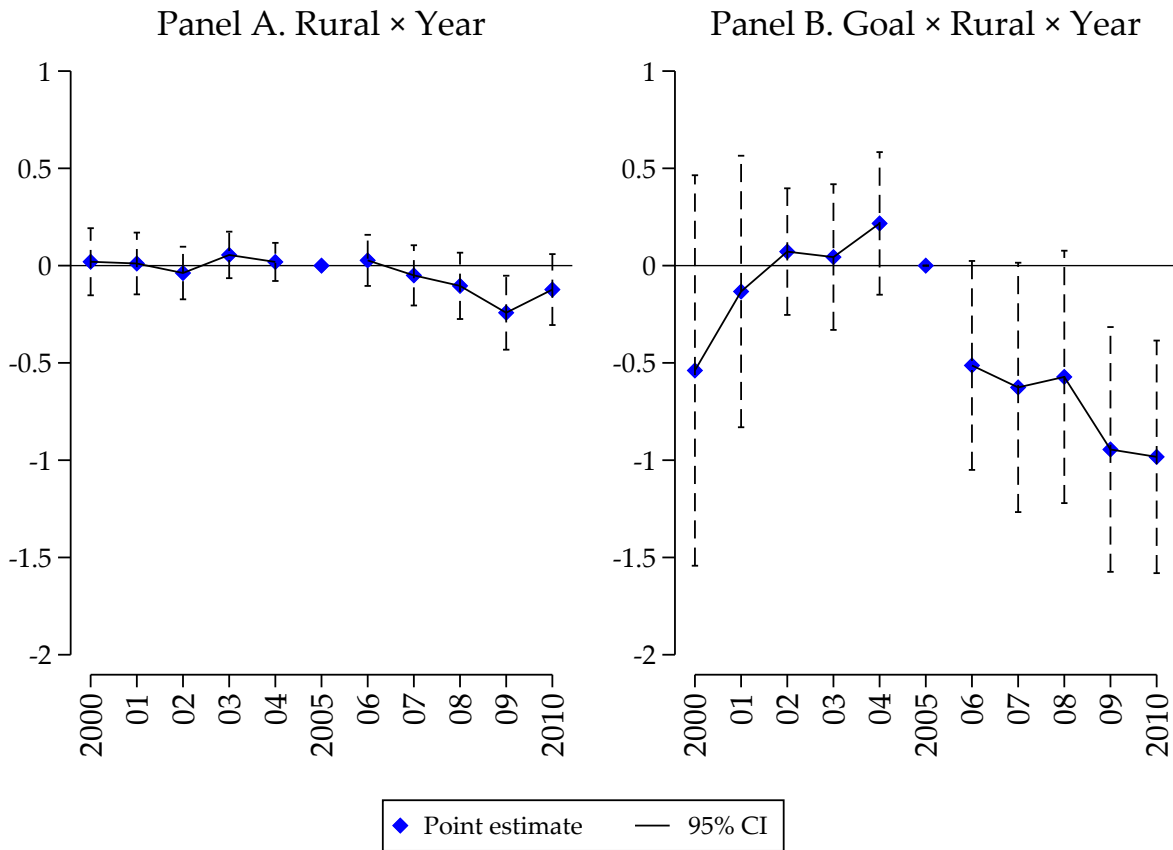
*Notes:* 1. This table shows estimates of Equation (6) in Panel A and Equation (7) in Panel B with different control variables specified at the bottom of the table. 2. The outcome variable is annual county-level log SO<sub>2</sub> emissions. 3. *Goal* is 2010 prefecture-level goal minus 2005 emissions normalized by 2005 emissions. 4. “X” includes log per-capita GDP, secondary industry GDP share, share of population engaged in non-agricultural industries, log population per square kilometer, and log fiscal revenue. 5. Robust standard errors in parentheses clustered at the prefecture level. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

variables that are used to classify counties as rural or urban are interacted with a linear time trend (Column (1)), a polynomial expansion of the time trend (Column (2)), or year dummies (Column (3)). Column (3) is our preferred specification because it uses the most flexible form of the time function. The results indicate that, following implementation of the *Plan*, a one percentage point increase in the prefecture-level goal resulted in a 0.71% smaller reduction in SO<sub>2</sub> emissions in rural compared to urban counties within the same prefecture. This coefficient is very similar to that in Column (4) of Table 2 (-0.730). The

only difference between these two regressions is the inclusion of prefecture-by-year fixed effects in Table 5. This implies that most of the rural-urban inequality was introduced at the prefecture level. Also, the double interaction ( $Rural \times Post$ ) in Panel A of Table 5 is relatively small and insignificant indicating that other factors coinciding with the *Plan* or other aspects of the *Plan* besides its goals did not significantly affect inequality.

Figure 2 confirms that the parallel trends assumption is met for identifying the estimates in Table 5 (Appendix Figures A1 and A2 show the same using the ESR data excluding power plants and the MEIC data, respectively). Panel A displays the point estimates and 95% confidence intervals for  $\beta_{1t}^R$  in Equation (8). The coefficients are small and statistically insignificant before the policy begins, confirming that the parallel trends assumption is met for the *Plan's* baseline effect on emissions. The coefficients remain so after the *Plan* begins, consistent with no baseline effect of the *Plan* on inequality outside of the effects of the prefecture-level goals. Panel B displays the point estimates and 95% confidence intervals for  $\beta_{3t}^R$  in Equation (8). Before the *Plan*, the parallel trends assumption is met for the effect of the prefecture-level goals on emissions. After the *Plan* starts in 2005, the coefficients decrease markedly, becoming negative and statistically significant in 2009. This time lag is similar to that found in Greenstone, List and Syverson (2012), which notes that it can take plants a couple years to implement abatement actions.

Panel B of Table 5 presents results from the more stringent specification – Equation (7) – which adds a rural-by-year fixed effect to the controls already included. This controls for any unobservables specific to all rural counties in a given year. This requires removing the collinear  $Rural \times Post$  interaction. The coefficient on the triple interaction is significant and almost identical to the results in Panel A for all specifications. This is again consistent with the inequality being introduced by the *Plan's* implementation within prefectures. The preferred and most demanding specification (Column (3)) estimates that a 1% increase in goal stringency leads to 0.71% lower emissions reductions for rural than urban counties.



**Figure 2:** Event-study results

*Notes:* This figure summarizes point estimates and 95% confidence intervals from estimating  $\beta_{1t}^R$  (panel A) and  $\beta_{3t}^R$  (panel B) in Equation (8). This shows the dynamic effects of the *Plan* on the baseline rural-urban inequality due to the *Plan*, conditional on the prefecture-level goal (panel A) and rural-urban inequality due to the prefecture-level goal (panel B). Standard errors clustered at the prefecture level.

