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Are the Rules 'Even' for an 'Odd' Policy: Analysis of Odd-Even Air Pollution Rationing Policy of New Delhi, India

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Air pollution poses a critical challenge to public health, particularly within the Global South, where it undermines the attainment of several Sustainable Development Goals (SDGs), notably Goal 3 (Good Health and Well-being), Goal 11 (Sustainable Cities and Communities), Goal 13 (Climate Action), and Goal 15 (Life on Land). In India, where air pollution levels rank among the highest globally, the associated health impacts are severe and pervasive. Despite extensive research on the immediate effects of vehicular rationing policies like the Odd-Even policy—implemented in Delhi by the Government under the Graded Response Action Plan (GRAP) to reduce vehicular emissions—there remains a significant gap in the literature regarding its efficacy in a high population pressure, high density area and its outcomes from a citizen-centric perspective.

This study critically examines the impact of the Odd-Even policy on air quality, focusing on key pollutants such as sulfur dioxide (SO_2), nitrogen dioxide (NO_2), particulate matter (PM), ozone (O_3), carbon monoxide (CO), and benzene. Additionally, the research evaluates public perceptions of the policy's effectiveness through statistical analysis of survey data. The findings reveal that while levels of particulate matter ($PM_{2.5}$) increased due to policy exemptions, no statistically significant reductions were observed in other pollutants. Public support for the reimplementation of the policy was notably higher among individuals owning multiple vehicles, especially those who could alternate between cars.

The paper concludes that, although the Odd-Even policy may yield more competent results in air quality in larger territory with lesser density with stricter restrictions it is insufficient as a medium to long-term solution. The medium to long run increase in vehicles was observed in short to medium run due to the metropolitan nature of the capital city. The study advocates for the development of more comprehensive and sustainable air pollution control strategies with fewer exemptions, including enhanced public transportation infrastructure, broader

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dissemination of air quality information, and collaborative cross-border efforts to mitigate exogenous sources of pollution like industrial and agricultural pollution. Ultimately, the research highlights the limitations of the Odd-Even policy in Delhi and similar high density cities of the Global South and calls for more robust, systematic approaches to air quality management.

Keywords
Odd-Even policy, Delhi, Particulate matter, Public perception, Vehicular emissions, Global South, Sustainable Development Goals

Introduction

Air pollution has emerged from a localized environmental problem into a transnational problem with enormous economic and health impacts on developing economies like India. Air pollution breeds negative externalities for society: the cost is borne not by the polluter but by society. Thus indicative of a market failure.

The Lancet Report 2024 stated that more than 6.7 million premature deaths worldwide occur annually due to air pollution. India has to bear the most disproportionate burden with more than 1.7 million premature deaths occurring each year. Such health outcomes incur some serious economic costs. According to estimates by the Asian Development Bank (ADB), Indian air pollution contributes around $36 billion towards the annual damages in terms of lost productivity and increased healthcare and premature mortality-expressed as equivalent to 3.1 percent of its GDP. This is not only through the direct cost of human capital deterioration.

Economic implications of air pollution in cities like New Delhi, which constantly feature on the world's list of most polluted cities, are at their peak. Both the State of Global Air Report 2024 and IQAir 2024 World Air Quality Report confirm that the annual $PM_{2.5}$ concentration in New Delhi is eight times higher than the WHO limit, which creates a serious threat to respiratory and cardiovascular health, thus lowers the productivity of the workforce. The empirical evidence suggests that exposure to a high dose of particulate matter significantly depressed both cognitive and physical performance, which further declines labour productivity. According to a paper from the Indian Institute of Management Ahmedabad (IIMA), air pollution alone decreased India's GDP growth rate by as much as 0.5–1 percent annually, thereby increasing economic costs from lost human capital and missed workdays.

The economic cost for India in fighting air pollution is evident. Cutting air pollution will have far-reaching effects beyond better public health, it will also generate substantial economic benefits. According to a report in The Lancet 2024, a 10 percent reduction in global air pollution could prevent millions of deaths and generate significant savings in the economy. For India, all these savings would come in terms of increased labor productivity, reduced health costs,

and an efficient labor force-all channeled into the long-term growth path. There is thus a good economic reason to invest in cleaner technologies, better public transport mechanisms, and stringent regulatory approaches.

The "Odd-Even" vehicle restriction scheme in Delhi may not have been very effective to check pollution as there are several sources of pollution from industries, agricultural residue burnings, and vehicular emissions. A better solution would be to combine market-based solutions such as carbon pricing or cap-and-trade systems, with stricter enforcement of air quality standards. This also includes the transnational nature of pollution, in particular, that of cross-border industrial emissions and agricultural practices. Regional cooperation amongst South Asian nations to create collective policy frameworks as well as benchmarks will serve this purpose.

What is the Odd-Even policy?

