

Shamlan Waleed Albahar
Kuwait University
Kuwait

Do Fuel Price Hikes Clean Local Pollution? Evidence from Ambi- ent Air Quality in Kuwait

Abstract

Purpose: This study evaluates the impact of Kuwait's 2016 gasoline price reform on ambient air quality, focusing on whether the policy has achieved the anticipated reductions in local pollution levels.

Study design/methodology/approach: The study employs three time-series Regression Discontinuity (RD) methods to assess the causal effect of the price change. The global polynomial RD approach uses a flexible time trend across a broad window. The local linear RD method narrows the focus to a short window around the reform date, capturing the immediate impacts. The two-step augmented RD technique first controls for weather and seasonal variation, then applies a localized RD model.

Sample and data: The analysis utilizes average hourly pollution data from 12 monitoring stations across Kuwait, spanning from January 2011 to December 2017. Six key local pollutants are analyzed: carbon monoxide, nitrogen oxides, nitrogen dioxide, nitric oxide, ozone, and sulfur dioxide.

Results: Contrary to expectations, the findings indicate no statistically significant improvement in ambient air quality following the price increase. Some pollutants, such as nitrogen dioxide and nitrogen oxides, exhibit increased concentrations; however, these results are not uniformly robust across models, raising concerns about potential unintended consequences.

Originality/value: This is the first study to apply high-frequency pollution data and a time-series RD design to evaluate the environmental impact of a gasoline price hike in Kuwait's subsidized, fixed-price system.

Research limitations/implications: The results suggest price reforms alone may not suffice. Broader measures—such as infrastructure investments, urban planning reforms, and behavioral incentives—are likely needed to achieve environmental goals.

Keywords: Air Quality, Gasoline Prices, Fuel Subsidies, Time-Series Regression Discontinuity, Environmental Policy, Kuwait.

JEL classification: Q41, Q48, Q51, Q53, Q58, R40

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الملخص

هل تسهم زيادات أسعار الوقود في الحد من التلوث المحلي؟ أدلة من جودة الهواء المحيط في الكويت

شملان وليد البحر

جامعة الكويت

الكويت

هدف الدراسة: تقييم تأثير إصلاح أسعار وقود السيارات في الكويت عام 2016 في جودة الهواء المحيط، وتحديد إذا ما كان هذا الإصلاح قد حقق التخفيضات المتوقعة في مستويات التلوث. تصميم/ منهجية/ طريقة الدراسة: اعتمدت الدراسة ثلاث منهجيات لانقطاع الانحدار في السلاسل الزمنية لتقدير الأثر السببي لتغير الأسعار، فاستخدمت منهجية الانحدار الشامل على اتجاه زمني مرن ضمن نافذة زمنية ممتدة، في حين ركزت المنهجية المحلية على نافذة ضيقة حول تاريخ الإصلاح لرصد التأثيرات الفورية، أما المنهجية المعززة ذات الخطوتين، فتتحكم بالعوامل الجوية والموسمية، ثم تُطبق طريقة الانحدار المحلي.

عينة الدراسة وبياناتها: اشتملت عينة الدراسة على متوسط بيانات التلوث لكل ساعة من 12 محطة لرصد جودة الهواء في الكويت خلال الفترة من يناير 2011 إلى ديسمبر 2017، مع التركيز على ست ملوثات محلية رئيسية، هي: أول أكسيد الكربون، وأكاسيد النيتروجين، وثاني أكسيد النيتروجين، وأكسيد النيتريك، والأوزون، وثاني أكسيد الكبريت.

نتائج الدراسة: خلافاً للتوقعات، لم يظهر تحسن إحصائي ملموس في جودة الهواء بعد زيادة الأسعار، بل أظهرت نتائج بعض النماذج ارتفاع مستويات بعض الملوثات، مثل: ثاني أكسيد النيتروجين وأكاسيد النيتروجين؛ مما يثير مخاوف من عواقب غير مقصودة للسياسة، رغم عدم اتساق تلك النتائج عبر جميع النماذج.

أصالة الدراسة: تُعد هذه الدراسة الأولى من نوعها التي استعملت بيانات التلوث عالية التردد، ومنهجية انقطاع الانحدار في السلاسل الزمنية، لتقييم الأثر البيئي لزيادة أسعار الوقود في نظام تسعير مدعوم وثابت مثل الكويت.

حدود الدراسة وتطبيقاتها: أشارت الدراسة إلى أن إصلاح الأسعار لوحده قد لا يكون كافياً لتحقيق النتائج البيئية المرجوة، مما يستدعي تبني سياسات أوسع تشمل الاستثمار في البنية التحتية، وإصلاحات التخطيط الحضري، والحواجز السلوكية.

الكلمات المفتاحية: جودة الهواء، أسعار وقود السيارات، دعم الوقود، انقطاع الانحدار في السلاسل الزمنية، السياسة البيئية، الكويت.

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Introduction

Fuel subsidies that keep fuel prices artificially low represent a classic case of market failure, in which fuel prices do not reflect their full social costs. Negative externalities—such as air pollution and climate-related damages—are rarely internalized due to either direct subsidies or insufficient taxation, which lead to elevated emissions and adverse public health outcomes. This market distortion is not confined to a single country; it is a global issue requiring urgent attention from policymakers. Addressing this failure through measures such as subsidy reform, pollution taxes, or tradable emissions permits is essential for advancing sustainable policy, improving urban air quality, safeguarding public health, and enhancing overall economic efficiency.

The underpricing of fossil fuels extends far beyond explicit subsidies like price controls or direct fiscal support. According to the International Monetary Fund (IMF), approximately 82 percent of the gap between actual fuel prices and their social cost stems from implicit subsidies—primarily the undercharging for environmental damages and other externalities arising from local air pollution, climate change, road congestion, and traffic accidents. Local air pollution alone accounts for roughly 30 percent of the total global fossil fuel subsidy burden (Black et al., 2023). This problem is further exacerbated in countries that not only fail to correct implicit subsidies but also provide explicit subsidies, setting fuel prices below supply costs. Such policies are particularly prevalent in regions like the Middle East and North Africa (MENA), the Commonwealth of Independent States (CIS), and East Asia and the Pacific (EAP).

Reforming fuel subsidies to better reflect the externalities associated with local air pollution could yield substantial environmental and public health benefits. Comprehensive meta-analyses and global burden of disease studies have established a robust association between exposure to transport-related air pollutants—including particulate matter, nitrogen dioxide, and ozone—and increased risks of mortality and morbidity, resulting in significant global health costs. These findings underscore the urgent economic need to implement fuel pricing reforms (Baddida et al., 2023; Yin et al., 2024). For example, comprehensive fossil fuel price reform by 2030 could prevent an estimated 1.6 million premature deaths annually due to local air pollution alone (Black et al., 2023). Despite this potential, rigorous empirical evidence identifying the causal relationship between fuel prices and local pollution—particularly using high-frequency pollution data—remains limited.

Moreover, the assumption that higher fuel prices automatically lead to improved air quality oversimplifies a complex dynamic: the relationship between fuel prices and ambient pollution is mediated by behavioral, technological, and institutional factors that vary across contexts.

This study makes five central contributions to the literature on energy pricing and environmental policy. First, it addresses a critical evidence gap by empirically estimating the causal effects of fuel price reform on ambient concentrations of short-lived, health-damaging air pollutants—a dimension underexplored relative to the more extensively studied impacts on global pollutants such as carbon dioxide. Second, it leverages a rare, large-scale natural experiment: Kuwait’s abrupt and substantial gasoline price increase in 2016, which was followed by several years of price stability. This unique setting enables a clean identification strategy that is rarely available in fuel pricing contexts. Third, the study utilizes high-frequency hourly data to evaluate the reform’s short-term environmental effects and implements three complementary time-series regression discontinuity (RD) designs, including a two-step augmented RD method, to enhance the robustness of causal estimates. Fourth, it offers local methodological value by being the first to extend the use of hourly pollution and meteorological data from Kuwait’s Environmental Protection Authority (EPA) beyond its traditional applications in engineering and chemistry, applying it instead to evaluate economic and policy-relevant outcomes. Finally, although centered on Kuwait, the study offers broader insights into the environmental limits of price-based reforms in countries considering transitions away from explicit fuel subsidies—particularly in regions such as MENA, CIS, and EAP—and contributes to a broader global understanding of how fuel price adjustments influence local air quality.