## 6.6 Robustness and specification tests

*Placebo tests.* To further assess if the observed rural-urban disparity is due to the *Plan*'s implementation, we conduct two placebo tests. First, following Topalova (2010), we exclude post-2006 data (the policy period) and treat each year from 2001 to 2004 as if it were the regulation's starting year. We then estimate Equation (6) for each pseudo-policy year. The left panel of Appendix Figure A3 shows the results. They suggest that the estimated inequality is not due to time-varying unobserved factors. Second, we assess whether the baseline results are driven by random factors between urban and rural

counties. We randomly classify counties as urban versus rural and re-estimate Equation (7) for each random allocation. We repeat the process 500 times. The right panel of Appendix Figure A3 presents the results. They suggest that the estimated inequality is not due to unobserved county characteristics.

*Unweighted regression.* For the baseline analyses, we weight the regression observations by fraction of rural population in the county. As a check, Row 1 of Appendix Figure A4 reports results from an unweighted regression of Equation (6). The point estimate is very similar to the baseline (Row 0) but the error bands are slightly larger (although still exclude zero).

*Smaller goal range.* Some prefectures were allowed large increases in emissions and others were required to reduce by large amounts. To check the robustness of the results to these extremes, we drop prefectures with goals higher than 35% or lower than -35%. The results are shown in Row 2 of Appendix Figure A4. The point estimate is slightly larger in absolute value and the confidence interval somewhat wider, but the basic result remains.

*Outliers.* To check the robustness of the results to outliers, we winsorize two percent of the county-year observations based on SO<sub>2</sub> emissions. Row 3 of Appendix Figure A4 shows the results with this smaller sample. The results are similar to the baseline results.

*Administrative changes.* To see whether our estimates are sensitive to changes in the classifications of counties as rural versus urban, we re-estimated excluding counties that change status during the sample period. There is one case in our data sample after the policy takes effect and seventeen transitions prior to the policy taking effect. Row 4 of Appendix Figure A4 reports the results. The results are similar to the baseline results.

*Other environmental policies.* The study period included other environmental policies. These would only affect our analyses to the extent that they were correlated with the province- or prefecture-level goals under the *Plan*. The only major policy that commenced at the same time as the *Plan* is the Top-1000 Enterprises Program. It required energy-efficiency improvements by 1,008 firms in nine energy-intensive industries (Price,

Wang and Yun, 2010). To make sure this does not confound our results, we exclude firms participating in this program and re-aggregate county-level pollution data. Row 5 of Appendix Figure A4 reports the results, which are similar to the baseline.

*Alternative measures of county-level emissions.* Column (1) of Appendix Table A7 replicates the most stringent specification of Table 5 (Column 3) using the ESR data excluding power plants and shows a somewhat smaller effect of the *Plan* on rural-urban disparity. Column (2) does the same using the total emissions data in the MEIC. The results are qualitatively consistent, though the effects on rural-urban inequality are smaller.

## 6.7 Health outcomes and costs

Tanaka (2015) documents that SO<sub>2</sub> causes severe health consequences for infants in China and Chen et al. (2021) find a significant increase in healthcare expenditures in China due to SO<sub>2</sub> emissions. The negative health effects of SO<sub>2</sub> exposure have been reported in other developed and developing countries (Barreca, Neidell and Sanders, 2021; Greenstone and Hanna, 2014; Yang and Chou, 2018). We use a survey measure of self-reported health (CHNS data) to estimate the effect of the policy on health outcomes. The survey asks respondents, “Did you become ill in the past four weeks?” Table 6 shows the results of estimating Equation (7) at the individual level with a dummy variable set to one if the answer is “yes” and zero if “no” as the dependent variable. The columns of the table use different combinations of fixed effects but the results are similar. The regulation increased rural-urban inequality in incidences of reported illness. A 1% increase in goal stringency leads to a 0.35% greater probability of reporting sickness for rural than urban counties.

We perform a back-of-the-envelope calculation of the health costs associated with the relatively lower reduction in SO<sub>2</sub> emissions in rural counties within those prefectures required to reduce emissions.<sup>35</sup> Using Equation (7), if there were no inequality related to

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<sup>35</sup>For this calculation, we also include data for the four centrally-administered municipalities.

**Table 6:** Effect of the *Plan* on rural-urban inequality in health outcomes

	Dependent variable: <i>Sick4ws</i>		
	(1)	(2)	(3)
<i>Goal</i> × <i>Rural</i> × <i>Post</i>	-0.359*** (0.162)	-0.351*** (0.164)	-0.345** (0.164)
<i>X</i> × Year dummy	Y	Y	Y
Individual controls	Y	Y	Y
Year FE	Y	Y	Y
County FE	Y		
Community FE		Y	
Individual FE			Y
Observations	25,011	25,011	25,011

*Notes:* 1. Impact of the *Plan* on individual health outcomes using unbalanced panel data from CHNS to estimate Equation (7). 2. *Sick4ws* is a dummy variable equal to one if the respondent answered “yes” to the question “Did you become ill in the past four weeks?” 3. *Goal* is 2010 prefecture-level goal minus 2005 emissions normalized by 2005 emissions. 4. A prefecture fixed effect cannot be included because CHNS includes only one county from each sampled prefecture. 5. “Individual controls” include marital status, age, smoking status, medical history, weekly exercise frequency, household per-capita income, household hygiene status, and three scores measuring community’s health condition, economic condition, and social services. 6. Robust standard errors in parentheses, clustered at the county level. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

the prefecture-level goals, emissions in rural counties in each year would be lowered by:

$$\Delta E_{ct} = D_t R_{ct} \left\{ \exp \left[ \log(E_{ct}) - \beta_3^R G_p \mathcal{I}_{c \in p} \right] - \exp \left[ \log(E_{ct}) \right] \right\}. \quad (9)$$

We use our preferred estimate  $\hat{\beta}_3^R = -0.711$ , the prefecture-level goals, and actual county-level emissions to calculate the total reduction across all counties and years (2006-2010):  $\sum_c \sum_t \Delta E_{ct}$ . This yields 3.87 million tonnes of emissions reductions that would occur in rural counties rather than urban, accounting for 5.2% of total emissions in the prefectures during the period. Existing literature provides estimates for the monetary value of health costs due to SO<sub>2</sub> exposure. [Chen, Li and Lu \(2018\)](#) estimate that the combined mortality and morbidity cost per ton of emissions is RMB 1,170 annually in 2010 RMB. Applying this, the lower reduction in SO<sub>2</sub> emissions in rural counties shifted health costs of 4.53

billion in 2010 RMB (about 0.67 billion US dollars)<sup>36</sup> from urban to rural counties over the five-year period. On a per-capita basis, this represents an annual burden of RMB 1.78 per rural resident. This calculation ignores other damages caused by SO<sub>2</sub>, such as labor productivity (Graff Zivin and Neidell, 2012), human capital accumulation (Graff Zivin et al., 2020), and innovation (Cui, Huang and Wang, 2023). It also ignores benefits to the rural counties such as avoided compliance costs and avoided output reductions (although our results below suggest these are minimal).