The Odd-Even policy has served to ration vehicle movement on roads. Under this policy vehicles with licence plates ending with even numbers (0, 2, 4, 6 and 8) are allowed to run on even dates, while those with odd (1, 3, 5, 7 and 9) number plates are permitted on odd dates. The arrangement was applicable in Delhi from 8 a.m. to 8 p.m. but not enforced on Sundays. Two-wheelers and electric vehicles were exempted. The same exemption was not extended to CNG vehicles. Women-only vehicles with children aged up to 12 years and those used by physically disabled people were also exempted. In addition, twenty-nine categories of vehicles, including those for the President, Prime Minister, emergency and enforcement, were also excluded. Violations of the policy leads to a fine of Rs 4,000. All cluster buses were pressed into service to facilitate the people. An entire fleet of Delhi Transport Commission (DTC) buses were deployed during the implementation period. Delhi Metro Rail Corporation (DMRC) also conducted additional trips during the scheme. In addition, 600 teams of Delhi Traffic Police, transport and revenue departments were deployed to ensure a strict implementation of the scheme. The policy has been imposed on multiple occasions for shorter durations under the Graded Response Action Plan (GRAP) for curbing air pollution. However, the time period extensively discussed in the paper pertains to **April 15–30, 2016 to eliminate exogenous pollution of agricultural residue burning, which is seasonally deposited due to the geographical location of Delhi.**

Literature review

Air pollution remains one of the most pressing public health challenges in urban areas across the globe, with New Delhi as the world's most polluted

capital city (Global Air Quality Report: IQAir). As urban population swells and industrial activities intensify, air quality continues to deteriorate, leading to severe health consequences. According to the World Health Organization (WHO), air pollution is linked to over 7 million premature deaths annually worldwide, with Delhi bearing the brunt of the burden in India (WHO, 2016). Air pollution in Delhi is primarily driven by vehicular emissions, industrial pollutants, and agricultural practices such as stubble burning in neighboring states like Punjab and Haryana.

Studies by Sharma et al. (2018) have revealed that pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), and particulate matter (PM) are rampant in Delhi's atmosphere, contributing to severe health conditions, including respiratory and cardiovascular diseases. These pollutants have reduce life expectancy in the capital, with estimates indicating that Delhiites lose an average of 9.7 years of their life due to poor air quality (Gandhiok, 2021). The gravity of this issue is underscored by data from the University of Chicago, which highlights the geographical spread of pollution, negatively impacting the health of millions across India (Greenstone et al., 2021).

The emissions of CO and NOx due to personal cars (PCs) are found to be about 34 percent and 50 percent respectively, and the emission of CO due to 2 W (2- Wheeler) is about 61 percent. The analysis of fuel-wise emission of pollutants reveals that CO is mainly emitted by petrol vehicles, whereas NOx and PM are emitted by diesel vehicles. It is also noticeable that CO, NOx and PM emissions at ITO, one of the busiest traffic intersections of Delhi, are approximately 15, 6 and 0.5 tons/day respectively, which are found to be the maximum followed by Kashmiri Gate (ISBT), and Nizamuddin (Goyal, P., et al, 2013). Additionally, it was found that Delhi had 1.7 times the prevalence of respiratory symptoms (in the past 3 months) compared with rural controls ($P < 0.001$); the odds ratio of upper respiratory symptoms in the past 3 months in Delhi was 1.59 (95 percent CI 1.32–1.91) and for lower respiratory symptoms (dry cough, wheeze, breathlessness, chest discomfort) 1.67 (95 percent CI 1.32–1.93) (Rizwan, S., et al, 2013). The gravity of the matter is highlighted by the severe and unprecedented health risks in the capital.

In response to this rising crisis, the government has taken various measures to reduce the levels of pollution, among which the odd-even traffic rationing scheme has been one of the most popular and replicable schemes across cities and countries. The odd-even policy was thought of as a short-term measure for managing traffic; it imposed restrictions on the use of private vehicles depending on whether the last digit of their number plates falls under odd or even numbers. Although conceptualized as a stop gap measure, the practice has given a clear view of its practicality in curbing vehicular emissions and thus effectively reducing the percentage of pollutants in the atmosphere.

The idea of rationing traffic was first applied extensively during the "Hoy No Circula" scheme implemented in Mexico City from 1989 onwards, when vehicles with odd and even number plates were allowed to run only on alternate days. Although this initiative resulted in short-term air quality improvements, it faced long-term challenges, such as an increase in the number of vehicles purchased by households to circumvent the policy, which ultimately exacerbated pollution levels (Down to Earth, 2015). Similar issues were observed in Bogotá, Colombia, where the policy showed promise in the short run, but its impact diminished over time as people adapted by acquiring additional vehicles.

Beijing, China, enforced the odd-even policy before the 2008 Olympic Games. During the implementation period, pollution decreased by 20 percent. It showed that such a measure could be effective for reducing vehicular emissions. However, when the policy was lifted post-Games, pollution levels rapidly rebounded, signaling the need for more comprehensive and sustainable solutions (Down to Earth, 2015). In Paris, the policy was enforced during high smog episodes in 2015, but while it temporarily reduced pollution, the long-term effectiveness of such a scheme has been questioned.