On September 1, 2016, Kuwait implemented its first gasoline price adjustment in nearly two decades, increasing prices by 42% to 83%. This policy shift offers a unique opportunity to assess its short- and medium-term environmental implications, particularly concerning local pollution. Ambient air quality serves as a comprehensive indicator of short-term environmental quality, reflecting the cumulative impacts of transportation, industrial, residential, and agricultural activities. Unlike global pollutants such as carbon dioxide, which primarily contribute to long-term climate change, local pollutants—including carbon monoxide, nitrogen oxides, nitrogen dioxide, nitric oxide, sulfur dioxide, and ozone—pose immediate risks to human health and ecosystems.

National air quality indices, including Kuwait's, prioritize the monitoring of ambient pollution from local pollutants due to their immediate and localized effects. Tackling these pollutants yields direct public health benefits by reducing respiratory and cardiovascular illnesses, lowering healthcare costs, and improving overall quality of life. Table 1 summarizes the direct health impacts of these pollutants and their ecological significance.

Table 1
Health and Environmental Impacts of Key Local Air Pollutants

Pollutant	Health Effects on Humans	Environmental Effects
Carbon Monoxide (CO)	Reduces oxygen transport in the blood, affecting the heart and brain. At high levels, it can cause dizziness, confusion, unconsciousness, and death. Short-term exposure worsens angina in people with heart disease. Vulnerable groups include unborn babies, infants, the elderly, and individuals with anemia or heart and respiratory diseases.	Contributes indirectly to climate change by participating in chemical reactions that form ground-level ozone, a short-lived pollutant with warming effects. No significant direct ecological effects were identified at ambient levels.
Nitrogen Oxides (NO _x)	Broad impacts of NO _x include airway irritation, exacerbated asthma, and cardiovascular stress. Combines with Volatile Organic Compounds to form ozone and contributes to Fine Particulate Matter pollution.	Forms smog, contributes to acid rain, nutrient pollution in water bodies, haze, and local warming due to trapped heat.
Nitrogen Dioxide (NO ₂)	Direct airway irritation worsens asthma and increases respiratory infections. Higher toxicity than NO. Plays a key role in Particulate Matter and ozone formation.	Contributes to acid rain, harms vegetation and ecosystems, and reduces visibility (haze).
Nitric Oxide (NO)	Causes respiratory irritation and lung issues. Converts to NO ₂ in the atmosphere. Less directly harmful but contributes to downstream effects.	Reduces plant photosynthesis, contributes to acid rain and smog, and harms aquatic ecosystems through acidification.

Cont. Table 1
Health and Environmental Impacts of Key Local Air Pollutants

Pollutant	Health Effects on Humans	Environmental Effects
Nitric Oxide (NO)	Causes respiratory irritation and lung issues. Converts to NO ₂ in the atmosphere. Less directly harmful, but it contributes to downstream effects.	Reduces plant photosynthesis, contributes to acid rain and smog, and harms aquatic ecosystems through acidification.
Ozone (O ₃)	Irritates the airways, causing coughing, sore throat, and difficulty breathing. Long-term exposure worsens asthma, chronic bronchitis, and emphysema. Increases asthma attacks, hospitalizations, and respiratory infections. It is most harmful to children, the elderly, and outdoor workers.	Harms sensitive vegetation by reducing photosynthesis and plant growth, and increases vulnerability to disease, insects, and severe weather. Alters ecosystems by changing plant compositions, degrading habitats, and disrupting nutrient and water cycles.
Sulfur Dioxide (SO ₂)	Causes respiratory irritation, difficulty breathing, and worsens asthma, especially in children. Contributes to Particulate Matter pollution, which penetrates deeply into the lungs, causing further health issues.	Contributes to acid rain, harming ecosystems by acidifying soil and water, damaging foliage, and decreasing plant growth. SO ₂ emissions also lead to secondary particulate pollution, reducing visibility and exacerbating environmental degradation.

Note: Data compiled from Airly (n.d.); Arizona Department of Environmental Quality (n.d.); Boningari and Smirniotis (2016); California Air Resources Board (n.d.); Queensland Government (n.d.); and United States Environmental Protection Agency (n.d.-a to n.d.-e). For full references, see the reference section.

The analysis employs a time-series regression RD design to examine average hourly pollution data for these local pollutants from 12 monitoring stations. Contrary to expectations, the findings indicate no statistically significant improvements in ambient air quality following the price adjustment. These results challenge the presumed efficacy of fuel price hikes as a standalone measure to reduce local pollution and underscore the necessity of complementary measures to achieve meaningful environmental improvements.

Literature Review and Hypotheses Development

Fuel Price Reforms and Air Quality Improvements

Although few studies have empirically examined the relationship between fuel pricing interventions and local air pollution, the existing research consistently finds that higher fuel prices are often associated with reductions in various pollutants, particularly those linked to road transport. While the magnitude of improvements varies across contexts, increasing fuel prices usually reduces emissions of key pollutants by discouraging private vehicle use, alleviating traffic congestion, and prompting behavioral changes. These changes contribute to improved urban air quality and deliver substantial environmental benefits. For example, Mayr and Rentschler (2023), in a global analysis of 133 countries over 20 years, find that a \$1 increase in gasoline and diesel prices reduces concentrations of fine particulate matter (PM_{2.5}) by 22.2 micrograms per cubic meter and 31.1 micrograms per cubic meter, respectively, highlighting significant air quality improvements. Similarly, He et al. (2017), using panel data from 306 cities in China (2002–2012), estimate that a 30% rise in road transport fuel prices reduces emissions of carbon monoxide, nitrogen oxides, and PM_{2.5} by 963,940 tons, 172,000 tons, and 11,330 tons, respectively, while preventing 15,534 to 16,149 premature deaths.

In Tehran, Iran, Raeissi et al. (2022) observe that a 1% increase in gasoline prices leads to short-term reductions of 0.020% in carbon monoxide and 0.012% in particulate matter with a diameter of less than 10 micrometers (PM₁₀) concentrations, with greater decreases over the long term. However, substitution effects, such as shifts to alternative fuels, may cause a slight short-term increase of 0.011% in nitrogen dioxide concentrations. By contrast, increases in diesel prices reduce concentrations of carbon monoxide, PM₁₀, and nitrogen dioxide in both the short and long terms. Similarly, in Egypt, Heger et al. (2019) estimate that fuel subsidy removal programs reduce PM₁₀ concentrations in Cairo by nearly 4%.

Fuel pricing reforms have broader environmental and economic implications. In the United States, Davis and Kilian (2011) find that higher gasoline prices, resulting from increased taxes, lead to environmental gains marked by significant reductions in carbon emissions in the United States. Similarly, Li et al. (2014) highlight the substantial potential of gasoline taxes as an effective policy tool for addressing environmental concerns. Their study suggests that increasing gasoline taxes could be more effective than previously estimated in reducing gasoline consumption and encouraging the adoption of more fuel-efficient vehicles. This leads

to lasting environmental benefits, including lower greenhouse gas emissions and reduced local air pollution. In Saudi Arabia, Aldubyan and Gasim (2021) analyze the economic and environmental effects of gasoline price reforms, showing that the 2018 price hike leads to significant economic and environmental benefits.

