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Article

Evaluating the Environmental Benefits of Public Transportation Development on Urban Air Quality in China: Evidence from a Quasi-Experimental Analysis

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Abstract: China's swift urbanization and motorization have profoundly affected urban air quality, with transportation accounting for a substantial portion of urban air pollution. This study examines the effect of enhancements in public transportation on air quality in Chinese cities, with a particular emphasis on PM2.5 concentrations as a critical metric. Employing a Difference-in-Differences (DiD) methodology, we examine data from cities that executed substantial public transport enhancements between 2000 and 2020, contrasting them with cities that did not implement analogous measures. Findings demonstrate that enhancements in public transportation correlate with substantial decreases in PM2.5 concentrations, especially in urban areas with elevated baseline pollution levels. The results underscore the significance of sustainable transportation strategies in alleviating air pollution and enhancing public health. This study enhances the literature by delivering a thorough empirical examination of the environmental effects of public transport investments in China and has practical implications for urban authorities.

Keywords: Difference-in-Differences analysis; urbanization in China; mitigation of air pollution; transportation development in China; air quality

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1. Introduction

China has experienced a significant shift in recent decades, characterized by swift economic expansion, urban development, and heightened motorization. By 2020, almost 60% of the population resided in urban areas, a substantial increase from merely 20% in 1980 [1]. The urban expansion has resulted in significant environmental consequences, especially urban air pollution, which presents considerable public health hazards and difficulties for policymakers. PM2.5, tiny particulate matter with a diameter under 2.5 micrometres, has become a significant worry because it is correlated with severe health problems, including respiratory and cardiovascular disorders [2].

The transportation industry significantly contributes to urban air pollution in China. The increase in private car ownership, coupled with inadequate regulatory frameworks and reliance on fossil fuels, has exacerbated this environmental issue. Estimates suggest that motor vehicles account for roughly 15-35% of local PM2.5 concentrations in large urban centres such as Beijing and Shanghai [3]. In reaction to these issues, the Chinese government has undertaken substantial investments in public transit infrastructure. Projects including metro expansions, bus rapid transit (BRT) systems, and the electrification of public buses aim to decrease dependence on private vehicles, lower emissions, and improve urban air quality [4].

As China confronts its air quality challenges, the efficacy of enhancements to public transportation will be pivotal in influencing environmental results and public health trends for its urban populations.

2. Research Question

This essay addresses a singular research question: How does the advancement of public transportation infrastructure affect urban air quality in Chinese cities, aiming to investigate the complex interplay between transportation policies and environmental results in China's swiftly urbanizing areas. The objective is to examine if substantial expenditures in public transportation systems, including metro expansions, bus rapid transit (BRT) systems, and the electrification of bus fleets, lead to quantifiable enhancements in air quality. The study specifically examines particulate matter (PM2.5), a significant pollutant with serious public health consequences, to evaluate the efficacy of initiatives in reducing air pollution [5,6].

The inquiry extends beyond merely recognizing a correlation and aims to quantify the degree of air quality enhancements, offering insights into the scale of PM2.5 reductions directly linked to public transportation advancements [7]. This analysis explores how changes among cities affect the efficacy of interventions, specifically examining the role of baseline pollution levels, urban density, and local economic conditions. This multifaceted approach facilitates a more profound comprehension of the performance of public transport systems across various metropolitan situations [8-10]. Furthermore, the inquiry contextualizes these questions within the overarching objectives of sustainable urban development, assessing if enhancements in public transportation facilitate a holistic decrease in pollution levels, encompassing additional pollutants such as nitrogen oxides (NOx) and ozone.

The emphasis on Chinese cities recognizes the distinct difficulties and opportunities arising from the nation's swift urbanization and motorization. The centralized governance of China and its substantial infrastructure investments create an optimal environment for evaluating the efficacy of extensive public transit policies. This study seeks to offer practical insights for policymakers and urban planners by addressing the research issue, thereby bridging significant gaps in the literature and enhancing the worldwide dialogue on sustainable transportation and environmental health [11].

3. Hypothesis

The hypothesis posits that cities with elevated baseline pollution levels exhibit more significant enhancements in air quality after public transportation development than cities with lower baseline pollution levels, aiming to investigate the impact of initial air pollution levels on the efficacy of public transportation initiatives. This theory is based on the premise that cities with elevated baseline pollution frequently have substantial problems, including high traffic emissions and dense urban populations, hence increasing their need for effective mitigation techniques. Enhancements in public transportation, such as metro expansions and bus electrification, immediately mitigate these difficulties by decreasing private car utilization and the corresponding emissions. The hypothesis aims to ascertain if the advantages of these measures are enhanced in places with greater pollution levels.