## 6.8 Economic and employment impacts

We now explore whether rural counties experienced economic benefits in exchange for their lower SO<sub>2</sub> emissions reductions. To do so, we estimate the DDD model in Equation (7) but with different left-hand side variables. We utilize two data sources and report the findings in Table 7. Panel A utilizes county-level data from the *China County Statistical Yearbook*. Columns (1) and (2) show that the regulation did not lead to greater GDP or employment. In Panel B, we construct the outcome variables from ASIF. Columns (3) and (4) analyze the effects on value added and employment, respectively. The point estimates are insignificant, reflecting no significant improvement in economic outcomes, although the standard errors are large. Economic effects of pollution reductions may take time to manifest themselves. Appendix Table A8 replicates Table 7 but uses a lagged value of the triple interaction. The results show no significant impacts.

These results suggest that the relative increase in emissions in rural counties was not accompanied by significantly greater economic or job growth. The literature offers potential explanations for this. First, air pollution decreases labor productivity in China, as demonstrated by Fu, Viard and Zhang (2021), who use the ASIF data for much of the years in our sample. Second, air pollution induces labor migration, especially among highly-skilled workers. While the presence of high-emitting industries could bring jobs to rural counties, the net employment effect could be negligible. Third, regulations lead

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<sup>36</sup>We apply a 2010 exchange rate of 6.80.

**Table 7:** Effect of the *Plan* on rural-urban inequality in economic and employment outcomes

	Panel A. CCSY		Panel B. ASIF	
	$\log(GDP)$ (1)	$\log(Emp\_Y)$ (2)	$\log(Val\_add)$ (3)	$\log(Emp\_A)$ (4)
<i>Goal</i> × <i>Rural</i> × <i>Post</i>	0.007 (0.042)	0.011 (0.015)	-0.010 (0.112)	-0.017 (0.084)
Rural × Year FE	Y	Y	Y	Y
X × Year dummy	Y	Y	Y	Y
Prefecture × Year FE	Y	Y	Y	Y
Prefecture × Rural FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
Observations	18,282	19,715	15,708	18,732

*Notes:* 1. Effects of the *Plan* on rural-urban inequalities in economic and employment outcomes (Equation (7) with different outcome variables). 2. Columns (1) and (2) use data on GDP and employment from the *China County Statistical Yearbook*. Columns (3) and (4) utilize data on value added and employment aggregated from the ASIF. 3. Number of observations differ across columns due to differences in missing values across sources. The number of observations in Columns (3) is much lower because the ASIF does not contain data on value added for 2008 and 2009. 4. Robust standard errors are in parentheses, clustered at the prefecture level. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

to increased productivity if it propels firms to rationalize their production process or innovate to lower costs (Porter, 1991).

## 7 Explanations for inequality

We examine some possible explanations for the rural inequality by testing whether four proxies for underlying reasons help explain it. The first is each area’s pre-policy (2005) emissions level.<sup>37</sup> Areas with higher initial emissions might be reduced by more if the cost-benefit ratio of pollution reduction decreases in the pollution level; or reduced by less if these are areas in which it is persistently difficult to reduce pollution. The second is the pre-policy (2005) ratio of emissions to GDP in each area. This could proxy for multi-tasking incentives. Lower-level officials face multiple objectives, two key ones being environmental and economic performance. If economic output is more measurable than

<sup>37</sup>Results using 2005 log emissions per capita (available upon request) yield similar results.

environmental performance, lower-level officials will emphasize the former and areas with a higher ratio will experience lower emissions reductions under the *Plan*. Alternatively, this ratio could proxy for the “dirtiness” of economic output and if officials target “dirtier” regions then reductions will increase in the ratio.

The third proxy is the distance between a region’s locus of government and that of the level above. [Du, Lu and Tao \(2014\)](#) show that the distance between Beijing and province-level capitals is an effective instrument for the central government’s power to enforce province-level policies. We use this idea and extend it to measure enforcement power at lower levels, using the distance between a prefecture and its province’s capital and the distance between the geographic center of a county and its prefecture. If officials face difficulties in monitoring or enforcing the *Plan* at the level below, pollution reductions will decline with distance. The fourth proxy is GDP per capita as a proxy for regional income. Greater reductions in higher-income regions could result from a “pollution haven” effect ([Becker and Henderson, 2000](#)); lower reductions if officials attempt to lessen this effect. If any of these proxies are correlated with ruralness, they could explain some or all of the rural inequality. Summary statistics for these proxies are shown in Appendix Table A9.

Column (1) of Panel B in Table 8 show estimates of Equation (3) for the province-level goal but adding the proxy variables.<sup>38</sup> A one standard deviation increase in pre-policy emissions is associated with a 20.3% relaxation in the province-level goal, consistent with leniency for regions facing greater difficulty in reducing emissions. Provinces with a higher ratio of pre-policy emissions to GDP were given more stringent goals (13.2% stricter for a one standard deviation increase). Thus, there is no evidence of multi-tasking incentive problems but rather an effort to target pollution in “dirtier” regions. The distance between the province capital and Beijing is not correlated with goals assigned to provinces, consistent with the central government not considering enforcement or

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<sup>38</sup>We also estimated using realized emissions as the dependent variable. The effects of ruralness are somewhat diminished controlling for the proxies: coefficient of 0.239 with a standard error of 0.098.

monitoring problems in setting them.<sup>39</sup> GDP per capita also has no significant effect. After controlling for these proxies, rural inequality still has no significant influence on the province-level goals as in the baseline results (Panel A).

**Table 8:** Relationship between ruralness and province- and prefecture-level goals – role of proxies

	Dependent variable:	
	<i>Province Goal</i>	<i>Prefecture Goal</i>
	(1)	(2)
<b>Panel A: Baseline model</b>		
<i>Fraction_rural_pop</i>	0.095 (0.096)	-0.003 (0.080)
<i>Province_goal</i>		0.976* (0.519)
<b>Panel B: Proxy variables</b>		
<i>Log(2005_emissions)</i>	0.140** (0.055)	-0.066 (0.057)
<i>Log(2005_emiss_per_GDP)</i>	-0.135** (0.052)	-0.122** (0.057)
<i>Log(dist_prov/pref)</i>	0.010 (0.007)	-0.008 (0.007)
<i>Log(2005_GDP_per_capita)</i>	0.027 (0.033)	-0.082* (0.047)
<i>Fraction_rural_pop</i>	-0.005 (0.079)	-0.058 (0.067)
<i>Province_goal</i>		0.388 (0.397)
X	Y	Y
R <sup>2</sup>	0.708	0.444
Observations	31	260