However, translating these gains into sustained policy action remains challenging due to significant political resistance. For example, Montes de Oca Leon et al. (2024), analyzing Bolivia and Mexico, find that fuel subsidy reforms can trigger steep declines in presidential approval, often leading to policy reversals. They emphasize the importance of public trust, gradual implementation, and compensatory measures to cushion potential public backlash. Similarly, Skovgaard et al. (2024) argue that global efforts to phase out fossil fuel subsidies should emphasize immediate and tangible local co-benefits—such as cleaner air, fiscal savings, and social equity—rather than focusing solely on climate goals. They highlight the importance of a just transition, where the fiscal space generated by reform is reinvested in renewable infrastructure and targeted support for vulnerable groups to maintain political feasibility.

Policy Change

On September 1, 2016, Kuwait implemented a substantial increase in its fixed, subsidized gasoline prices, ranging from 42% to 83%—the first adjustment since 1998. This policy applied to all three available gasoline grades—octane 91, octane 95, and octane 98—with the most significant increase affecting octane 98. Since this adjustment, the prices of the most commonly consumed grades, octane 91 and 95, have remained stable throughout the study period. Although octane 98 underwent a few additional price adjustments starting in July 2021, these occurred after the study period, which concludes at the end of 2017. Table 2 summarizes the price changes and their market implications.

Table 2
Gasoline Price Adjustments in Kuwait (Effective September 1, 2016)
Source: Kuwait National Petroleum Company

	Octane 91 Gasoline	Octane 95 Gasoline	Octane 98 Gasoline
Price Before Adjustment (fils/L)	60	65	90
Price After Adjustment (fils/L)	85	105	165

Cont. Table 2
Gasoline Price Adjustments in Kuwait (Effective September 1, 2016)
Source: Kuwait National Petroleum Company

	Octane 91 Gasoline	Octane 95 Gasoline	Octane 98 Gasoline
% Increase	42%	62%	83%
Stability of Price	Single adjustment on September 1, 2016, since 1998	Single adjustment on September 1, 2016, since 1998	Single adjustment on September 1, 2016, since its introduction in 2002; stable until July 2021, with a few additional changes starting thereafter (beyond this study's dataset).
Market Share	Largest market share after the price change	Largest market share before the price change	Smallest share both before and after the price change; primarily used in high-end vehicles such as sports cars

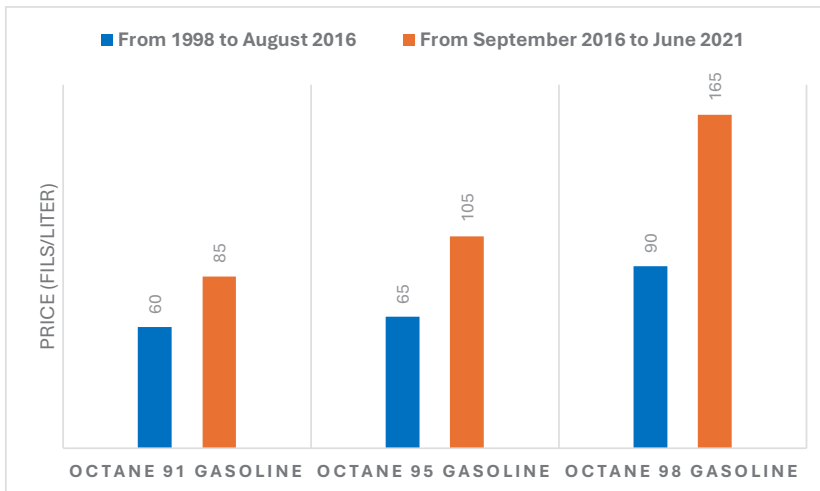


Figure 1: Stable Gasoline Prices in Kuwait (1998–2021)

Projected Short-Run Reductions in Local Pollution

The 2016 gasoline price reform may influence ambient pollution through various demand- and supply-side channels, with a key mechanism being a reduction in gasoline consumption. Estimating the short-run reduction in local pollution via this channel requires an assumption about Kuwait's price elasticity of demand for gasoline in the short-run. For this purpose, a short-run elasticity of -0.25 is selected and used as a back-of-the-envelope estimate to provide a simple, illustrative basis for the projections in Table 3. While grounded in the literature, this elasticity is not employed for identification purposes or prediction, and the empirical results of the paper do not depend on this assumption.

The emphasis on a short-run elasticity is motivated by both conceptual and methodological considerations. Conceptually, it is appropriate for reflecting the immediate response to a one-time price shock, particularly within the 16-month post-reform window covered by the data, as many behavioral adjustments—such as vehicle stock turnover or residential relocation—are more characteristic of long-run dynamics. Methodologically, the choice aligns with the empirical strategy, since it is designed to detect short-run discontinuities in ambient pollution levels.

The selected value of -0.25 is supported by both country-specific and international evidence. First, it draws on limited empirical research in Kuwait's unique context, characterized by decades of fixed, subsidized fuel pricing. Eltony and Al-Mutairi (1995) estimate a short-run elasticity of -0.37 , while Al-Faris (1997) reports a more inelastic value of -0.10 . Accordingly, the selected estimate lies approximately between these two national benchmarks.

Second, a meta-analytic review of the literature shows that short-run price elasticities of gasoline demand typically lie within the range of -0.16 to -0.36 . For example, Espey (1998) analyzes 101 papers from 1929 to 1993 and finds a short-run elasticity of -0.16 for gasoline demand. Graham and Glaister (2002), covering 113 studies from 1966 to 2000, report a short-run elasticity of -0.25 for car fuels. Brons et al. (2008), synthesizing 43 studies over the period 1949 to 2003, find a somewhat higher short-run elasticity estimate of -0.36 . More recently, Labandeira et al. (2017) analyze the findings of 428 papers between 1990 and 2016 and estimate the short-run gasoline price elasticity at -0.29 . Taken together, these meta-analyses collectively indicate that the selected short-run elasticity of -0.25 is well within accepted global ranges, providing a balanced figure that re-

flects both the local specificity of Kuwait and the international generalizability of gasoline demand response to price changes.

To calculate the projected emissions reductions, the estimated percentage change in gasoline demand is combined with figures on the transportation sector's contribution to total emissions for each pollutant. These projections, shown in Table 3, are meant as preliminary illustrations of the expected direction and magnitude of changes through the gasoline consumption channel—an important, though not exclusive, policy-related mechanism affecting ambient air quality outcomes.

Given that the different gasoline grades experienced varying price hikes, a weighted average of the price increases, calculated at 59%, based on pre-reform consumption levels, is used to assess the anticipated environmental outcomes (Kuwait National Petroleum Company, n.d.). To estimate the expected changes in local pollutant concentrations from the anticipated reduction in gasoline demand, it is essential to account for the transport sector's contribution to emissions. To my knowledge, no study has precisely quantified the transportation sector's contribution to emissions of various pollutants in Kuwait. However, evidence from other countries indicates that the transport sector is a dominant source of several key local pollutants. Accordingly, the lower and upper bounds for the transport sector's contribution to local pollutants are estimated based on findings from other regions.

In Kuwait, key sources of air pollution include transportation, the oil industry, power and desalination plants, and other industrial activities (Al-Awadhi, 2014; Environmental Systems Information Center [eMISK], n.d.). Among these, transportation is a leading contributor to ambient air pollution, generating substantial emissions of carbon monoxide, hydrocarbons, and nitrogen oxides (Al-Mutairi & Koushki, 2009; Al-Salem & Khan, 2008; El Desouky & Abdulraheem, 1988; Koushki, 2007). Carbon monoxide is considered a primary transport pollutant, with a significant proportion of its emissions worldwide attributed to transport sources. El Desouky and Abdulraheem (1988) estimate that traffic account for 96% of carbon monoxide emissions in Kuwait City, a rate similar to the transport contribution of 80-90% of carbon monoxide emissions in U.S. urban areas (Godish, 2004). Comparable contributions are observed in Australia, some Asian cities, and Mexico City, where the transport sector contributes 95%, 98%, and 99% of carbon monoxide emissions, respectively (Behera & Balasubramanian, 2016; Davis, 2008; World Health Organization, 2012).

