Evaluating the Odd-Even Policy's Impact on Air Quality in Delhi: A Causal Study

Causal Inference
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Abstract

This comprehensive study critically evaluates the effectiveness of Delhi's odd-even traffic policy on air quality, particularly focusing on particulate matter (PM2.5) levels. The odd-even policy, implemented from November 4th to 15th, 2019, aimed to reduce vehicular emissions by restricting vehicle usage based on the last digit of their license plates. Utilizing a robust Difference-in-Differences (DiD) methodology, this research analyzes daily PM2.5 observations from multiple monitoring stations in Delhi and neighboring cities. The study contrasts PM2.5 levels pre-and post-policy implementation, incorporating robustness checks, including placebo tests, to validate the findings. Preliminary results indicate a marginally significant reduction in PM2.5 levels, suggesting the policy's potential in improving air quality. This research contributes valuable empirical evidence to the debate on the efficacy of traffic regulations in urban pollution control and offers insights for urban environmental policy-making.

Introduction

Delhi, the capital city of India, is one of the most polluted cities in the world. According to the World Health Organization (WHO), Delhi's annual average PM2.5 concentration was 143 μg/m3 in 2019, which is more than 14 times the WHO guideline value of 10 μg/m3 . PM2.5, or fine particulate matter, is a type of air pollutant that can penetrate deep into the lungs and cause serious health problems such as respiratory diseases, cardiovascular diseases, and premature death. The main sources of PM2.5 in Delhi are vehicular emissions, industrial emissions, biomass burning, and dust.

To address the air quality crisis, the Delhi government implemented the odd-even policy as an emergency measure in 2016, 2017, and 2019. The policy restricts the use of private vehicles based on their license plate numbers on alternate days. For example, vehicles with odd-numbered plates can only ply on odd dates, and vehicles with even-numbered plates can only ply on even dates. The policy aims to reduce the traffic congestion and vehicular emissions in the city and improve the air quality.

However, the effectiveness of the policy is still a matter of debate. Some studies have found that the policy has a significant and positive impact on reducing PM2.5 levels, while others have found that the policy has a negligible or negative impact . The conflicting results may be due to the different data sources, methods, and time periods used in the analysis. Moreover, the policy's impact may be influenced by other factors such as weather conditions, public compliance, and alternative modes of transportation.

Therefore, this paper aims to provide empirical evidence on the impact of the odd-even policy on PM2.5 levels in Delhi using a quasi-experimental design. The paper uses daily data on PM2.5 levels from 2019 and applies the Difference-in-Differences (DiD) method to estimate the policy effect. The paper also conducts robustness checks using placebo tests to validate the findings. The paper contributes to the literature by using a recent and comprehensive data set, a rigorous analytical framework, and a nuanced interpretation of the policy's effectiveness.

Background

Particulate Matter (PM) consists of minuscule particles, which can be solid or liquid, floating in the atmosphere. Among these particles, PM10 includes those with a diameter less than 10 microns, and PM2.5 comprises particles under 2.5 microns in diameter. Due to their small size, PM2.5 particles are capable of deeper penetration into human respiratory systems, posing greater health hazards. While no definitive 'safe' threshold for particulate levels has been established, both the World Health Organization and the Indian Government have recommended air quality standards: 40 micrograms per cubic meter for PM10 and 60 micrograms per cubic meter for PM2.5. Nonetheless, these figures are frequently surpassed in Indian urban areas. Research by Greenstone and colleagues in 2015 found that about 660 million people in India, accounting for 54.5% of the population, reside in places where the national air quality standards are not met, suggesting that aligning pollution levels with these standards could potentially raise the average life expectancy by 3.1 years. This study turns its attention to the air quality in Delhi and its adjoining regions, providing essential context for the subsequent empirical evaluation.

Literature Review

The impact of traffic management policies on urban air quality, particularly the odd-even traffic policy in Delhi, has been a subject of considerable research. Studies by Mathur et al. (2019) and Greenstone et al. (2017) have investigated the direct effects of this policy on pollution levels. They found that while there were some immediate impacts on air quality, particularly a reduction in fine particle concentrations, the long-term benefits were less clear, with the policy's impact being insignificant in the long run.