*Notes:* 1. Estimates of Equation (3) (Column (1)) and Equation (5) (Column (2)) with the control variables shown at the bottom of the table. 2. *Goal* is 2010 goal minus 2005 emissions normalized by 2005 emissions. 3. Controls are same as those in Table 3 (Column (1)) and Table 4 (Column (2)). 4. Robust standard errors in parentheses. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

Column (2) of Panel B show estimates of Equation (5) for the prefecture-level goal but

<sup>39</sup>Distance is associated with greater realized emissions (5.6% greater for a one standard deviation increase) significant at better than the 1% level, consistent with monitoring or enforcement difficulties.

adding the proxy variables.<sup>40</sup> The positive effect of pre-policy emission levels reflected in the province-level goals is not present at the prefecture level. Distance from a county's center to its prefecture's center is not significant. The prefecture-level goals reflect "dirtier" output of a similar magnitude to that at the province level (12.0% stricter in response to a one standard deviation increase). The prefecture-level goals decline in regional income, although of only borderline significance. Including the proxy variables eliminates the tight correlation between the prefecture- and province-level goals because they each depend differentially on these proxies. Most importantly, after controlling for the proxies, ruralness is still not significantly associated with the prefecture-level goals.

Panel B of Table 9 shows the results of estimating Equation (7) but adding triple interactions of each proxy with the policy variables. Column (1) shows that none of the proxies affect emissions differentially with the advent of the *Plan*. Column (2) shows that the effect of rural status remains much the same as the baseline results (Panel A) after controlling for the proxy variables. None of the proxies play a significant role in outcomes within prefectures.

## 8 Conclusion

This paper shows that an environmental regulation in China increased rural-urban inequality. The implementation of the Eleventh FYP led to a lower percentage reduction in SO<sub>2</sub> emissions in rural counties compared to urban counterparts within the same prefecture. The relative increase in emissions appears to have not been accompanied by relatively greater economic or job growth in rural counties. At the same time, it contributed to worsening health inequality. Our back-of-the-envelope calculation suggests that at least 4.53 billion RMB in health costs was shifted from urban to rural counties over the five-year period after the policy began. The inequality emerged in implementation at the lowest level (prefecture) of government – goals set at the top two levels of government

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<sup>40</sup>We also estimated using realized emissions as the dependent variable. The effects of ruralness are somewhat diminished controlling for the proxies: coefficient of 0.145 with a standard error of 0.073.

**Table 9:** Effect of *Plan* implementation on county-level emissions within prefectures – role of proxies

	Dependent variable:	
	<i>Log(emissions)</i>	
	(1)	(2)
<b>Panel A: Baseline model</b>		
<i>Goal</i> × <i>Rural</i> × <i>Post</i>		-0.711** (0.285)
<b>Panel B: Proxy variables</b>		
<i>Goal</i> × <i>Log(2005_emiss)</i> × <i>Post</i>	0.083 (0.167)	0.029 (0.163)
<i>Goal</i> × <i>Log(2005_emiss_per_GDP)</i> × <i>Post</i>	-0.151 (0.195)	-0.096 (0.187)
<i>Goal</i> × <i>Dist_county</i> × <i>Post</i>	0.192 (0.144)	0.174 (0.148)
<i>Goal</i> × <i>Log(2005_GDP_per_capita)</i> × <i>Post</i>	0.230 (0.260)	0.098 (0.254)
<i>Goal</i> × <i>Rural</i> × <i>Post</i>		-0.652** (0.318)
<i>X</i> × Year dummy	Y	Y
<i>Rural</i> × Year FE	Y	Y
Prefecture × Year FE	Y	Y
Prefecture × <i>Rural</i> FE	Y	Y
County FE	Y	Y
$R^2$	0.869	0.870
Observations	18,686	18,686

Notes: 1. Estimates of Equation (7) with the control variables specified at the bottom of the table. 2. The outcome variable is annual county-level log SO<sub>2</sub> emissions. 3. “X” includes same variables as in Table 5. 4. Robust standard errors in parentheses clustered at the prefecture level. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

(central and province) reflected no bias.

We attempt to uncover the underlying reasons for the rural inequality including cost-benefit explanations, incentive problems, and tradeoffs between economic output and pollution. These play a role in the province- and prefecture-level goals. Nonetheless, after conditioning on these effects, rural inequality in outcomes remains almost as strong. This suggests that there are unobserved incentives or bureaucratic procedures within the levels

of government that favor reductions in urban over rural areas. This would be a useful avenue of future work to better inform our understanding of China's decentralized system. It would require more detail on the functioning of China's environmental bureaucracy within the prefectures. We are also unable to determine if the policy is welfare improving or not. This would require additional data on the costs of complying with the regulation and firm productivity and human capital in rural versus urban counties. This would be useful to investigate from a policy standpoint.