Nitrogen oxides are also primary transportation-related pollutants. The transport sector's contribution to nitrogen oxides emissions ranges from 32% to 85% in Asian cities, 48% to 65% in the United States, 47% in the United Kingdom, 54% in Canada, 63% in Australia, and 81% in Mexico City (Behera & Balasubramanian, 2016; Davis, 2008; Dore et al., 2007; Government of Canada, 2021; United States Environmental Protection Agency, 1999; United States Environmental Protection Agency, 2025; World Health Organization, 2012). Globally, the transport sector contributes approximately 43% of anthropogenic nitrogen oxides emissions, with this share rising to 49% in developing countries (Onursal & Gautam 1997).

Additionally, the European Environment Agency (EEA) estimates that the transport sector is responsible for approximately 45% of ozone precursor emissions in European Economic Area countries as of 2002 (European Environment Agency, 2005). Notably, although ozone is a prevalent pollutant associated with transportation, it is classified as a secondary pollutant. Primary pollutants, such as carbon monoxide and nitrogen oxides, are emitted directly from sources like road transport exhaust, whereas secondary pollutants, such as ozone, are produced through chemical reactions of primary pollutants in the atmosphere (Godish, 2004).

While transportation also contributes to sulfur dioxide emissions, its contribution is significantly lower, as sulfur dioxide is primarily produced by burning sulfur-containing fuels in power plants. However, the transport sector's contribution to sulfur dioxide emissions varies by country, ranging from 1–2% in the United States, Canada, and the United Kingdom, to approximately 30% in Mexico City (Davis, 2008; Dore et al., 2007; Government of Canada, 2021; United States Environmental Protection Agency, 2025). Although sulfur dioxide is not predominantly produced by the transportation sector, its impact is still worth investigating.

Given the estimated range of the transport sector's contribution to the local pollutants of interest, the expected change in pollutant concentrations is calculated by multiplying the percentage change in gasoline demand based on a short-run price elasticity of gasoline demand of -0.25 and a weighted average price increase of 59%, by the respective bounds of the transport sector's contribution to total emissions for each pollutant. This calculation is applied to all pollutants of interest to determine the expected change in pollution levels across the full range of contribution boundaries, as shown in Table 3. For ozone, however, only the available estimated contribution is reported, as its share from transportation is difficult to estimate due to its classification as a secondary pollutant.

Table 3
Projected Short-Run Emission Reductions from Transport (%)

Local Pollutant	Contribution from Transport (%)	Projected Short-Run Emission Reductions from Transport (%)
Carbon monoxide	80% - 99%	11.8% - 14.6%
Nitrogen oxides	32% - 85%	4.7% - 12.5%
Sulfur dioxide	1% - 30%	0.15% - 4.4%
Ozone	45%	6.6%

Note: These projections estimate emission reductions from the transportation sector, assuming the reform affects only gasoline consumption. Calculations use a short-run price elasticity of -0.25 and a weighted average price increase of 59%. Actual ambient concentrations may also be influenced by other policy-related factors not accounted for here.

The anticipated reductions in gasoline consumption in the transportation sector, as shown in Table 3, suggest potential improvements in ambient air quality. However, Kuwait's specific context—such as limited availability of alternatives to private vehicle travel—may imply a more inelastic demand for gasoline than the assumed short-run price elasticity of -0.25. This suggests that the projections may be somewhat optimistic, and the actual reduction in emissions through the gasoline consumption channel could be smaller than reported. It is also important to emphasize that the assumed elasticity is used solely for illustrative, back-of-the-envelope calculations. It is not employed for identification or prediction, and the empirical results of the paper do not rely on this assumption.

Furthermore, these projections focus exclusively on anticipated reductions in gasoline consumption and do not incorporate the broader pathways through which air quality may be affected. In practice, emissions depend not only on the volume of fuel used but also on how and where it is consumed. In the short run, changes in behavior—such as shifting to longer but less congested routes, chaining trips, or substituting newer vehicles with older ones—may lead to emissions reductions that are smaller than the corresponding decline in fuel consumption, or even result in net increases. Moreover, fuel prices are not the sole determinants of behavior. As shown in Axhausen et al. (2021), individuals adjust their travel choices in response to the salience of externalities such as congestion, health, and climate damages. Their field experiment found that when these external costs were made visible, participants responded by altering routes, travel timing, and mode choice. While the overall external cost burden declined, the emissions effects likely varied

across behaviors—public transit use may reduce emissions, while route changes to avoid congestion could lower travel time but raise total emissions. These complexities underscore that short-run emissions outcomes reflect not just the scale of fuel consumption but also its behavioral context.

On the demand side, multiple adjustment margins shape the environmental impact of reform. These include not only reductions in fuel use but also changes in driving style (e.g., carpooling, speeding, idling), shifts in vehicle type or technology, modal substitution, switching to lower-grade fuel, and decisions related to trip timing or frequency. Urban form further constrains or enables these responses: Kuwait's dispersed residential patterns and limited transit infrastructure may restrict substitution away from private vehicles. Moreover, while adjustments such as vehicle replacement or residential relocation are typically associated with the long run, they may begin to emerge even within a short-run window if households or firms act in anticipation of persistent price changes. Fuel use in other sectors—including agriculture, industry, and residential energy—may also respond nonlinearly, depending on the availability and emissions profile of substitute fuels. These layered behavioral and sectoral dynamics are not captured in the elasticity-based projections presented in Table 3 but are essential for interpreting the true environmental impact of subsidy reform, even over short horizons.

On the supply side, adjustments by producers further complicate the relationship between subsidy reform and air quality. In some cases, higher fuel prices may incentivize producers to adopt more efficient technologies that reduce emissions per unit of fuel produced or invest in cleaner production methods, leading to environmental gains. Reforms might also improve how producers manage fuel leakages, waste, and gas flaring, which are significant sources of air pollution. However, outcomes are not uniformly positive. Refining processes and shifts in gasoline-grade demand may alter the emissions profile, as producing certain grades can entail different pollution intensities. Reduced local demand may also prompt greater oil exports, offsetting domestic air quality improvements. More concerning, some industrial or transport users may respond to rising gasoline costs by switching to diesel, which can emit higher levels of certain pollutants under typical conditions. Additionally, to reduce operational costs, some producers may rely on older, less efficient machinery with worse emission profiles or delay upgrades to cleaner technologies. Lastly, subsidy removal may disproportionately affect smaller producers, potentially leading to shutdowns or a shift in

market share toward larger operators—with environmental effects that depend on the practices of those gaining market dominance.

Overall, reduced gasoline consumption provides a clear pathway to improved ambient air quality. However, the net short-run impact of a subsidy reform is theoretically ambiguous due to complex demand and supply responses. The projected gains from lower transportation emissions from lower gasoline consumption may be amplified, diminished, completely offset, or even reversed. This study empirically examines the net effect of the 2016 reform on ambient air quality, thereby quantifying the ultimate ambient air quality outcome, as measured by local pollution concentrations, that arises from the interplay of all relevant policy-related factors.