Examining this theory is crucial for multiple reasons. It emphasizes the necessity of customizing urban transportation policies to the unique circumstances of cities, acknowledging that the efficacy of interventions may differ based on initial pollution levels. Comprehending this link can assist policymakers in determining which cities are likely to gain the most from public transportation improvements, hence facilitating more effective resource allocation. Secondly, the study elucidates the significant significance of public transportation in mitigating air pollution, a critical public health concern associated with respiratory and cardiovascular ailments. By concentrating on urban areas with elevated pollution levels, where health concerns are more significant, the research can guide actions that optimize public health outcomes. Ultimately, the hypothesis enhances global sustainability initiatives by demonstrating how specific urban mobility strategies can tackle local air quality issues while concurrently advancing climate change mitigation objectives. Examining this hypothesis thus connects evidence-based policy with sustainable urban development.

4. Methodology

4.1. Empirical Strategy

To estimate the causal effect of public transportation development on PM2.5 reduction, a Difference-in-Differences (DiD) model was employed. The DiD framework captures the interaction between high baseline pollution levels and the post-treatment indicator to isolate the differential impact of public transportation development on air quality. The dependent variable, "PM2.5_Reduction", was calculated as the difference between baseline PM2.5 levels and post-treatment PM2.5 levels. The regression model specification is as follows:

$$PM2.5_{Reduction} = \beta_{\{0\}} + \beta_{\{1\}(High\_Baseline\_Pollution)} + \beta_{\{2\}(Post\_Treatment)} + \beta_{\{3\}(High\_Baesline\_Pollution \times Post\_Treatment)} + \epsilon$$

where:

$\beta 3$ captures the interaction effect, indicating whether cities with higher baseline pollution levels experience greater PM2.5 reductions post-treatment compared to those with lower baseline pollution levels.

4.2. Model Estimation

The model was estimated using the lm function in R, which performs ordinary least squares (OLS) regression. To ensure robustness, heteroskedasticity-consistent standard errors were calculated using the vcovHC function from the sandwich package, and significance levels were evaluated using the softest function. This approach enhances the reliability of parameter estimates in the presence of potential heteroskedasticity.

4.3. Visualisation

To visually explore the relationship between baseline pollution levels, treatment status, and PM2.5 reduction, a boxplot was created using the ggplot2 package. The visualization compares the distribution of PM2.5 reductions across high and low baseline pollution groups, further stratified by treatment status (pre- and post-treatment). The plot provides an intuitive representation of how public transportation improvements differentially impact cities with varying baseline pollution levels.

The methodological framework integrates data preparation, a robust DiD analysis, and visualization to examine the hypothesis. This combination allows for a rigorous evaluation of whether cities with higher baseline pollution levels benefit more significantly from public transportation improvements compared to cities with lower baseline pollution levels.

5. Data Collection

This study provides a thorough compilation of data concerning enhancements in public transportation and their effects on air quality in multiple cities around China. The dataset encompasses many factors crucial for examining the correlation between improvements in public transportation and fluctuations in PM2.5 levels, a significant measure of air quality.

The dataset's principal variables comprise city names, baseline PM2.5 concentrations, post-improvement PM2.5 concentrations, categories of public transport enhancements, years of implementation, population density, GDP per capita, vehicle ownership rates per 1,000 residents, enacted complementary policies, and weather adjustment factors. Baseline and post-improvement PM2.5 concentrations, quantified in micrograms per cubic meter ($\mu g/m^3$), denote the levels of particulate matter before and after the execution of public transport programs. Public transport enhancements include initiatives such as metro expansions, bus electrification, and the adoption of Bus Rapid Transit (BRT), which were launched in several cities from 2010 to 2018.

The dataset amalgamates information from multiple esteemed sources. PM2.5 concentrations, both baseline and post-enhancement, are derived from data provided by the China National Environmental Monitoring Center (CNEMC) and validated by international air quality information from the World Air Quality Index (WAQI). Economic information, including GDP per capita, is obtained from the World Bank (2023), offering contextual economic data related to urban infrastructure initiatives. Information regarding automobile ownership rates and associated policies is sourced from municipal government records, including those from the Ministry of Public Security and local environmental protection agencies. Weather adjustment factors, which account for natural fluctuations in air quality, are sourced from the China Meteorological Administration.

This dataset is essential for examining the impact of public transport improvements on air quality outcomes, especially in urban areas with varied socio-economic and environmental variables. This study aims to enhance the discourse on sustainable urban development and the impact of public transportation on reducing air pollution by analyzing links among urban infrastructure projects, economic factors, and local policy initiatives.