Delhi's own experiment with the odd-even scheme, first introduced in 2016, sought to address the capital's severe air quality crisis. The Central Pollution Control Board (CPCB) reported a decrease in pollutants during the period when the policy was enforced, particularly nitrogen oxides (NOx) and carbon monoxide (CO), which are major contributors to vehicular pollution (CPCB, 2016). However, the short-lived success of the policy in Delhi also highlighted challenges such as insufficient public transportation infrastructure, which left many residents without viable alternatives to private vehicle use.

The effectiveness of the odd-even scheme has also been studied by a number of researchers with mixed findings. For instance, Garg and Gupta (2020) found a pronounced decrease in pollution levels during the implementation of the policy in Delhi but mentioned that other measures like the improvement of public transport and better enforcement of emission norms must be combined with the odd-even scheme. Similarly, Rizwan et al. (2013) concluded that despite a temporary decrease in vehicular emissions due to an odd-even policy, industrial emissions, construction dust, and stubble burning continue to pollute the air.

Despite its widespread research, the long-term effectiveness and citizen-oriented outcomes of the odd-even policy remains largely under-researched. While there have been numerous evaluations of its short-term impact on air quality, there is a dearth of studies that investigate how such policies could be integrated into broader, sustainable air pollution control strategies. Recent studies by Singh et al. (2020) and Mehta and Kumar (2021) underscore the need to explore not only the temporary effects of traffic rationing but also the long-term health

outcomes and socio-economic implications, particularly for low-income groups who may be disadvantaged by such policies.

Furthermore, Aitalieva et al. (2019) highlights the importance of citizens' perceptions in shaping the success of government policies, indicating that public opinion and citizen satisfaction are crucial factors in evaluating the effectiveness of governmental actions. Additionally, they indicate that within countries, citizens' perceptions of government policy success are largely influenced by individual sociodemographic attributes and political attitudes. This suggests that while individual citizens' views are important, the broader context of public institutions and economic stability also greatly influences how citizens perceive the success of government policies.

This paper seeks to fill these gaps by providing a statistical overview of the pollutant quantity pre and post the vehicular experimentation in New Delhi. The study will also evaluate the citizen perception associated with air pollution reduction during periods of traffic rationing, providing a more holistic understanding of the policy's benefits and limitations.

The odd-even traffic rationing scheme has been implemented with varying degrees of success in cities around the world. While it offers short-term relief from vehicular emissions and improves air quality during its enforcement, the policy alone is insufficient to tackle the complex, multifaceted problem of air pollution. This paper's exploration of the impacts of the odd-even policy in a rapidly developing country, its social equity implications, and the potential for its integration into broader air quality management strategies will contribute valuable insights to both local and global policymaking efforts aimed at improving urban air quality. By addressing the research gaps related to the sustainability and comprehensiveness of such measures, this study will provide a nuanced understanding of the role of traffic rationing policies in the broader context of air pollution control and public health improvement.

Materials and methodology

A. Pollution levels pre and during odd-even

In accordance with this, this research outlines of the current state of air quality in Delhi. The data were extensively collected, cleaned and compiled to conduct the analysis. Sulphur dioxide (SO_2), nitrogen dioxide (NO_2), suspended particulate matter (PM), ozone (O_3), carbon monoxide (CO) and benzene are observed to be prominent polluters in Delhi.

The Odd-Even policy was analysed by implementing Welch's t-test on the data to draw conclusions about the effectiveness of the policy and determine

whether a statistically significant difference in the air quality is observed when the policy was implemented and when it was not due to the small sample size. Welch's t-test is an unequal variance parametric test of the conventional two-sample t-test. The data used for this is published by the **CPCB (Central Pollution Control Board, Ministry of Environment, Forest and Climate Change, Government of India)**.

The dataset for NO_2 contains fifteen observations, **$PM_{2.5}$ has ten observations, benzene has five observations, CO (carbon monoxide) has six observations, O_3 (ozone) has five observations, and SO_2 (sulphur dioxide) has fifteen observations.**

B. Survey

The survey yielded a total of 425 responses, which were analyzed using a probit regression model and is summarized below. The experience variable, two-wheeler possession and variable recording reimplementation of Odd-Even are statistically significant. The participants were randomly selected. The survey includes participants from both vehicle-owning and non-owning groups to capture a broader view of the capital's demographic. Furthermore, the non-vehicle-owning group uses public transport systems, Their perspectives also shape the general perception of the policy.

Public opinion is crucial because the policy's success depends on it. If the public is not inclined to follow the policy, then its benefits will not materialize. The survey was bilingual to reflect Delhi's diversity. The languages used were Hindi and English, the most prominent languages in Delhi. The survey was distributed via social media (WhatsApp, Facebook) and in person and in person as well. To make the survey **user friendly** the majority of the questions were yes/no/maybe. The probit model requires a binary dependent variable (yes or no). The survey was analysed by **conversion of yes and no values into dummy variables of 1 and 0** respectively. The data with maybe as reply was excluded. Participants who chose "maybe" may exhibit bandwagon bias (i.e., following the majority).