Conceptual Pathways and Hypotheses

The preceding discussion suggests two competing theoretical pathways for the impact of gasoline price reform on ambient pollution. On the one hand, standard economic theory predicts that, *ceteris paribus*, fuel price increases reduce gasoline consumption and alter driving behavior by raising the cost of vehicle use. This reduction in fuel use can improve air quality through several mechanisms, including decreased reliance on private vehicles, greater adoption of carpooling or public transportation, and behavioral adjustments such as reduced idling and more efficient driving. Some responses may emerge in the short run and continue to evolve over time; for instance, consumers may adopt more fuel-efficient vehicles or relocate closer to work to reduce commuting distances. These pathways support the expectations of improved ambient air quality following Kuwait's 2016 gasoline price increase by reducing emissions from the transport sector. This leads to the first hypothesis:

H1: *The gasoline price reform led to a statistically significant reduction in the ambient concentrations of transportation-related air pollutants, specifically carbon monoxide (CO), nitrogen dioxide (NO₂), nitrogen oxides (NO_x), nitric oxide (NO), ozone (O₃), and sulfur dioxide (SO₂).*

These mechanisms are reinforced by preliminary illustrative projections based on a short-run price elasticity of gasoline demand -0.25 and estimated contributions of the transport sector to pollutant emissions, as summarized in Table 3. These projections anticipated reductions in carbon monoxide 11.8%–14.6%, nitrogen oxides 4.7%–12.5%, ozone 6.6%, and sulfur dioxide 0.15%–4.4%.

On the other hand, the unique structural and institutional characteristics of the Kuwaiti economy, as outlined in previous sections, may constrain the magnitude of behavioral responses. Moreover, complex dynamics on both the demand and supply sides could counteract the expected environmental gains. For example, on the demand side, consumers might shift to lower-grade fuels or face limited alternatives due to the country's weak public transportation infrastructure. On the supply side, refiners might adjust production in ways that increase emissions, or firms may continue operating older, less efficient machinery to reduce their private costs. These countervailing forces raise the possibility that the reform may have had no discernible effect on pollution levels. Therefore, the null hypothesis is theoretically plausible:

H0: *The gasoline price reform had no statistically significant effect on the ambient concentrations of local air pollutants.*

These hypotheses are tested using rigorous time-series regression discontinuity methods described in the next section. The pollutant-specific results provide a nuanced empirical assessment of the competing forces influencing the net environmental effect of the reform.

Research Methods

Data

This study utilizes time-series average hourly pollution and meteorological data from Kuwait's Environment Public Authority (EPA). The pollution dataset includes measurements for six key local pollutants: carbon monoxide, nitrogen oxides, nitrogen dioxide, nitric oxide, ozone, and sulfur dioxide. The analysis focuses on ground-level ozone, a harmful pollutant that exacerbates respiratory issues and damages crops, trees, and ecosystems. This should not be confused with stratospheric ozone, which forms the ozone layer, and shields life on Earth by absorbing the sun's ultraviolet radiation (United States Environmental Protection Agency [EPA] n.d.-f, n.d.-g). Furthermore, nitrogen oxides, a group of seven compounds that includes both nitrogen dioxide and nitric oxide, are analyzed in this study (United States Environmental Protection Agency, 1999). In addition, nitrogen dioxide is specifically examined because it is the most prevalent nitrogen oxide emitted by human activities, and represents a major atmospheric pollutant with significant potential to harm human health and the environment (Godish, 2004). Its prominence makes it a frequent target of air quality regulations and

the only nitrogen oxide included in the Kuwait EPA's air quality index. Nitric oxide, while less directly harmful, is also analyzed because of its critical role as a precursor in the atmospheric formation of nitrogen dioxide (Godish, 2004). By examining both nitrogen dioxide and nitric oxide, this analysis provides a more comprehensive understanding of the role nitrogen oxides play in air pollution in Kuwait.

The data utilized in this study were collected from 12 air quality monitoring stations operated by Kuwait's EPA. These stations, distributed across the country, monitor pollution concentration levels and weather variables, including temperature, relative humidity, and wind speed. The stations are strategically positioned to capture a diverse range of environments with varying levels of human activity and pollution sources, including residential areas, congested transport routes, commercial and industrial zones, oil fields, and power and desalination plants.

The dataset spans from January 2011 to December 2017, encompassing both pre- and post-reform periods. Since the gasoline subsidy reform was implemented on September 1, 2016, the dataset includes more pre-reform data than post-reform data. However, the time-series RD methodology employed in this study mitigates the need for extensive post-reform data by focusing on the estimation window around the policy change. Furthermore, the substantial amount of pre-reform data strengthens the analysis by allowing for effective control of seasonality and weather-related variations, enhancing the robustness of the results. Further details on the methodology are provided in the empirical approach section.

Empirical Approach

This study employs a time-series regression discontinuity (RD) design, aligning with a growing body of research in economic studies, particularly within the field of environmental economics. In this framework, time serves as the running variable, and policy implementation acts as the cut-off point to evaluate its impact. Policies that affect all observations at a specific point in time, such as national-level interventions, are particularly well-suited for this analytical approach. Observations prior to the intervention serve as a control group for those recorded afterward (Anderson, 2014; Auffhammer & Kellogg, 2011; Bento et al., 2014; Burger et al., 2014; Chen & Whalley, 2012; Davis, 2008; Grainger & Costello, 2014; Hausman & Rapson, 2018; Lang & Siler, 2013; Zhang et al., 2017).

This study estimates the effect of the gasoline subsidy reform on mean pol-

lution levels in Kuwait using three methodologies within the time-series RD framework. The first is the global polynomial RD, a common methodology in time-series RD studies. The second is a basic local linear RD, which applies RD regression to observations within a narrow time window, though it is generally less precise than the global approach (Hausman & Rapson, 2018). The third and preferred method is the two-step augmented RD introduced by Hausman and Rapson (2018), which combines the advantages of the global and local methods. Each methodology is discussed in detail.

The global polynomial RD model employs a high-order flexible polynomial time trend over a long time-series window, consistent with methodologies used in prior literature (Auffhammer & Kellogg, 2011; Bento et al., 2014; Burger et al., 2014; Chen & Whalley, 2012; Davis, 2008; Zhang et al., 2017), as expressed in Equation (1):

$$\log(y_t) = \beta_0 + \beta_1 I(Reform_t) + \sum_{i=1}^3 \sum_{j=1}^5 \beta_{ij} x_{it}^j + \sum_{m=1}^{12} \gamma_m Month_m + \sum_{d=1}^7 \delta_d Day_d + \sum_{h=0}^{23} \eta_h Hour_h + \sum_{k=1}^K \theta_k \tau^k + \sum_{k=1}^K \phi_k I(Reform_t) \cdot \tau^k + u_t \quad (1)$$

Note: For each categorical variable — Month, Day, and Hour — I omit one category as the reference group (January, Sunday, and hour 0, respectively) to avoid perfect multicollinearity. The indices shown in the equation run over all categories purely for notational convenience.

Each observation represents an hour indexed by the time variable t , with the dependent variable y_t denoting the average hourly concentration of one of six pollutants (carbon monoxide, nitrogen dioxide, nitrogen oxides, nitric oxide, ozone, or sulfur dioxide). The key variable of interest, $I(Reform_t)$, is an indicator for the gasoline subsidy reform implementation, which equals 1 from September 1, 2016. The coefficient β_1 estimates the reform's average impact on mean pollutant concentrations. The model includes a polynomial function of the continuous daily time index (τ) to flexibly account for long-term time-series variations. A primary assumption in global polynomial RD is that no other factors caused a discontinuous change in air quality on September 1, 2016, aside from the gasoline price reform. Gradual changes around the policy date are captured by the polynomial time trend. Newey–West standard errors are applied to address serial correlation and heteroskedasticity.

Additionally, the model incorporates weather variables (temperature, relative humidity, and wind speed) using fifth-order polynomials, along with fixed effects

to account for seasonality and daily and weekly patterns (fixed effects for the month, day of the week, and hour of the day). However, year fixed effects are not included in this model to prevent potential bias and maintain statistical power. Given that the sample spans only three years, including year fixed effects could absorb variation that should be attributed to the treatment effect, especially since the policy was implemented in the last quarter of 2016. Treating all observations within that year as homogeneous, risks obscuring the sharp discontinuity critical to the RD design. Moreover, year fixed effects might inadvertently capture gradual changes in the outcome variable, which are accounted for through the flexible time trend polynomial, thereby distorting the estimation of the policy's impact.