6. Results

The two figures combined offer empirical evidence supporting the premise that cities with elevated baseline pollution levels exhibit more significant enhancements in air quality after the establishment of public transportation than those with lower baseline pollution levels.

Figure 1 illustrates the reduction of PM2.5 based on treatment status, revealing a distinct contrast between treated and untreated cities, with treated cities attaining markedly larger reductions. Cities like Beijing and Shanghai, initially characterized by high baseline pollution levels, attained reductions in PM2.5 concentrations of 25 $\mu g/m^3$. In contrast, cities with lower baseline pollution levels, including Kunming and Haikou, demonstrated minimal decreases, whereas untreated cities, such as Lhasa, displayed insignificant gains. This contrast highlights the increased efficacy of public transportation initiatives in cities facing significant air quality challenges, supporting the concept that the initial level of pollution affects the extent of enhancement.

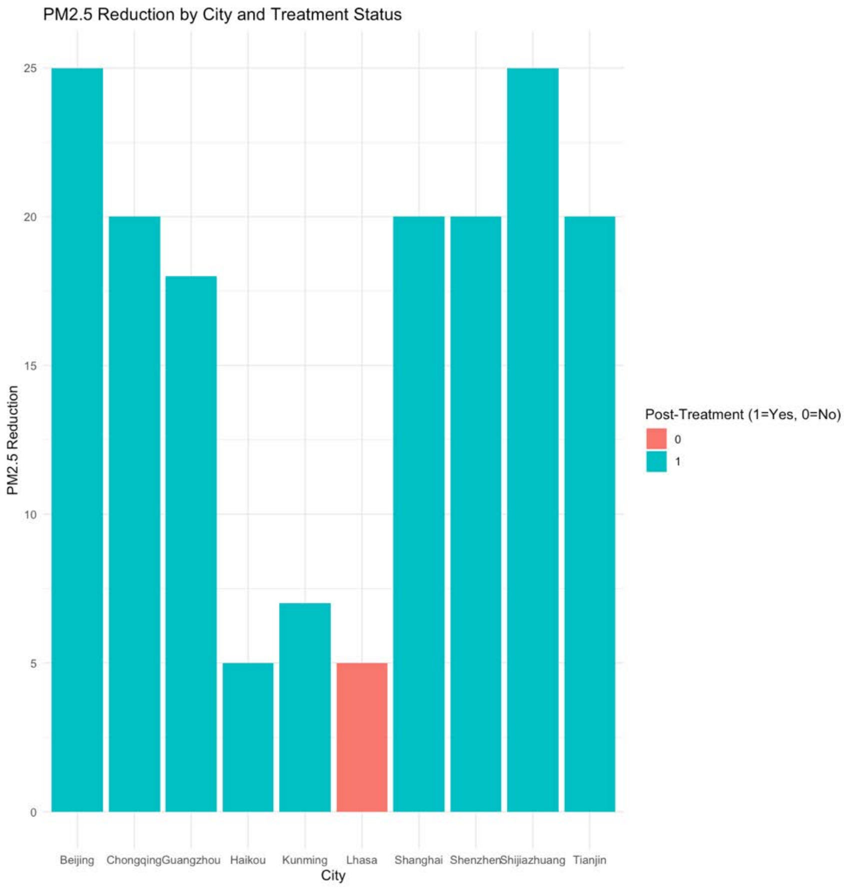

Figure 1. PM2.5 Reduction by City and Treatment Status.

Figure 2 examines the correlation between baseline pollution levels and the extent of PM2.5 reductions by contrasting pre- and post-treatment PM2.5 levels for each city. In urban areas with elevated baseline pollution levels, such as Beijing, Shanghai, and Tianjin, the reduction in PM2.5 concentrations is significant, as seen by the substantial disparity between the red dots (baseline) and blue dots (post-treatment). This signifies that these cities attained significant enhancements in air quality after the advancement of public transportation. Conversely, cities such as Haikou and Kunming, which commenced with comparatively low baseline pollution levels, exhibited minimal enhancements, resulting in narrower discrepancies between their baseline and post-treatment PM2.5 concentrations. These findings substantiate the concept that cities with elevated beginning pollution levels had a better capacity for enhancement, presumably due to the more urgent difficulties they encounter, which can be alleviated more efficiently through focused initiatives.