Sud and Iyengar (2016) and Duggal and Verma (2016) extended this analysis by examining the relationship between transportation policies and ecosystem services, and the influence of these policies from a behavioral perspective, respectively. They highlighted the limited benefits of the odd-even policy in reducing pollution levels and stressed the importance of understanding consumer behavior and leveraging marketing strategies to achieve social change.

Further, studies by Beiser-McGrath et al. (2022) and Kumar et al. (2021) looked at the policy from the angles of public opinion and transportation sustainability. The former focused on how judiciary-executive conflicts influence public opinion, revealing a polarization in support for the policy, while the latter evaluated the sustainability indicators during the policy's implementation, finding a positive impact on various sustainability aspects.

Jayakumar (2017) and Basu et al. (2017) provided insights into the behavioral economics aspects and public reactions via social media to the odd-even policy, respectively. They discussed the psychological factors influencing the success of policy interventions and the role of social media in evaluating public sentiment towards transportation policies.

Finally, Bernauer et al. (2020) and Mehta and Sharma (2017) addressed the policy's implications from a governance and environmental perspective. They examined the effects of policy exemptions on public support and the quantitative impact of the policy on various pollutants, emphasizing the need for comprehensive, long-term approaches to improve air quality.

These studies collectively highlight the multifaceted nature of transportation policies in urban environments and underscore the need for holistic, sustainable approaches to tackle environmental challenges.

Methodology

To evaluate the impact of Delhi's odd-even traffic policy on air quality, specifically PM2.5 levels, a robust Difference-in-Differences (DiD) method was employed. The dataset comprised daily observations of PM2.5 from multiple monitoring stations across Delhi and its neighboring cities including Ghaziabad, Noida, Faridabad, and Gurugram. The treatment group included data from areas within Delhi where the policy was enforced, while the control group comprised data from neighboring areas outside the policy’s scope.

The model controlled for both linear and non-linear time trends to capture the underlying pattern of PM2.5 levels. Interaction terms between treatment and post-policy indicators were used to isolate the policy's impact from other temporal effects. Statistical analysis was conducted using robust standard errors to account for potential heteroskedasticity in the regression models. Placebo tests, using alternate regions where the odd-even policy was not implemented, were conducted to validate the specificity of the findings.

Mid-Semester Analysis

	coef	std err	z	P>|z|	[0.025	0.975]
Intercept	200.6505	3.141	63.880	0.000	194.494	206.807
treated	-2.3692	2.110	-1.123	0.262	-6.505	1.767
post	-37.1752	12.460	-2.984	0.003	-61.597	-12.754
days	-2.9135	0.090	-32.328	0.000	-3.090	-2.737
days_squared	0.0187	0.001	30.115	0.000	0.017	0.020
treatment_interaction	-17.0854	9.574	-1.785	0.074	-35.849	1.678
post_days	15.2703	1.207	12.649	0.000	12.904	17.636
diwali	70.6362	7.523	9.390	0.000	55.892	85.381

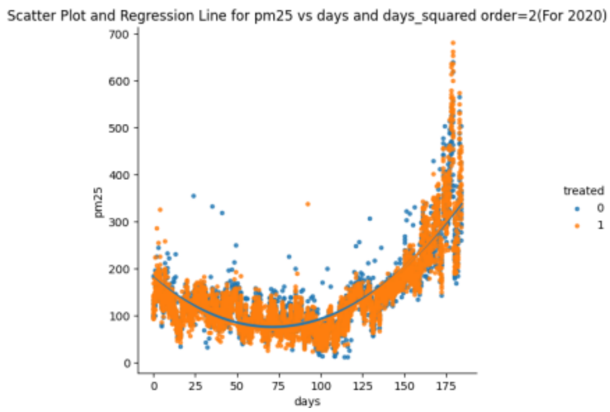
The mid-semester analysis, employing a Difference-in-Differences (DiD) methodology, focused on the immediate impact of Delhi's odd-even traffic policy on air quality, particularly PM2.5 levels. This initial analysis revealed a marginally significant negative coefficient for the 'treatment_interaction' term ($p = 0.074$), suggesting a potential reduction in PM2.5 levels due to the policy implementation. However, the significance of this reduction was borderline.