The global polynomial RD requires a sufficiently extended time window to control for seasonality without undermining the relevance of pre-reform observations as a control group. The window used for Equation (1) spans September 1, 2015, to July 31, 2017, providing a nearly balanced sample and aligning with similar studies (e.g., Chen & Whalley, 2012; Davis, 2008). Similar to Anderson (2014), Chen and Whalley (2012), and Lang and Siler (2013), the model in Equation (1) incorporates an interaction term between the reform indicator and the time trend polynomial. This extension enhances the model's flexibility, allowing it to better capture differential trends in pollutant concentrations before and after the policy implementation. It also accounts for potential discontinuities in the rate of change and accommodates more complex dynamics, such as gradual adjustments in pollution levels induced by the reform. Furthermore, the inclusion of the interaction term enables the model to account for different time trends on either side of the cut-off, which is particularly important when other interventions or shocks coincide with the policy.

Despite its strengths, the global polynomial RD approach has limitations. It estimates short-term effects using a long time-series, which can introduce noise. A time-series local RD approach, also common in the literature, mitigates this issue by using a smaller estimation window around the policy date, thereby reducing noise and better capturing local effects, as shown in Equation (2):

$$\log(y_t) = \beta_0 + \beta_1 I(\text{Reform}_t) + \sum_{i=1}^3 \sum_{j=1}^3 \beta_{ij} x_{it}^j + \theta \tau + \phi I(\text{Reform}_t) \cdot \tau + u_t \quad (2)$$

In this local RD specification, bandwidths ranging from two-month to four-month windows are used. This approach restricts the sample to observations near the policy date, with pre-reform observations serving as the control group. Unlike

the global polynomial RD, which applies a high-order flexible polynomial to a long time-series, the local RD approach employs a linear time trend, making it more suitable for smaller sample sizes (see, for example, Anderson, 2014; Bento et al., 2014; Burger et al., 2014; Grainger & Costello, 2014). For the same reason, a cubic polynomial is used for weather variables instead of higher-order polynomials. However, smaller sample sizes limit robustness and preclude the inclusion of key time-fixed effects (e.g., month, day-of-the-week, hour-of-day) due to potential collinearity within the narrow window.

The two-step augmented RD method, introduced by Hausman and Rapson (2018), is the preferred empirical approach in this study. This method combines the strengths of global and local approaches, enhancing the detection of the local effect, reducing noise, and addressing issues such as global polynomial overfitting and sensitivity to specific observations (Hausman & Rapson, 2018). In the first step, residuals from a full time-series regression of weather controls and time-fixed effects (2011–2017) are stored. In the second step, these residuals are regressed on the reform indicator and linear time trends within a narrow window around the policy date. These procedures are represented in Equations (3) and (4).

Step 1:

$$\log(y_t) = \mu_0 + \sum_{i=1}^3 \sum_{j=1}^5 \mu_{ij} x_{it}^j + \sum_{m=1}^{12} \gamma_m \text{Month}_m + \sum_{d=1}^7 \delta_d \text{Day}_d + \sum_{h=0}^{23} \eta_h \text{Hour}_h + \epsilon_t \quad (3)$$

Step 2:

$$\hat{\epsilon}_t = \beta_0 + \beta_1 I(\text{Reform}_t) + \beta_2 \tau + \beta_3 I(\text{Reform}_t) \cdot \tau + u_t \quad (4)$$

Note: For each categorical variable — Month, Day, and Hour — I omit one category as the reference group (January, Sunday, and hour 0, respectively) to avoid perfect multicollinearity in equation (3). The indices shown in the equation run over all categories purely for notational convenience.

This method combines global controls, leveraging the entire dataset, with a local focus, to enhance statistical precision and isolate the policy’s local effect. By addressing the weaknesses of other time-series RD approaches, this method provides robust identification of short-term impacts while effectively controlling for confounders.

Research Results

Preliminary Assessment of Pollutant Levels After Policy Intervention

Figures 2–7 illustrate changes in average daily pollutant levels over the entire seven-year dataset, using a flexible fifth-order time-trend polynomial. These graphs provide preliminary insights into how the introduction of fixed, higher gasoline prices may have influenced pollution levels. Outliers have been excluded from the plots for clarity, and dashed vertical lines indicate the date when gasoline prices were raised and subsequently fixed. Notably, the data reveal a clear decrease in concentrations of carbon monoxide, ozone, and sulfur dioxide following the price hike. However, the family of nitrogen oxide pollutants exhibits a more complex pattern. Specifically, while nitrogen dioxide concentrations decrease and nitric oxide levels increase, the broader category of nitrogen oxides—which includes other compounds in addition to nitrogen dioxide and nitric oxide—does not show a distinct jump but rather a smooth increase across the threshold. Additionally, there is a discernible upward trend in nitrogen dioxide, nitric oxide, and nitrogen oxides concentrations in the period following the gasoline price change.

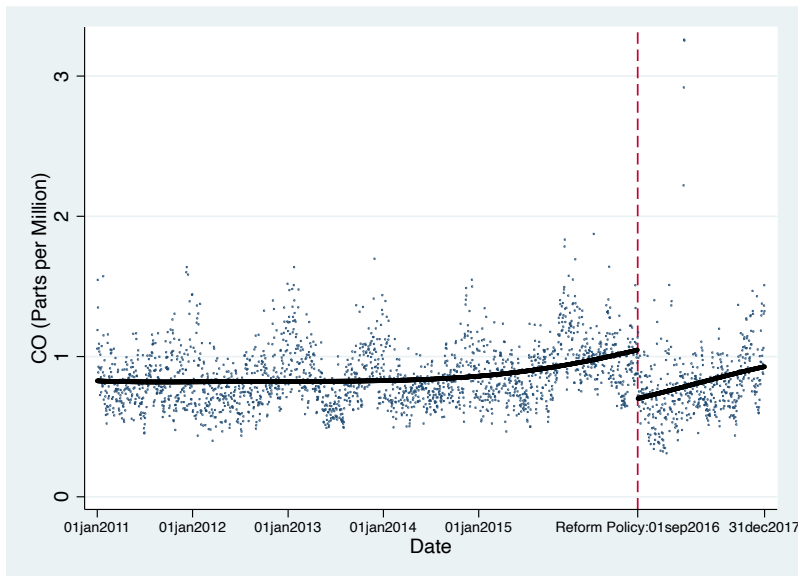


Figure 2: Globally Fitted Average Carbon Monoxide Concentrations Using the Whole Time-Series Data

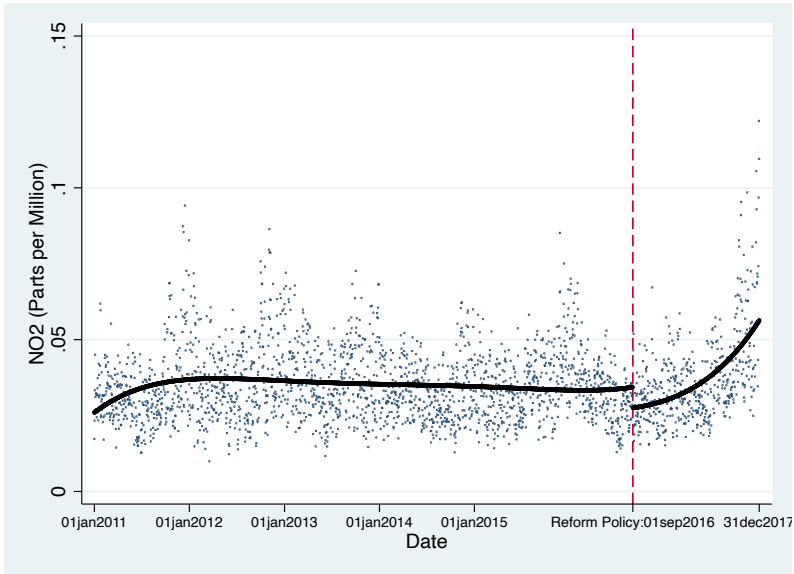


Figure 3: Globally Fitted Average Nitrogen Dioxide Concentrations Using the Whole Time-Series Data