Cross-tabulation of the survey responses was also performed to provide a more holistic analysis of different variables. The paper analysed the Odd-Even policy to draw conclusions about the success of the policy to reduce air pollution. The survey questions are summarised below:

1. **What is your age?**
2. **What do you think about Air Pollution?**

3. **Do you have any two-wheelers?**
4. **How many cars do you have?**
5. **What is the last number on your car's licence plate?**
6. **Do you think Odd-Even policy helped in reducing Air Pollution in Delhi?**
7. **Should the Odd-Even policy be implemented again?**

Result and discussion

A. Pollution levels pre and during odd-even

In Delhi, the variation in pollution levels between before and after the Odd-Even scheme implementation was measured from April 15th, 2016 to April 30th, 2016 by conducting Welch's t test on six pollutants: PM2.5, NO_2, O_3, CO, SO_2, and benzene in $\mu g/m^3$ at ten monitoring stations over the city. It tried to find out whether the changes were statistically significant for the said period of implementation of the scheme.

Primary pollutants

$PM_{2.5}$

The mean comparison highlighted a statistically significant increase in the level of $PM_{2.5}$ from the implementation of the Odd-Even scheme, p=0.0048. Thus, this would mean that the policy has not succeeded in decreasing concentrations of $PM_{2.5}$. The 95 percent confidence interval of the true mean difference in $PM_{2.5}$ levels between the pre- and during-scheme periods was (-69.88689, -11.11311), thereby clearly showing that there was an increase in the levels of pollutants during the implementation phase. This calls into question the effectiveness of the Odd-Even policy regarding this critical pollutant, directly linked to respiratory problems and harmful health impacts on the urban populace. These results may be a sign that vehicular emissions, the core of the policy, are still one of the leading sources of the city's $PM_{2.5}$ levels.

NO_2

No decreasing trend was observed in NO_2 concentrations during the Odd-Even scheme. This is significant because NO_2 is the largest component of

vehicular exhaust, and it is usually targeted by policies aimed at improving air quality. Multiple factors may contribute to NO_2 levels, but it may even be a representation of non-compliance with the scheme or the increase in pollution exacerbated from other alternate sources such as industrial activities, or power generation.

CO

There is no statically significant difference on the concentrations of carbon monoxide (CO) between the two periods, i.e., the pre-policy period and the policy period. CO is primarily emitted by vehicles, and given no considerable changes in CO concentrations, then it can be regarded that Odd-Even scheme has failed to present an effect on reducing the vehicle emissions of this pollutant.

SO_2

There is no discernible difference between the pre- and post-Odd-Even periods for SO_2. SO_2 is mainly emitted by industrial sources or power generation rather than by vehicles. The lack of significant change in SO_2 during the policy of the odd-even scheme is not unexpected; the scheme was not instituted to target the major emitters of this pollutant. This suggests that reducing SO_2 requires targeted measures such as would be through enhanced regulatory control over industrial emissions or promotion of clean energy supply among other interventions.

Secondary pollutants

Benzene

There was no statistically significant change in benzene concentrations during the Odd-Even period. This suggests that the policy did not make a visible impact on the concentration of benzene in the air. Benzene, as a volatile organic compound, is largely associated with industrial sources, gases from gasoline, and other non-vehicular emissions. Lack of strong evidence of alteration in benzene levels suggests that Odd-Even may have made minimal impacts on pollutants emanating from non-vehicular sources.

O_3

No statistical difference was observed in ozone levels for the Odd-Even period. Ozone is a secondary pollutant formed through photochemical reactions with some precursors, mainly NOx and VOCs. Since the Odd-Even scheme targets emissions from vehicles, which are precursors to ozone formation, the lack of significant change in O_3 levels indicates that the effect of the policy concerning secondary pollutants may be constrained and also influenced by multiple factors, including meteorology and precursor emissions from non-vehicular sources, such as climatic factors and industrial emissions.

POLLUTANT	OBSERVATION	MEAN	STANDARD ERROR	STANDARD DEVIATION
PM2.5	Ha: diff < 0 Pr(T < t) = 0.0048	Ha: diff ! = 0 Pr(|T| > |t|) = 0.0095		Ha: diff > 0 Pr(T > t) = 0.9952
PRE ODD EVEN	10	85.5	11.09	35.1
DURING ODD EVEN	10	126	8.57	27.1
BENZENE	Ha: diff < 0 Pr(T < t) = 0.5352	Ha: diff ! = 0 Pr(|T| > |t|) = 0.9259		Ha: diff > 0 Pr(T > t) = 0.4648
PRE ODD EVEN	5	5.6	3.4	7.6
DURING ODD EVEN	5	5.2	2.8	6.2
NO2	Ha: diff < 0 Pr (T < t) = 0.0577	Ha: diff ! = 0 Pr (|T| > |t|) = 0,1153		Ha: diff > 0 Pr (T > t) = 0.9423
PRE ODD EVEN	15	50.33	4.65	18.01
DURING ODD EVEN	15	62	5.48	21.22
SO2	Ha: diff < 0 Pr (T < t) = 0.1138	Ha: diff ! = 0 Pr (|T| >| t |) = 0.2276		Ha: diff > 0 Pr (T > t) = 0.8862
PRE ODD EVEN	15	16.53	3.43	13.31
DURING ODD EVEN	15	22.46	3.37	13.06