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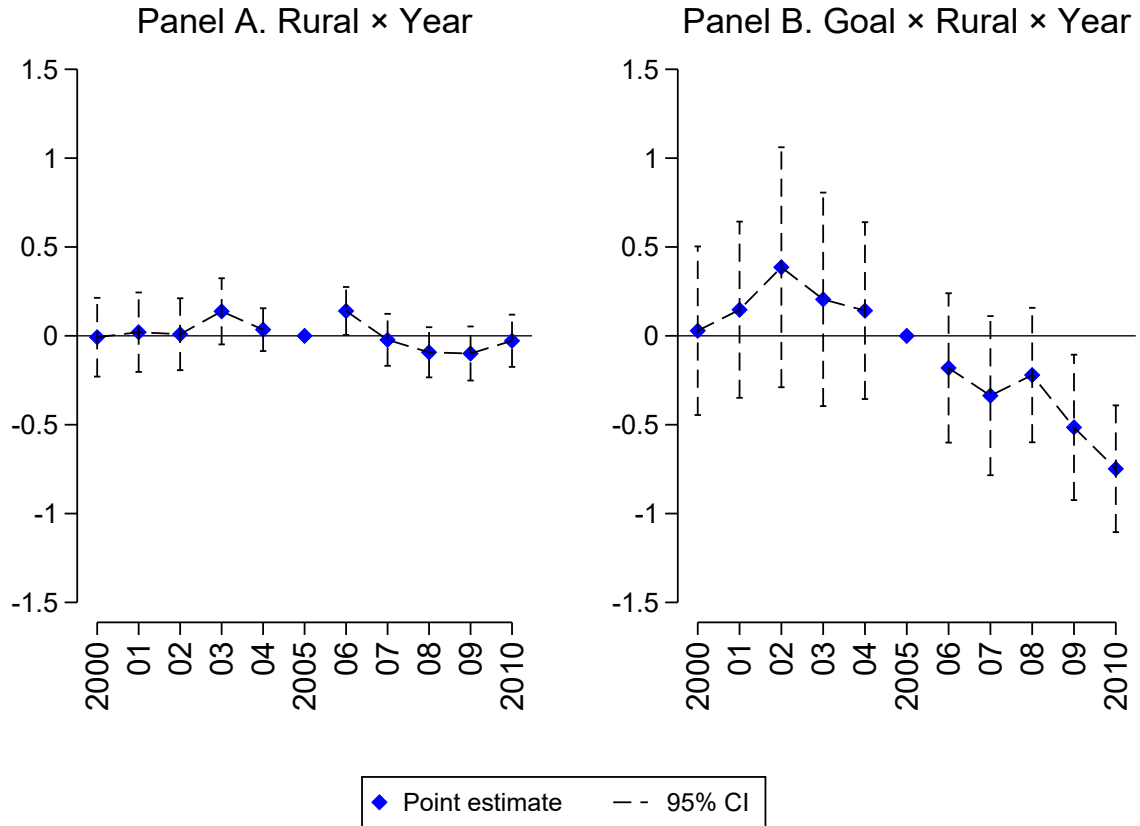
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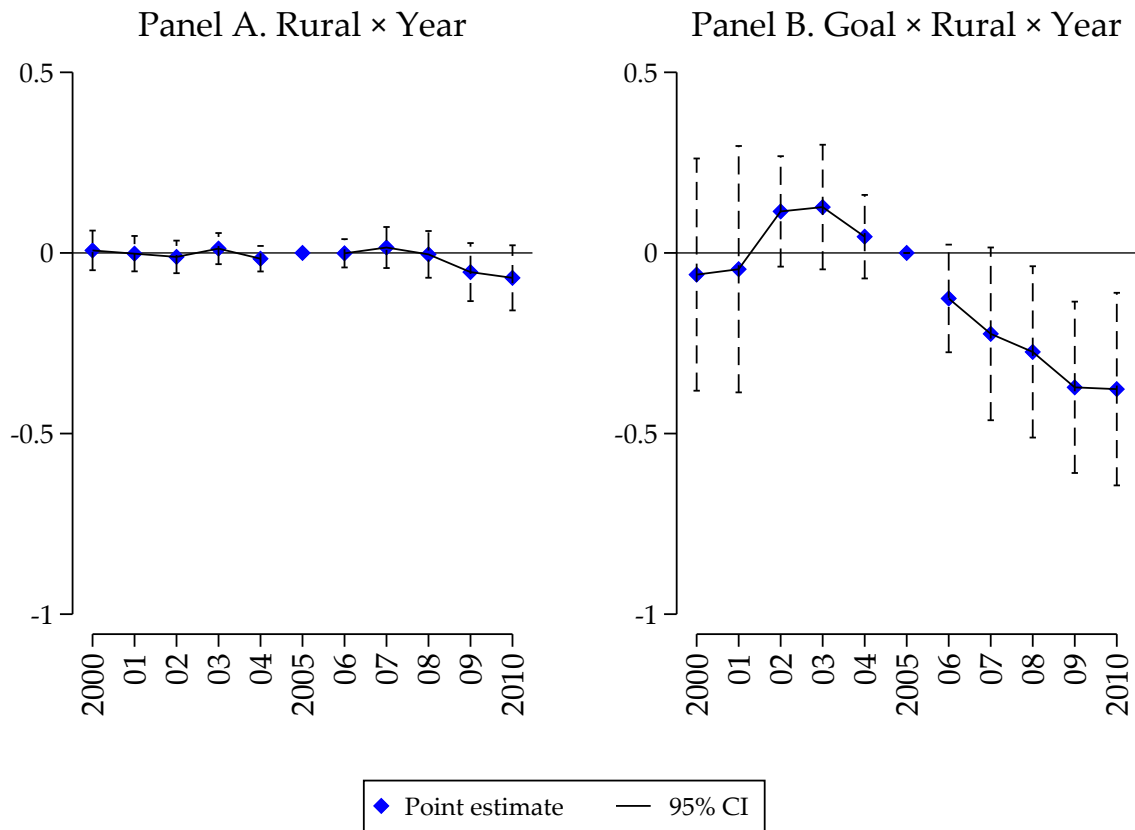
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# APPENDIX



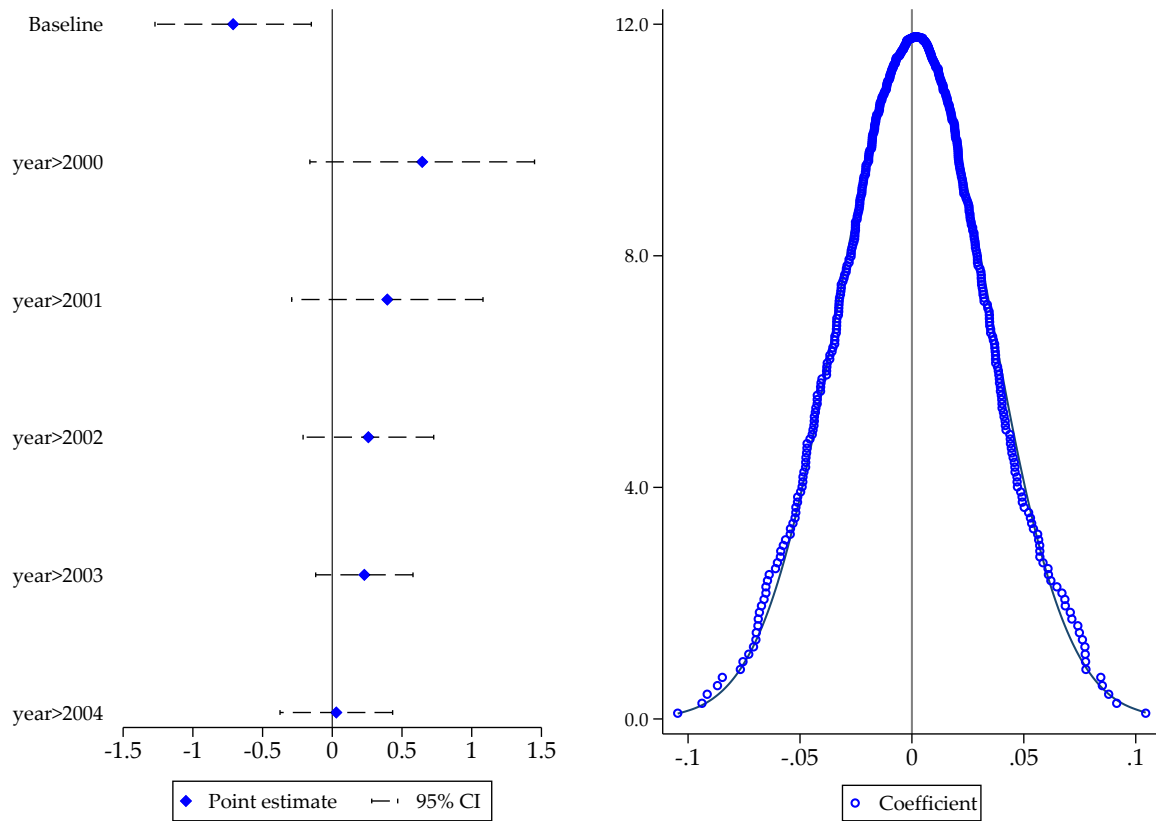
**Figure A1:** Event-study results using ESR data excluding power plants