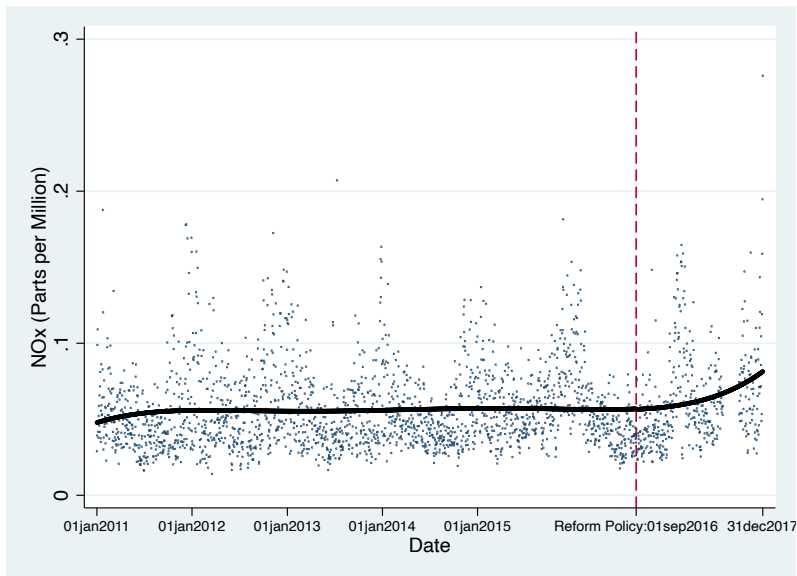


Figure 4: Globally Fitted Average Nitrogen Oxides Concentrations Using the Whole Time-Series Data

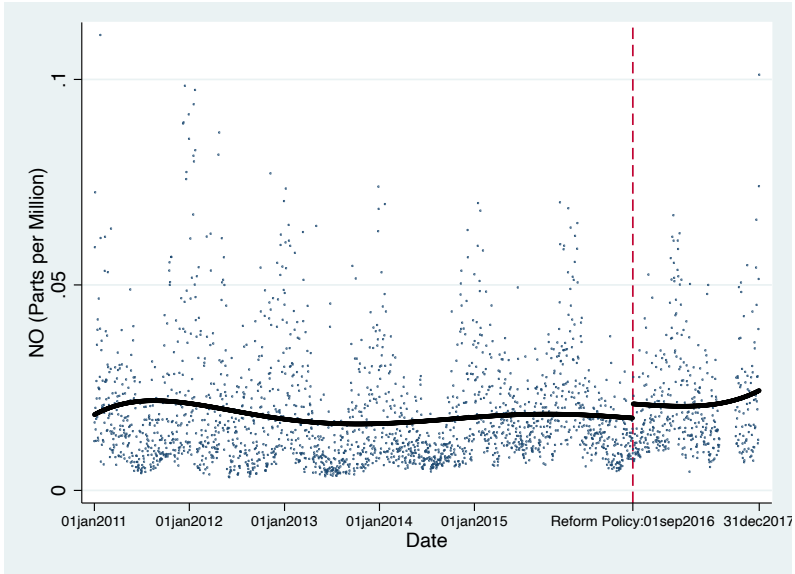


Figure 5: Globally Fitted Average Nitric Oxide Concentrations Using the Whole Time-Series Data

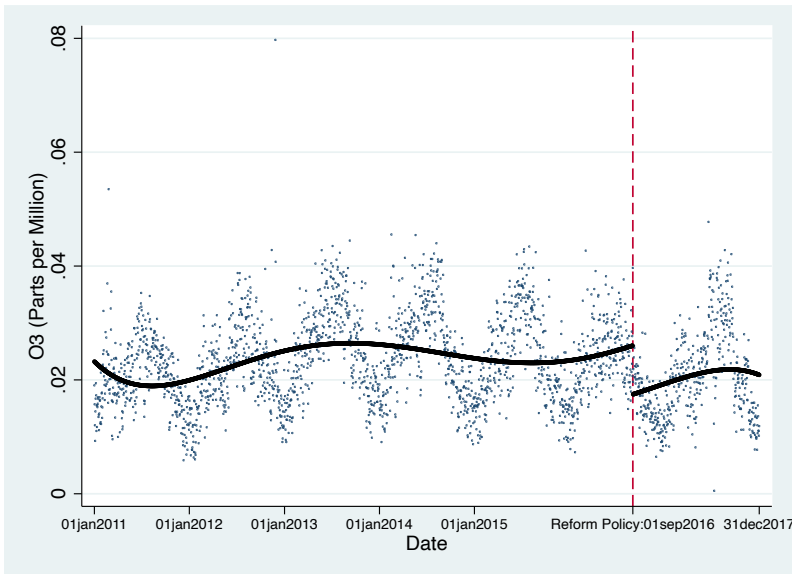


Figure 6: Globally Fitted Average Ozone Concentrations Using the Whole Time-Series Data

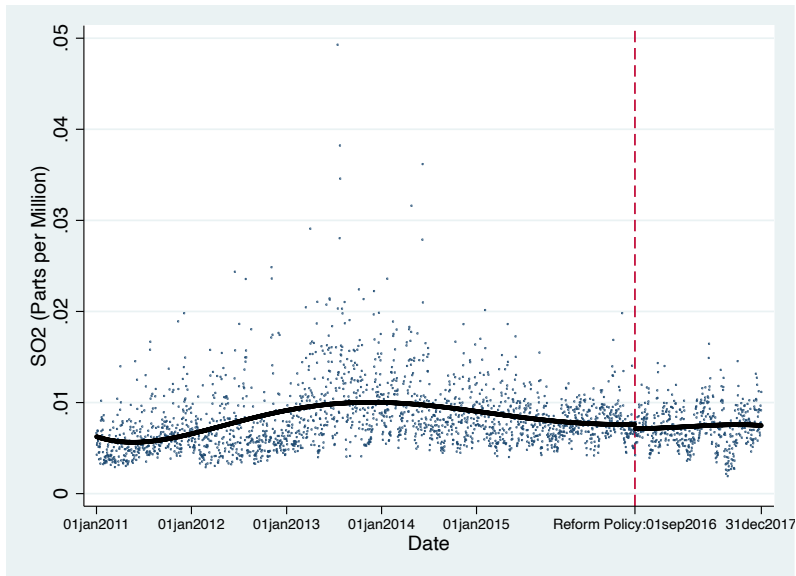


Figure 7: Globally Fitted Average Sulfur Dioxide Concentrations Using the Whole Time-Series Data

Figures 8–13 display smoothed plots derived from kernel-weighted local polynomial regressions using the Epanechnikov kernel, illustrating the relationship between the logarithm of average daily pollutant concentrations and the fitted daily time index. These plots offer insights into how pollutant concentrations fluctuate within a short, localized timeframe, specifically focusing on the 30 days before and after the policy implementation date. Following the price hike, a noticeable drop and a subsequent declining trend are observed in the concentrations of carbon monoxide and ozone. Sulfur dioxide also exhibits a downward jump at the policy threshold, though it trends upward afterward. In contrast, the levels of nitrogen dioxide and nitrogen oxides show an upward jump, while nitric oxide levels change smoothly without a distinct shift following the policy change. The cyclical behavior of nitrogen dioxide, nitrogen oxides, and nitric oxide concentrations appears to persist, seemingly unaffected by the price reform.