Table 1: welch's t test result of primary and secondary pollutants

CO	Ha: diff < 0 Pr (T < t) = 0.0670	Ha: diff ! = 0 Pr (|T| > |t)|) = 0.1339		Ha: diff > 0 Pr (T > t) = 0.9330
PRE ODD EVEN	6	891.16	127.23	311.67
DURING ODD EVEN	6	1333.83	235.86	577.74
O3	Ha: diff < 0 Pr (T < t) = 0.1398	Ha: diff ! = 0 Pr (|T| > |t|) = 0.2796		Ha: diff > 0 Pr (T > t) = 0.8602
PRE ODD EVEN	5	58.8	11.52	25.76
DURING ODD EVEN	5	78.4	12.68	28.36

Table 1: (Continued)

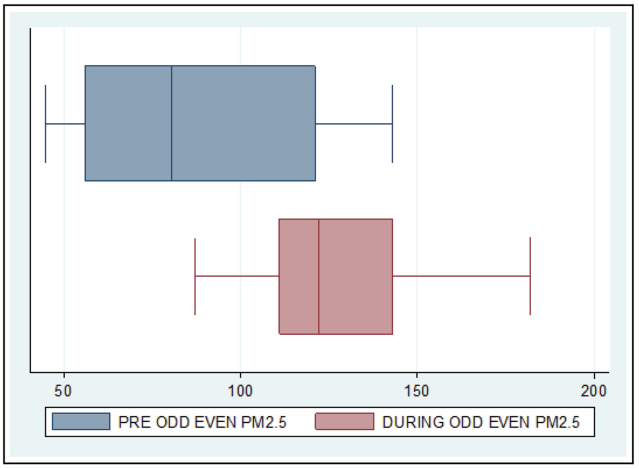

Figure 1: Box plot comparison of $PM_{2.5}$ before and during Odd-Even

Exemptions and Population Density

An estimated 20–25% of vehicles were exempt from the restrictions. These included vehicles used by women, emergency services, and government officials. Given Delhi's exceptionally high population density exceeding 11,000 individuals per square kilometer (Sharma & Dixit, 2016) and the city's limited

road space, these exemptions significantly diluted the potential impact of the policy in reducing traffic volumes and improving air quality. The persistent traffic congestion during the enforcement period underscores the difficulty of implementing such policies in densely populated urban environments, where the demand for mobility is substantial and growing.

Vehicle Growth and Policy Challenges

In the fiscal year 2015–16, Delhi experienced a notable increase of 9.94% in the number of registered vehicles (Delhi Transport Department Annual Report, 2015–16). This rapid expansion of the vehicle fleet outpaced the ability of the Odd-Even policy to effectively mitigate congestion. Furthermore, research conducted by the Indian Institute of Technology (IIT) Delhi indicated that vehicle registration rates accelerated during the policy's implementation, with a 7 percent increase in registrations between 2015 and 2016, exceeding the historical average growth rate of 5 percent. This implies that the policy had inadvertently changed vehicle usage patterns, as people used alternative registration plates or relied on exempt categories to circumvent the rules. This may result in a short-term behavioral change, rather than resulting in a more permanent reduction in vehicular use. These findings further substantiate the t-test results. High-density areas with limited geographical area require exemptions, but these exemptions render the policy ineffective. For successful implementation, either population density must be lower or the implementation area larger. The vehicular rationing policy is not effective in the Global South.

Medium to Long-Term Implications

The rapid urbanization and population growth in Delhi, coupled with the rising demand for mobility, present significant challenges to the long-term success of the Odd-Even policy. According to projections by the Delhi Transport Department, the number of vehicles on Delhi's roads was expected to exceed 10 million by 2020, with vehicle ownership continuing to increase at an annual rate of 5–6 percent. The fact that the growth of vehicles during the Odd-Even period was accelerated by a 7 percent increase in registrations indicates that this policy has **shifted short-term behavior, not changed long-term usage permanently**. This likely does not translate into a decreased vehicle density and therefore the reduction in emissions was not maintained long term.

The Odd-Even policy provided a short-term respite, its high exemption rate along with rapid growth in vehicles and scarce road space undermined it considerably toward any long-term basis of success in solving congestion-related issues and air pollution. A more holistic and sustainable approach aimed at tackling the root causes of vehicular growth and congestion would be required to bring about long-term benefits to air quality and urban mobility.