*Notes:* This figure summarizes point estimates and 95% confidence intervals from estimating  $\beta_{1t}^R$  (panel A) and  $\beta_{3t}^R$  (panel B) in Equation (8) using ESR data excluding power plants. This shows the dynamic effects of the *Plan* on the baseline rural-urban inequality due to the *Plan*, conditional on the prefecture-level goal (panel A) and rural-urban inequality due to the prefecture-level goal (panel B). Standard errors clustered at the prefecture level.



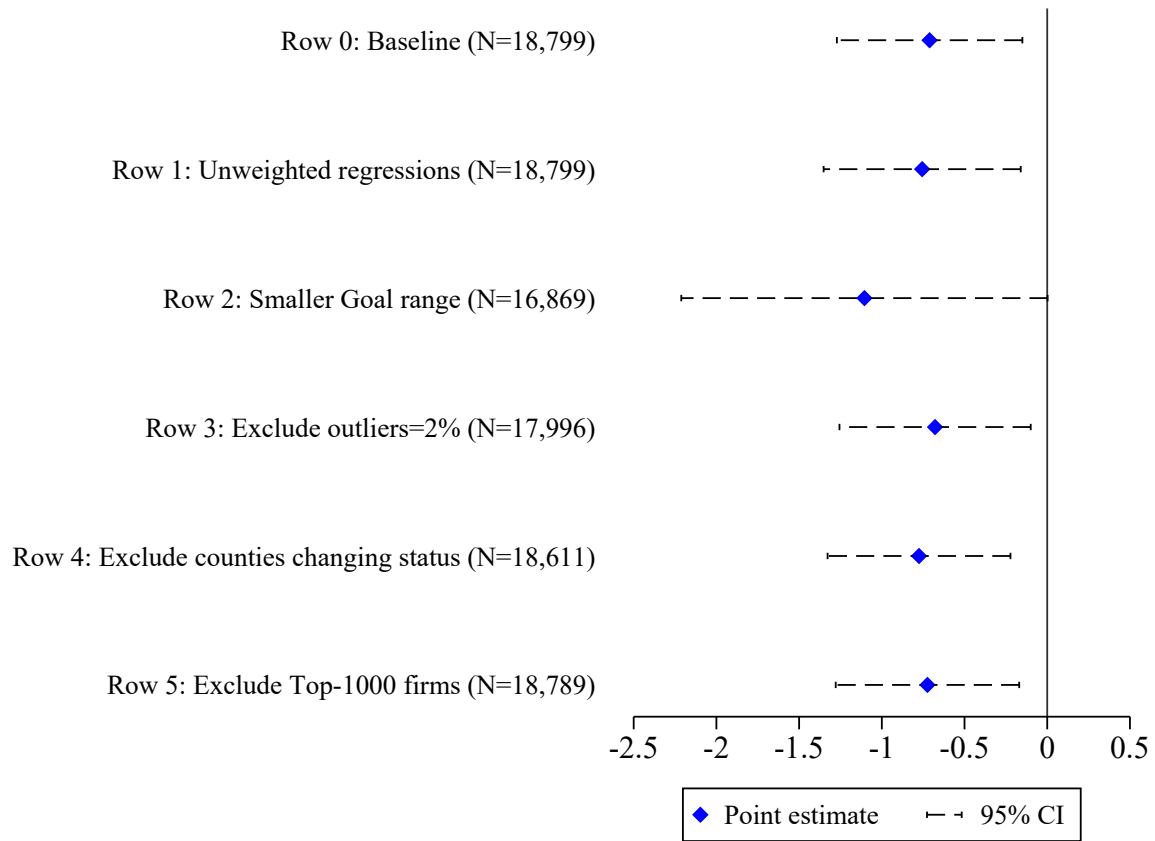
**Figure A2:** Event-study results using MEIC data

*Notes:* This figure summarizes point estimates and 95% confidence intervals from estimating  $\beta_{1t}^R$  (panel A) and  $\beta_{3t}^R$  (panel B) in Equation (8) using MEIC data. This shows the dynamic effects of the *Plan* on the baseline rural-urban inequality due to the *Plan*, conditional on the prefecture-level goal (panel A) and rural-urban inequality due to the prefecture-level goal (panel B). Standard errors clustered at the prefecture level.



**Figure A3: Placebo tests**

*Notes:* This figure plots the results of two separate placebo tests. The left panel displays baseline results (first row) and results from estimating Equation (6) in the main text using the 2000–2005 subsample and a “fake” policy implementation year (other rows). The plot shows the point estimates and 95% confidence intervals for the  $\beta_3^R$  coefficient. The right panel presents the results from 500 estimates of Equation (6) with counties randomly assigned to urban or rural status. The plot shows the density of the point estimates of  $\beta_3^R$ .



**Figure A4: Robustness checks**

*Notes:* This figure reports the results of robustness checks of estimating Equation (6). Row 0 reports the baseline result. Row 1 presents the results from an unweighted regression. Row 2 uses a subsample of prefectures with reduction goals between -35% and 35%. Row 3 uses a subsample that winsorizes the top and bottom 2% of observations based on emissions. Row 4 excludes counties that changed their rural-urban designation during the sample period. Row 5 excludes firms that were regulated under the Top-1000 energy conservation program.

**Table A1:** Criteria for classifying a county as a county-level city based on its population density

Population density (per sq km)	< 100	100 - 400	> 400
Non-agricultural employment in county seat and % of total	> 100,000 & > 20%	> 120,000 & > 25%	> 150,000 & > 30%
Industrial output value in RMB millions and % of total	> 800 & > 60%	> 1200 & > 70%	> 1500 & > 80%
GDP in RMB millions	> 600	> 800	> 1,000
Annual fiscal revenue in RMB millions and per-capita	> 40 & > 60	> 50 & > 80	> 60 & > 100

*Notes:* 1. This table shows criteria for converting a rural county to a county-level city based on the county's population density. 2. The information comes from a document published by Ministry of Civil Affairs in 1993. 3. There is no publicly-available, approved document showing the criteria for classifying a county as a municipal district of a prefecture-level city. However, there is a publicly-available draft for consultation that shows that the criteria are similar to those above.