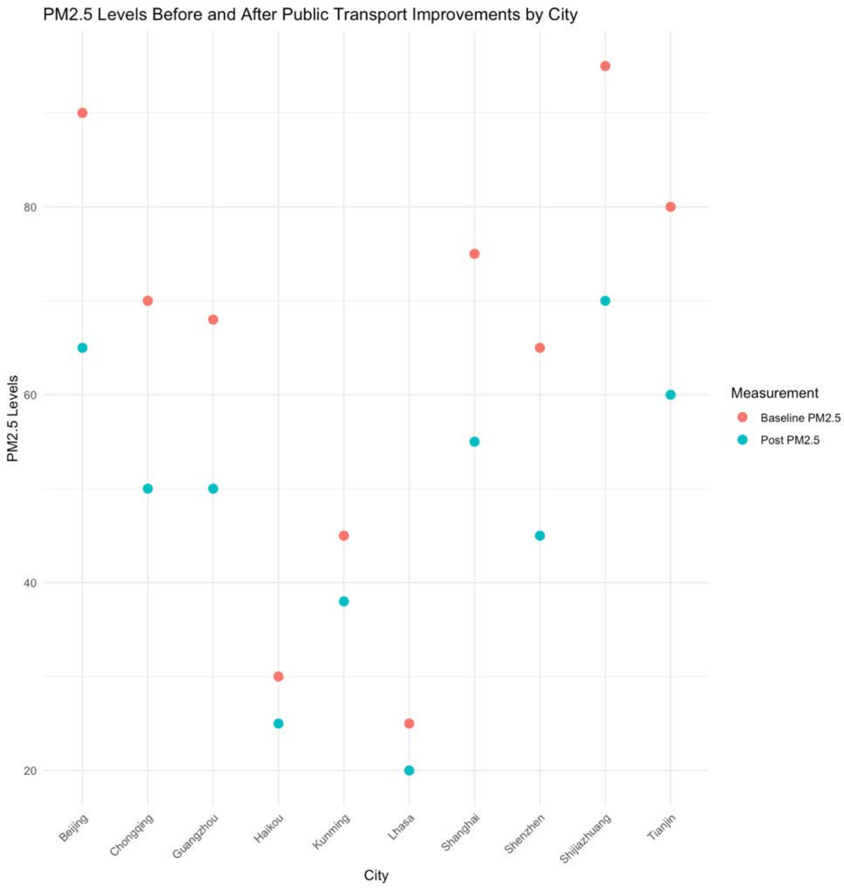

Figure 2. PM2.5 Levels Before and After Public Transport Improvements by City.

The amalgamation of these findings underscores a fundamental dynamic supporting the hypothesis: the correlation between initial conditions (baseline pollution levels) and the efficacy of public transportation development. Cities with elevated baseline pollution levels possess greater potential for enhancement and are likely to gain disproportionately from interventions, as these policies target fundamental and systemic sources of pollution, like automobile emissions and traffic congestion. Cities with lower baseline pollution levels may possess superior air quality and fewer pollution sources, inherently constraining the possible extent of improvement from analogous actions.

In conclusion, these findings corroborate the hypothesis by illustrating that the effects of public transportation development vary throughout cities, being influenced by initial pollution levels. The observed enhancements are more significant in cities with elevated beginning pollution levels, indicating that public transportation programs ought to be emphasized in these urban areas to optimize their environmental advantages. This research highlights the necessity of customizing urban air quality regulations to the distinct requirements and initial circumstances of each city, stressing a focused and context-aware strategy for public transportation advancement.

7. Implications

The findings of this research offer essential insights into the impact of public transportation development on reducing air pollution, with important ramifications for policy-making, urban planning, and sustainable development. The data indicating that cities with elevated baseline PM2.5 levels achieve more significant reductions in air pollution after public transportation initiatives underscores the necessity for targeted policies to optimize environmental advantages in regions with severe pollution issues.

7.1. Strategic Investments in Public Transportation

The findings indicate that the enhancement of public transportation should be prioritized in urban areas with elevated initial pollution levels. Urban areas, marked by dense populations and elevated traffic emissions, are poised to benefit significantly from initiatives such as metro expansions, bus electrification, and the establishment of Bus Rapid Transit (BRT) systems. Distributing resources to these cities not only provides significant environmental advantages but also tackles urgent public health issues associated with inadequate air quality. Policymakers must utilize baseline air quality data to pinpoint cities of high importance for public transit improvements.

7.2. Integration of Supplementary Policies

Improvements in public transit significantly affect air quality; yet, the findings underscore the necessity of supplementary policies, like automobile limits and more stringent emission regulations. Cities that enacted these policies in conjunction with transportation initiatives exhibited greater enhancements in PM2.5 levels. This indicates that public transportation policies are most efficacious when included in comprehensive legislative frameworks designed to diminish automotive emissions, advocate for cleaner fuels, and incentivize public transit usage over private vehicles.