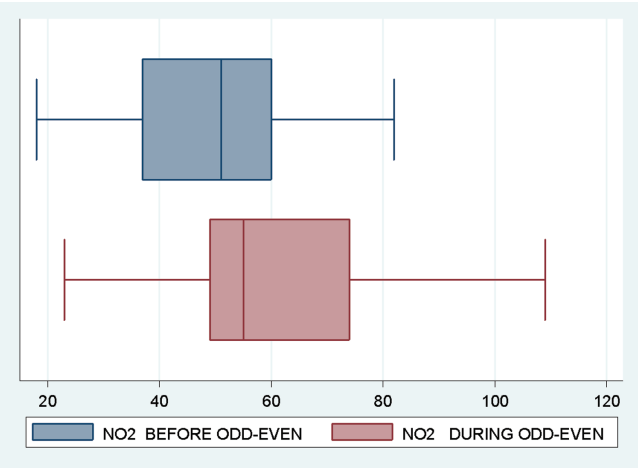

Figure 2: Box plot comparison of NO_2 before and during Odd-Even

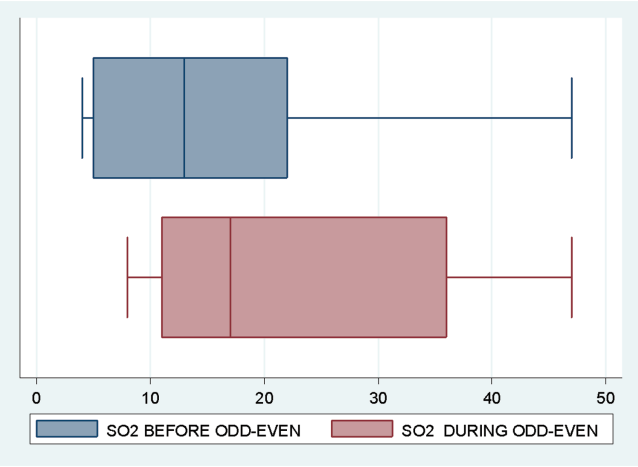

Figure 3: Box plot comparison of SO_2 before and during Odd-Even

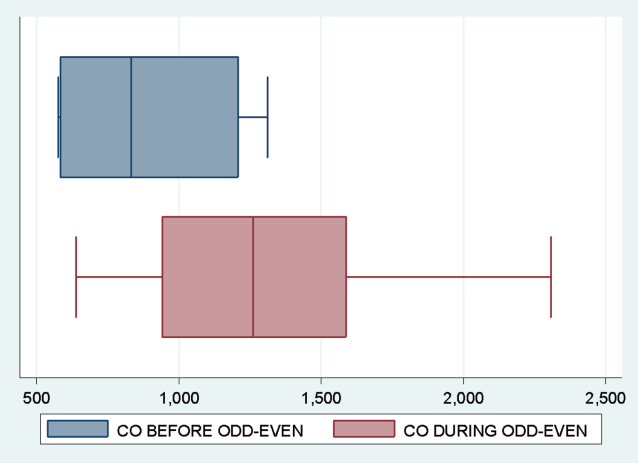

Figure 4: Box plot comparison of CO before and during Odd-Even

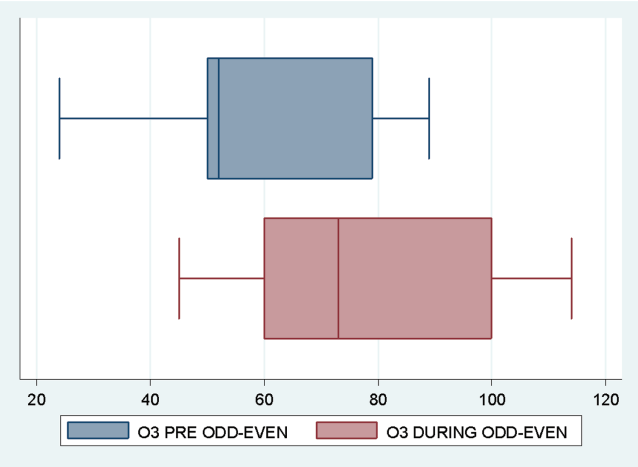

Figure 5: Box plot comparison of O_3 before and during Odd-Even

B. Survey

Support for reimplementation of the Odd-Even policy is influenced by several factors. A positive prior experience with the scheme notably motivates individuals to support its reintroduction. Furthermore, ownership of two-wheelers significantly influences support, likely because two-wheelers were exempt during the policy's initial rollout. A large majority of the population recognizes

air pollution as a pressing issue, and this shared concern aligns with widespread support for the policy's reimplementation. Individuals who perceive the Odd-Even policy as effective are more likely to advocate for its return. Moreover, those with multiple vehicles, particularly those who own both cars and two-wheelers, tend to express greater support for the policy compared to those reliant on public or alternative transportation during vehicle off days. These findings suggest that individual experiences and vehicle ownership play crucial roles in shaping attitudes toward the Odd-Even scheme. Falling within the exemption category made individuals more likely to comply.