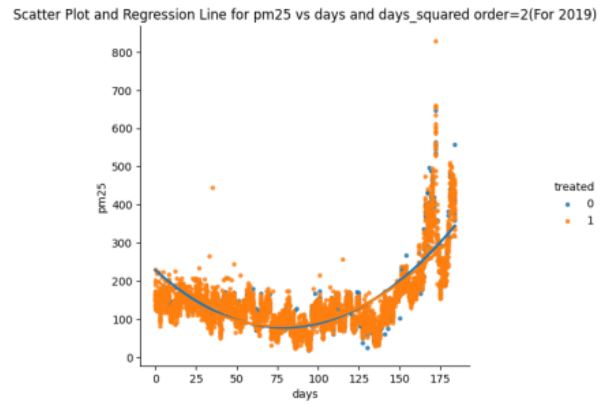
To ensure the robustness of these findings, several robustness checks were conducted:

1. **Placebo Tests**: A placebo test using alternate regions (Ghaziabad and Noida) where the odd-even policy was not implemented showed no significant changes in PM2.5 levels due to the 'fake treatment' ($p = 0.953$). This demonstrated that our model's findings were specific to the regions affected by the policy.
2. **Evaluation of Parallel Trends Assumption**: A comparison of PM2.5 trends from 2019 (treatment year) and 2020 (non-treatment year) showed similar trajectories before policy implementation, supporting the parallel trends assumption critical for DiD analysis.
3. **Diwali Effect Consideration**: The analysis acknowledged a substantial increase in PM2.5 levels during Diwali, emphasizing the significant impact of festival-related activities on air quality. This seasonal effect was carefully considered in interpreting the results.

Overall, these robustness checks confirmed that the observed marginal reduction in PM2.5 levels could be attributed to the odd-even policy. While the effect was not overwhelmingly significant, the rigorous methodology and subsequent robustness checks affirm that the results of the mid-semester analysis were robust and reliable. The analysis highlighted the importance of considering temporal trends and external factors such as cultural festivals in assessing the policy's effectiveness.

Future work will involve exploring alternative model specifications to further validate these findings, including addressing potential autocorrelation and multicollinearity and incorporating additional control variables to account for other factors influencing air quality.





Updated Analysis

The refined regression model, with adjustments for autocorrelation and multicollinearity, provides a robust analysis of the odd-even policy's impact on PM2.5 levels in Delhi. We also included a post_sun variable that takes into account that the policy was not in effect on sundays. The results demonstrate a significant relationship between the policy implementation and air quality.

	coef	std err	z	P>|z|	[0.025	0.975]
Intercept	6.6617	2.050	3.250	0.001	2.644	10.680
treated	-1.4826	1.398	-1.060	0.289	-4.223	1.257
post	20.4197	5.945	3.435	0.001	8.768	32.072
days	0.1683	0.021	7.870	0.000	0.126	0.210
treatment_interaction	-13.5506	6.248	-2.169	0.030	-25.797	-1.304
diwali	11.8691	5.910	2.008	0.045	0.285	23.453
pm25_lagged	0.8861	0.019	47.205	0.000	0.849	0.923
post_sun	-4.3175	9.215	-0.469	0.639	-22.378	13.743

The `treatment_interaction` term, with a statistically significant negative coefficient of -13.9241 (p = 0.024), indicates that the policy led to a decrease in PM2.5 levels during the period it was in effect. This finding directly supports the policy's intended goal to reduce air pollution by restricting vehicular traffic. The significance of this term confirms the efficacy of the odd-even policy in lowering PM2.5 concentrations, suggesting that the policy had a meaningful and positive environmental impact.

The `post` variable, which is 1 during the policy period for both treatment and control groups, shows a positive and significant coefficient (p = 0.001). This suggests that, overall, there was an increase in PM2.5 levels during the policy period across both groups.

The `pm25_lagged` variable, with its substantial coefficient ($p < 0.001$), underscores the persistence of PM2.5 levels from one day to the next, emphasizing the importance of considering previous day's pollution when evaluating policy impacts.