**Table A2:** Province-level summary statistics (N = 31)

Variable	Definition	Mean	S.D.	Min	Max
<i>Goal</i>	SO <sub>2</sub> target reduction for province	-0.097	0.068	-0.259	0
<i>Realization</i>	SO <sub>2</sub> actual reduction for province	-0.091	0.164	-0.397	0.450
<i>Gdp_pc</i>	log per-capita GDP (in RMB 1,000)	2.580	0.527	1.652	3.899
<i>Manuf_share</i>	% of secondary industry GDP share	43.894	8.602	24.887	58.575
<i>Pop_density</i>	log population per square kilometer	7.002	0.834	5.242	8.705
<i>Fiscal</i>	log fiscal revenues (in RMB 1,000)	17.241	1.100	14.000	19.013
<i>Manuf_firms</i>	log number above-scale firms	8.409	1.281	5.283	10.603
<i>Fraction_rural_population</i>	fraction rural population	0.533	0.211	0.052	0.804

Notes: This table reports summary statistics for the key province-level variables from *China Statistical Yearbook*.

**Table A3:** Prefecture-level summary statistics

Variable	Definition	Mean	S.D.	Min	Max	N
<i>Goal</i>	SO <sub>2</sub> target reduction for prefecture	0.097	0.984	-0.553	9	281
<i>Realization</i> <sup>2</sup>	SO <sub>2</sub> actual reduction for prefecture	-0.024	0.685	-0.656	7.8	274
<i>Goal</i> (excluding outliers) <sup>3</sup>	SO <sub>2</sub> target reduction for prefecture	-0.069	0.292	-0.553	1.439	269
<i>Realization</i> (excluding outliers) <sup>3</sup>	SO <sub>2</sub> actual reduction for prefecture	-0.113	0.358	-0.656	2.521	262
<i>Gdp_pc</i> <sup>4</sup>	log per-capita GDP (in RMB 1,000)	2.504	0.707	0.894	5.606	278
<i>Manuf_share</i> <sup>4</sup>	% of secondary industry GDP share	45.958	12.340	9	88.46	278
<i>Pop_density</i> <sup>5</sup>	log population per square kilometer	5.671	0.912	1.552	7.887	280
<i>Fiscal</i> <sup>5</sup>	log fiscal revenues (in RMB 1,000)	14.418	1.027	11.851	17.535	280
<i>Manuf_firms</i> <sup>5</sup>	log number above-scale firms	6.083	1.101	3.091	9.081	280
<i>Fraction_rural_population</i> <sup>5</sup>	fraction rural population	0.501	0.259	0	0.928	280

Notes: 1. This table reports summary statistics for the key prefecture-level variables from *China City Statistical Yearbook*. It excludes the four centrally-administered municipalities. 2. Number of observations for *Realization* is smaller since some prefectures do not publish emissions data. 3. Outliers defined as goal of 150% or more. 4. The *Yearbook* does not provide data on *Gdp\_pc* and *Manuf\_share* for three prefectures (Lhasa, Wuzhou and Fangchenggang) in 2005. 5. No data for Lhasa in 2005.

**Table A4: County-level summary statistics**

Variable	Definition	Mean	S.D.	Min	Max	N
<i>Emissions analysis</i>						
<i>Cnty_emissions (ESR +MEIC)*</i>	log SO2 emissions (in tons) from ESR + (MEIC power sector)	7.138	1.953	-5.238	12.486	18,799
<i>Rural**</i>	rural county indicator	0.795	0.404	0	1	18,799
<i>Gdp_pc**</i>	log per-capita GDP (in RMB 1,000)	1.970	0.669	0.276	4.643	18,799
<i>Manuf_share**</i>	% of secondary industry GDP share	38.995	16.173	3.477	93.118	18,799
<i>Pop_density**</i>	log population per square kilometer	5.198	1.252	-1.889	8.715	18,799
<i>Manuf_pop**</i>	% population in non-agricultural industries	18.141	14.339	0	100	18,799
<i>Fiscal_rev**</i>	log fiscal revenues (in RMB 1,000)	11.408	1.046	8.216	15.394	18,799
<i>Cnty_emissions (ESR)***</i>	log SO <sub>2</sub> emissions (in tons) from ESR	6.475	1.733	-5.809	11.336	18,799
<i>Cnty_emissions(MEIC)****</i>	log SO2 emissions (in tons) from MEIC	8.181	1.391	2.493	12.414	19,963
<i>Economic and health outcomes</i>						
<i>GDP**</i>	log GDP (RMB 1,000)	14.845	1.070	11.169	18.948	18,282
<i>Emp_Y**</i>	log employment ( <i>Yearbook</i> ) (persons)	12.048	0.887	8.247	13.918	19,715
<i>Val_Add*****</i>	log value added ( <i>ASIF</i> ) (RMB 1,000)	12.608	1.854	2.197	18.248	15,708
<i>Emp_A*****</i>	log employment ( <i>ASIF</i> ) (persons)	8.652	1.510	0	14.319	18,732
<i>Sick4ws*****</i>	interviewee sick in past four weeks	0.140	0.347	0	1	25,011

Notes: This table reports summary statistics on 1,783 counties from: \* ESR database (without power plants) combined with power sector data from MEIC, \*\* the *China County Statistical Yearbook*, \*\*\* ESR database (excluding power plants), \*\*\*\* MEIC database including all five sectors, \*\*\*\*\* ASIF database, \*\*\*\*\* CNHS. See Section 4.3 for details on data sources.

**Table A5:** Comparison of urban and rural county characteristics before the *Plan* (2000 to 2005)

	Rural (1)	Urban (2)	Uncond diff (3)	Cond diff (4)
<b>Panel A. Classification variable</b>				
<i>Gdp_pc</i>	1.813 (0.610)	2.485 (0.632)	-0.672*** (0.035)	
<i>Gdp_share</i>	36.025 (15.906)	45.499 (15.905)	-9.474*** (0.879)	
<i>Manuf_pop</i>	15.887 (12.016)	27.178 (19.806)	-11.291*** (1.018)	
<i>Pop_density</i>	4.956 (1.401)	5.643 (1.120)	-0.687*** (0.066)	
<i>Fiscal_rev</i>	11.060 (1.018)	12.348 (0.988)	-1.288*** (0.055)	
<b>Panel B. Other characteristics</b>				
<i>Student</i>	15.318 (3.630)	14.652 (3.357)	0.666*** (0.241)	-0.306 (0.261)
<i>Investment_pc</i>	0.502 (0.986)	1.156 (0.907)	-0.654*** (0.064)	-0.057 (0.046)
<i>Expenditure_pc</i>	-0.167 (0.558)	-0.058 (0.546)	-0.108** (0.043)	0.012 (0.029)
<i>Grain</i>	11.754 (1.258)	12.155 (1.157)	-0.401*** (0.085)	0.041 (0.085)
Observations	1,528	416		