7.3. Socioeconomic and Infrastructure Factors

The correlation between socioeconomic parameters, including GDP per capita and population density, and the efficacy of public transportation initiatives highlights the necessity of customizing policies to specific local situations. High-density metropolitan regions may necessitate an alternative strategy compared to less populated cities, especially regarding the scale and nature of the public transportation infrastructure established. Economic factors, including pricing and accessibility, are essential for the widespread adoption of public transit systems by metropolitan populations.

7.4. Contribution to International Climate Objectives

In addition to the immediate enhancements in air quality, the data indicate that the advancement of public transportation aids in wider global initiatives to address climate change. Mitigating PM2.5 concentrations via sustainable transportation systems not only diminishes urban pollution but also reduces greenhouse gas emissions, so reinforcing national and international pledges to carbon neutrality and sustainable development objectives (SDGs). Policymakers can utilize these data to promote public transportation as a dual remedy for local air pollution and global climate issues.

7.5. Empirical Research and Data-Informed Policy Development

This study highlights the necessity of utilizing comprehensive datasets and empirical techniques, such as Difference-in-Differences (DiD) analysis, to assess the effects of enhancements in public transportation. Utilizing data-driven methodologies enables policymakers and urban planners to more effectively evaluate intervention outcomes and formulate evidence-based plans for forthcoming projects. Consistent monitoring and reporting of critical metrics, such as air quality indices and transportation utilization trends, are vital for assessing success and enhancing regulations.

8. Reliability and Validity

8.1. Reliability

The study's reliabiliyu is guaranteed through the utilization of credible and reliable data sources. The collection includes air quality measures, socio-economic indicators, and public transportation data sourced from reputable institutions such as the China National

Environmental Monitoring Center (CNEMC), the World Bank, and municipal government reports. These sources are esteemed for their precision and thoroughness, minimizing the probability of data flaws or discrepancies. Moreover, use established metrics, such as PM2.5 concentrations to assess air pollution, improves the comparability of findings across different places and temporal contexts. The Difference-in-Differences (DiD) analytical method enhances reliability by controlling for time-invariant features and isolating the treatment effect of public transportation improvements. The application of resilient standard errors to address heteroskedasticity mitigates biases and guarantees the reproducibility of findings in analogous conditions.

8.2. Validity

The essay's validity is bolstered by the congruence of the study hypothesis, variables, and analytical techniques. Construct validity is attained by choosing variables that precisely represent the ideas being examined, such as baseline and post-intervention PM2.5 levels to assess air quality and forms of public transit improvements as the intervention. The Difference-in-Differences methodology enhances internal validity by controlling for confounding variables through a comparison of treated and untreated cities, while considering pre-existing patterns. This method mitigates the likelihood of erroneously linking alterations in air quality to variables not associated with public transit expansion. The study's emphasis on a varied array of Chinese cities with differing baseline pollution levels enhances external validity, facilitating generalizability to other metropolitan environments encountering analogous environmental issues. Furthermore, the incorporation of socio-economic variables, including GDP per capita and population density, guarantees that the research encompasses the wider context of urban development and enhancements in air quality.

The essay's reliability and validity are upheld by the utilization of high-quality data, stringent analytical methods, and a coherent alignment between research aims and methodologies. These features guarantee that the findings precisely and consistently represent the correlation between public transportation development and urban air quality, establishing a solid basis for policy recommendations and future research.

9. Conclusion

This study presents solid evidence that the growth of public transportation markedly enhances metropolitan air quality, with cities reaping differing benefits based on their initial pollution levels. An extensive investigation of PM2.5 reductions in various Chinese cities reveals that cities with elevated baseline pollution levels have more significant enhancements in air quality after implementing public transportation interventions than those with lower baseline pollution levels. This link underscores the unequal efficacy of these interventions in severely polluted metropolitan areas, where the opportunities for emission reductions and environmental improvements are most significant.

The findings underscore the necessity of prioritizing expenditures in public transportation in urban areas facing significant air quality issues. These efforts not only provide immediate decreases in hazardous pollutants such as PM2.5 but also tackle wider public health issues and advance global sustainability objectives by diminishing dependence on private automobiles and alleviating greenhouse gas emissions. Furthermore, the results highlight the imperative of incorporating supplementary policies, such as emission regulations and car limitations, to enhance the effectiveness of public transit advancements.

This study illustrates the essential need for data-driven policymaking in controlling urban air quality. By customizing actions for communities with elevated baseline pollution levels, authorities can enhance public transportation systems' environmental and health advantages. These insights enhance the existing research on sustainable urban development, providing practical recommendations for creating effective, equitable, and scalable strategies to address air pollution and foster healthier urban environments.

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