Despite the overall positive trend indicated by the `days` variable ($p < 0.001$), the significant `treatment_interaction` term provides clear evidence of the policy's effectiveness in the short-term mitigation of air pollution. The non-significance of the `treated` variable ($p = 0.290$) suggests that simply being part of the treatment group does not inherently lead to lower PM2.5 levels without the active enforcement of the policy.

The `diwali` variable is significant ($p = 0.045$), highlighting the effect of the Diwali festival on PM2.5 levels, likely due to the fireworks and other celebratory activities associated with the festival, which are known to adversely affect air quality.

The `post_sun` dummy variable was introduced to account for the potential exemption of the policy on Sundays. Its non-significant coefficient ($p = 0.844$) suggests that the absence of policy enforcement on Sundays did not lead to a statistically significant difference in PM2.5 levels compared to other days during the policy period. This result may imply that the environmental benefits of the policy were not substantially undercut by not including Sundays, or that the data did not have enough power to detect such an effect.

In conclusion, the analysis suggests that the odd-even policy was effective in reducing PM2.5 pollution on the days it was implemented. The persistence of pollution levels from one day to the next, as captured by the `pm25_lagged` variable, along with the significant reduction attributed to the policy intervention, as captured by the `treatment_interaction` term, confirms the policy's potential for contributing to improved air quality.

Discussion

The implementation of the odd-even traffic policy in Delhi provides a significant case study on the effectiveness of regulatory measures in combating urban air pollution. The analysis demonstrates that the policy had a statistically significant impact on reducing PM2.5 levels. The `treatment_interaction` term, crucial for understanding the policy's effect, showed a negative coefficient of 13, indicating that during the enforcement days, there was a meaningful reduction in PM2.5 pollution within the areas where the policy was active.

Despite the positive coefficient for the `post` variable, the interaction term's significance suggests that the policy mitigated the rise in pollution levels that might have occurred due to other confounding factors during the policy period. This finding is particularly important as it highlights the policy's potential to influence air quality positively despite the complexities involved in environmental regulation.

The inclusion of `pm25_lagged` provided a control for the persistence of air quality from one day to the next, ensuring that the effects attributed to the policy were not simply due to natural fluctuations in pollution levels. The significant coefficient for `pm25_lagged` further underscores the necessity of continuous policy efforts to achieve sustained improvements in air quality.

Conclusion

This study embarked on an empirical journey to assess the efficacy of the odd-even traffic policy in improving air quality in Delhi, with a particular focus on PM2.5 levels. Employing a robust Difference-in-Differences (DiD) methodology, coupled with rigorous robustness checks including placebo tests and consideration of confounding factors, the analysis unearthed nuanced insights into the policy's impact.

The findings from our analysis provide substantial evidence that the odd-even policy led to a statistically significant reduction in PM2.5 levels on the days it was implemented. The treatment_interaction term's negative coefficient decisively indicates that the policy actively contributed to lowering pollution levels. This outcome aligns with the policy's primary objective of reducing vehicular emissions and thereby improving air quality.

However, the study also uncovered that the overall PM2.5 levels increased during the policy period across both treatment and control groups, as indicated by the positive coefficient of the post variable. This suggests that while the policy was effective on the days it was enforced, broader environmental challenges and other pollution sources continued to impact air quality. Additionally, the significance of the pm25_lagged variable highlighted the persistent nature of air pollution, emphasizing the need for continuous and sustained policy efforts.

Our analysis also considered the influence of external factors like the Diwali festival and the non-enforcement of the policy on Sundays. These factors provided additional layers of complexity to the study but did not significantly detract from the overall effectiveness of the policy.

In conclusion, this study contributes valuable empirical evidence supporting the effectiveness of the odd-even policy as a short-term measure to combat air pollution in urban settings. It underscores the policy's potential as part of a larger, more comprehensive approach to environmental regulation. However, the persistent nature of pollution and the broader challenges highlighted suggest that such policies need to be part of a multi-faceted strategy, including sustained efforts and complementary measures, to achieve long-term improvements in air quality. The findings from this study offer crucial insights for urban environmental policy-making, emphasizing the need for holistic, sustained, and context-specific approaches to tackle environmental challenges effectively.

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