Notes: 1. Panel A compares 2005 values of variables used to classify a county as rural versus urban. Columns (1) and (2) present the means and standard deviations (in parentheses). Column (3) shows the unconditional difference between urban and rural areas. 2. Panel B compares other 2005 characteristics of urban and rural counties. Columns (1) and (2) present the means and standard deviations (in parentheses). Column (3) shows the unconditional difference between them. Column (4) reports the conditional difference in these characteristics from a regression on the  $R_{ct}$  dummy, controlling for the classification variables in Panel A. 3. *Student* is enrollment in primary and secondary school relative to total population; *Investment\_pc* is log construction investment per capita (in RMB 1000), *Expenditure\_pc* is log government expenditures per capita (in RMB 1000). *Grain* is log total grain production in tons. 4. Standard errors are reported in parentheses in Columns (3) and (4). Significance: \*\*\*  $p < 0.01$  \*\*  $p < 0.05$ ; \*  $p < 0.10$ .

**Table A6: County-level emissions and population**

	Dependent variable: $\text{Log}(\text{emissions})$		
	(1)	(2)	(3)
$\text{Log}(\text{population})$	1.090*** (0.078)	1.085*** (0.078)	1.205*** (0.090)
Year FE		Y	Y
Prefecture FE			Y
$R^2$	0.167	0.177	0.459
Observations	18,799	18,799	18,799

Notes: 1. This table shows the relationship between log emissions and log population. All observations at county-year level. 2. Robust standard errors in parentheses clustered at the prefecture level. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

**Table A7:** Effect of implementation of the Plan within prefectures on county-level emissions inequality: robustness to emissions measures

	<i>Log(emissions)</i> ( <i>ESR w/o power</i> )	<i>Log(emissions)</i> ( <i>MEIC</i> )
	(1)	(2)
<b>Panel A: DDD model I</b>		
<i>Rural</i> × <i>Post</i>	-0.054 (0.063)	-0.020 (0.035)
<i>Goal</i> × <i>Rural</i> × <i>Post</i>	-0.556*** (0.170)	-0.303*** (0.115)
<b>Panel B. DDD model II</b>		
<i>Goal</i> × <i>Rural</i> × <i>Post</i>	-0.555*** (0.169)	-0.304** (0.115)
<i>Rural</i> × Year FE	Y	Y
<i>X</i> × Year dummy	Y	Y
Prefecture × Year FE	Y	Y
Prefecture × Rural FE	Y	Y
County FE	Y	Y
Observations	18,799	19,963

*Notes:* 1. This table shows estimates of Equation (7) with control variables specified at the bottom of the table. 2. This table is the same as Table 5 except the outcome variable is the sum of annual county-level SO<sub>2</sub> emissions from the ESR excluding power-plant emissions in Column (1) and county-level emissions from MEIC, which includes manufacturing, mining, power plants, residential, and transportation, in Column (2). 3. *Goal* is 2010 prefecture-level goal minus 2005 emissions normalized by 2005 emissions. 4. “*X*” includes log per-capita GDP, secondary industry GDP share, share of population engaged in non-agricultural industries, log population per square kilometer, and log fiscal revenue. 5. Robust standard errors in parentheses clustered at the prefecture level. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

**Table A8:** Lagged effect of the *Plan* on rural-urban inequality in economic and employment outcomes

	Panel A. CCSY		Panel B. ASIF	
	$\log(\text{GDP})$ (1)	$\log(\text{Emp}_Y)$ (2)	$\log(\text{Val\_add})$ (3)	$\log(\text{Emp}_A)$ (4)
<i>Lagged : Goal</i> × <i>Rural</i> × <i>Post</i>	0.002 (0.040)	0.001 (0.014)	0.050 (0.104)	0.016 (0.092)
Rural × Year FE	Y	Y	Y	Y
X × Year dummy	Y	Y	Y	Y
Prefecture × Year FE	Y	Y	Y	Y
Prefecture × Rural FE	Y	Y	Y	Y
County FE	Y	Y	Y	Y
Observations	18,282	19,715	15,708	18,732

*Notes:* 1. This table replicates Table 7 but uses one-year lagged rather than contemporaneous DDD variable. 2. Columns (1) and (2) use data on GDP and employment from the *China County Statistical Yearbook*. Columns (3) and (4) utilize data on value added and employment aggregated from the ASIF. 3. Number of observations differ across columns due to differences in missing values across sources. The number of observations in Columns (3) is much lower because the ASIF does not contain data on value added for 2008 and 2009. 4. Robust standard errors are in parentheses, clustered at the prefecture level. Significance: \*\*\*  $p < 0.01$ , \*\*  $p < 0.05$ , \*  $p < 0.10$ .

**Table A9:** Summary statistics for proxies

Variable	Definition	Mean	S.D.	Min	Max	Obs.
<b>Panel A: Province level</b>						
<i>log(emissions_2005)</i>	log SO <sub>2</sub> emissions in 2005 (tons)	13.003	1.453	6.908	14.355	31
<i>log(emiss_per_GDP)</i>	log SO <sub>2</sub> emissions per unit GDP (tons/1,000 yuan)	-6.825	0.981	-10.099	-5.258	31
<i>log(dist_prov)</i>	distance province capital to Beijing (km)	7.442	1.558	0	8.570	31
<i>log(GDP_per capita)</i>	log per-capita GDP (RMB 1,000)	2.580	0.527	1.652	3.899	31
<b>Panel B: Prefecture level</b>						
<i>log(emissions_2005)</i>	log SO <sub>2</sub> emissions in 2005 (tons)	10.742	1.074	4.174	12.627	260
<i>log(emiss_per_GDP)</i>	log SO <sub>2</sub> emissions per unit GDP (tons/1,000 yuan)	-6.814	0.985	-13.178	-4.174	260
<i>log(dist_pref)</i>	distance prefecture to province capital (km)	5.360	1.747	0	7.831	260
<i>log(GDP_per capita)</i>	log per-capita GDP (RMB 1,000)	2.513	0.691	1.002	5.606	260
<b>Panel C: County level</b>						
<i>log(emissions_2005)</i>	log SO <sub>2</sub> emissions in 2005 (tons)	7.222	2.089	-7.787	12.486	18686
<i>log(emiss_per_GDP)</i>	log SO <sub>2</sub> emissions per unit GDP (tons/1,000 yuan)	-7.598	1.751	-20.596	-2.391	18686
<i>log(dist_county)</i>	distance county to prefecture centers (km)	3.806	1.869	-25.435	6.030	18799
<i>log(GDP_per capita)</i>	log per-capita GDP (RMB 1,000)	1.970	0.669	0.276	4.643	18799