How Many cars do you have?	**Should Odd-Even policy be implemented again?**			**Total**
	Maybe	**No**	**Yes**	
l	26	34	105	165
2	7	17	51	75
3	2	9	25	36
More than 3	1	2	4	7
None	42	39	61	142
Total	78	101	246	425

Table 2: Number of cars and desire for reimplementation of Odd-Even policy

The Odd-Even policy is similar to a coordination game, where individuals are deciding on the basis of expectations of others' behavior. In terms of discounts, vehicle owners faced an option: either to follow restrictions or to find loopholes to evade. Given the exemptions and the large number of unaffected vehicles, many owners bought additional vehicles to circumvent the restrictions. This behavior can be understood as a Nash equilibrium, where every player's strategy (buying more vehicles) is optimal given the strategies of others (using discounts and ignoring the policy). Consequently, second-hand vehicle sales increased, and a free-rider problem emerged on the days of restrictions. Four-wheeler sales reached 8,298 vehicles, an increase from 7,679 vehicles sold during the same period in the previous four years. These data support the argument that the policy inadvertently stimulated vehicle purchases as individuals sought to evade restrictions, suggesting that a policy intended to reduce vehicles on the road instead led to a surge in vehicles, particularly second-hand ones.

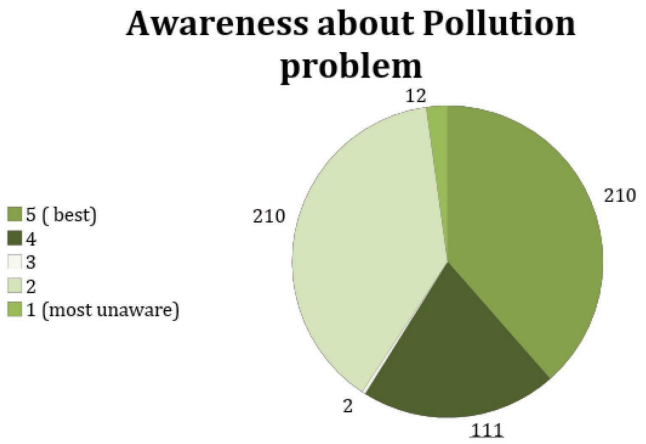

Figure 6: Rating air pollution on a scale of 1 to 5

What is your age?	Does Air Pollution affect your life?			Total
	Maybe	No	Yes	
18 to 28	13	3	124	140
28 to 38	0	5	44	49
38 to 48	2	12	36	50
48 to 58	0	18	67	85
58 to 68	0	15	40	55
More than 58	0	6	40	46
Total	15	59	351	425

Table 3: Effect of air pollution in individual's life by age

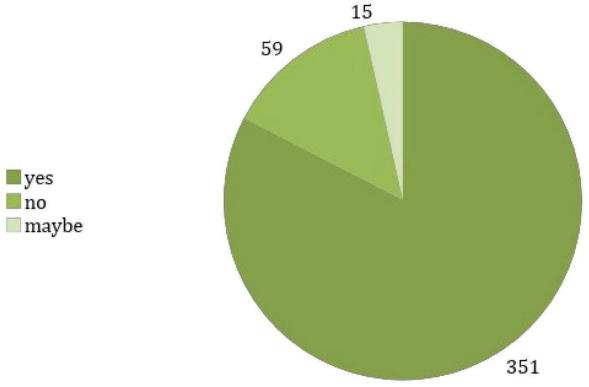

Figure 7: Does air pollution affect your life?

Do you have any two-Wheelers	Should odd-Even policy be implemented again? Maybe	No	Yes	Total
No	41	56	65	162
Yes	37	45	181	263
Total	78	101	246	425

Table 4: Two-wheelers and reimplementation of policy

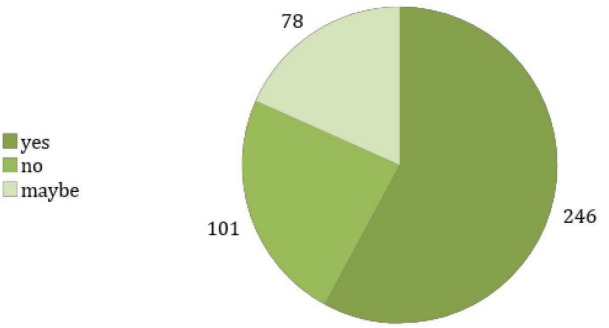

Figure 8: Should Odd-Even be implemented again?

Conclusion

The study provides an in-depth economic analysis of the Odd-Even policy in Delhi through the lenses of public economics, behavioral economics, and environmental economics, through the lenses of public economics, behavioral economics, and environmental economics, in Delhi. From a public economics perspective, the Odd-Even policy aims to address the market failure of air pollution — a classic negative externality. Air pollution imposes substantial social costs health expenditures, lost productivity, and environmental degradation. This divergence between private and social costs results in overproduction of pollution of pollution. The Odd-Even plan, designed as a command-and-control regulatory intervention, sought to reduce these externalities by limiting the emissions of vehicles. However, the results suggest that the policy has limited success in addressing pollution. Pollutants such as SO_2, NO_2, CO, and benzene did not show statistically significant reductions, while $PM_{2.5}$ levels increased during implementation. This suggests that policy effectiveness is constrained by factors such as behavioral responses and partial nature of intervention. In cost-benefit terms, the social cost of pollution is not adequately internalized

by the policy alone, questioning the scalability and stability of such regulatory measures for long-term environmental reforms. From the point of view of behavior economics, asymmetrical policy underlines the important importance of understanding individual decisions under constraints and incentives. The policy design did not account for the strategic behavior of car owners, who could exploit exemptions and buy additional vehicles. This creates a coordination game in which individuals act in their own self-interest, deciding on the basis of the anticipated behavior of others. According to Nash equilibrium, each vehicle owner's strategy of buying an additional vehicle to maintain mobility becomes optimal when others do the same. This response exacerbates pollution rather than reducing it, as evidenced by the increase in vehicle ownership during implementation of the policy. The free-rider problem is also evident: individuals buy additional vehicles to avoid compliance, creating an externality generated by the very policy designed to reduce pollution. This behavioral response highlights the limitations of the Odd-Even policy, which fails to account for individuals' inability to fully internalize the social costs of their actions. In addition, the economic theory of market failure and principal-agent problem also provides insight into the shortcomings of policy. The policy suffered from moral hazard and adverse selection, as individuals were left to self-regulate without adequate enforcement through individual compliance without adequate enforcement mechanisms, where individuals, acting as rational agents, reduced individual discomfort at the cost of collective good. sought to. Failure to impose sufficient costs for non-compliance reduced the policy's effectiveness in reducing pollution. According to projections by the Delhi Transport Department, the number of vehicles on Delhi's roads was expected to exceed 10 million by 2020, with vehicle ownership continuing to increase at an annual rate of 5–6 percent. The fact that the growth of vehicles during the Odd-Even period was accelerated by a 7 percent increase in registrations indicates that this policy has **shifted short-term behavior, not changed long-term usage permanently**. This likely does not translate into a decreased vehicle density and therefore the reduction in emissions was not maintained long term.

From an environmental economics perspective, the results suggest that the Odd-Even policy's narrow focus on restricting vehicular emissions was inadequate to address the wider scope of pollution. While vehicle emission are an important contributor to deteriorating urban air quality, the policy ignores other major sources, such as industrial emissions, manufacturing, and crop burning. The lack of a significant decrease in $PM_{2.5}$ levels and other pollutants reflects the importance of a holistic approach to environmental regulation. A policy mix combining regulatory measures for industrial emissions, incentives for cleaner technologies, and investment in public transport infrastructure is necessary to achieve meaningful improvement in air quality. As the Case

theorem suggests, environmental externalities may be addressed more effectively through well-defined property rights and market-based solutions such as cap-and-trade systems or pollution taxes, Market-based instruments can sometimes achieve pollution reduction more efficiently than command-and-control regulations alone.

The study also reveals significant insights into public opinion regarding the behavioral effects of the Odd-Even policy. While the policy has faced challenges in terms of its direct environmental results, it has promoted a public awareness about the pollution crisis, which can serve as a basis for more effective intervention in the future. A significant proportion of individuals expressed support for reimplementation of the policy, especially those who had a positive experience during its early stages. This suggests that public support is influenced not only by policy effectiveness but also by individual experiences and perceived success. These findings align with prospect theory, which highlights that individuals weigh positive experiences more heavily than negative ones, shaping their willingness to support future interventions. Additionally, individuals who owned multiple vehicles were more likely to support reimplementation, suggesting that those with higher private costs were more invested in maintaining the policy.

Finally, while the Odd-Even policy raised awareness and garnered some public support, its effectiveness in addressing Delhi's severe pollution crisis remains limited. The policy's failure to significantly reduce key pollutants and its unintended effect on vehicle ownership highlight the need for broader, longer-term solutions that integrate economic encouragement with environmental regulation. The structure of high density areas specially with less geographical area require exemptions but these make the policy ineffective. For successful implementation, either population density must be lower or the implementation area larger. The vehicular rationing policy is not effective in the Global South. A combination of market-based instruments (such as carbon taxes and tradable permits) and behavioral interventions (such as clean energy subsidies and public transport subsidies) would be more sustainable for developing and developed countries with high population densities.

Ultimately, the limits of the policy underlying the requirement for a broad and more integrated approach to urban air quality management, that combines regulatory measures with incentives, taking into account both environmental and economic factors. Without this type of innings, the odd policy would be a temporary measure with limited long -term effectiveness in reducing Delhi's air pollution crisis.

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Conflict of Interest

The author declares that there is no conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the author.

Life Science Reporting

No life science threat was practised in this research.

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