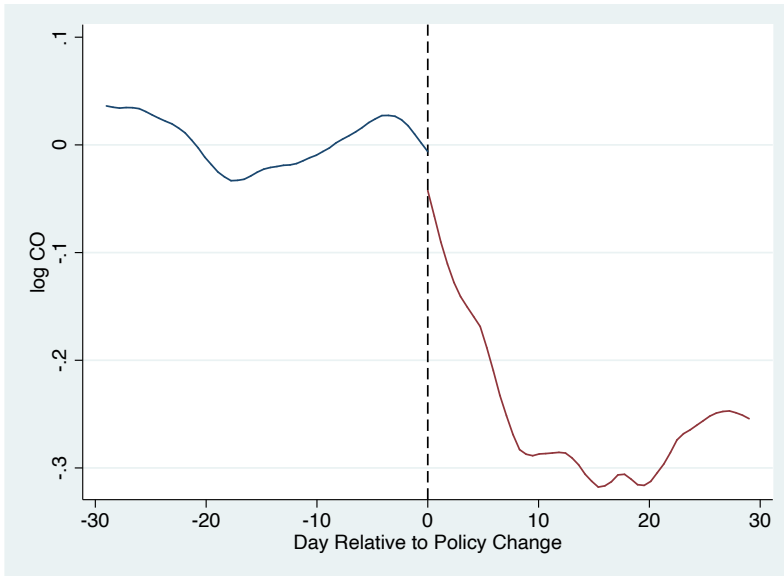


Figure 8: Fitted Log Carbon Monoxide Concentrations in a Local Two-Month Window

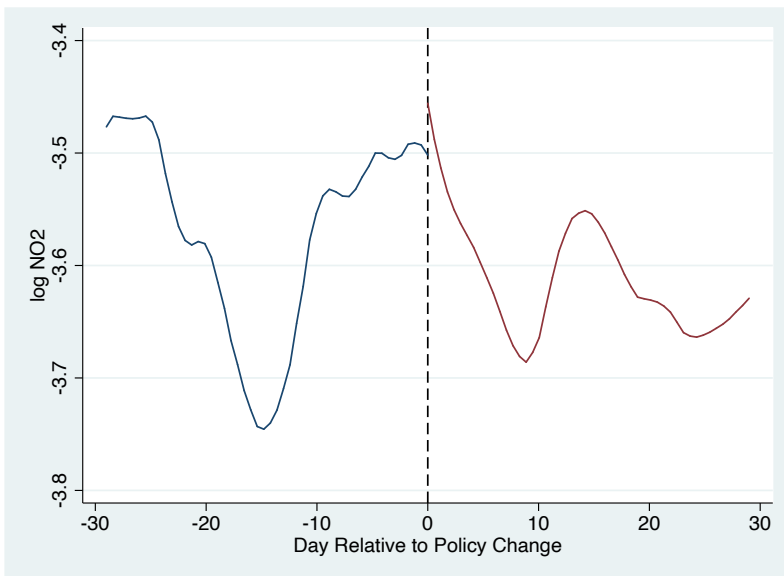


Figure 9: Fitted Log Nitrogen Dioxide Concentrations in a Local Two-Month Window

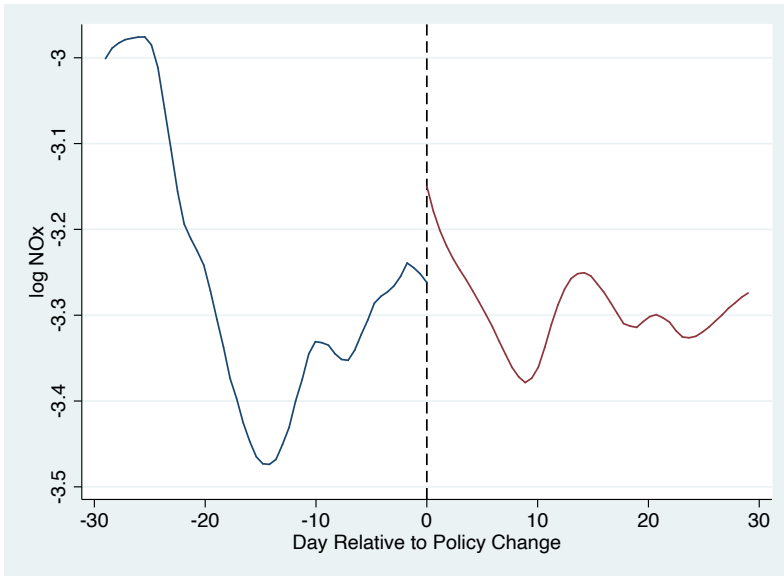


Figure 10: Fitted Log Nitrogen Oxides Concentrations in a Local Two-Month Window

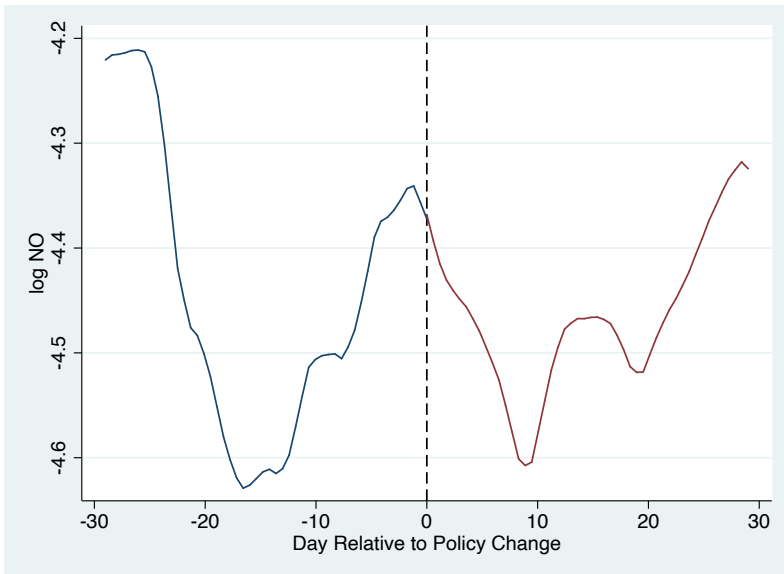


Figure 11: Fitted Log Nitric Oxide Concentrations in a Local Two-Month Window

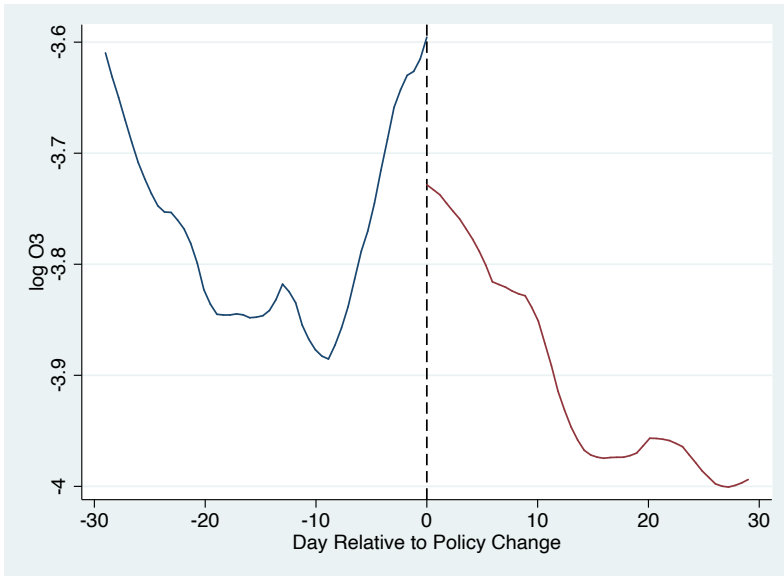


Figure 12: Fitted Log Ozone Concentrations in a Local Two-Month Window

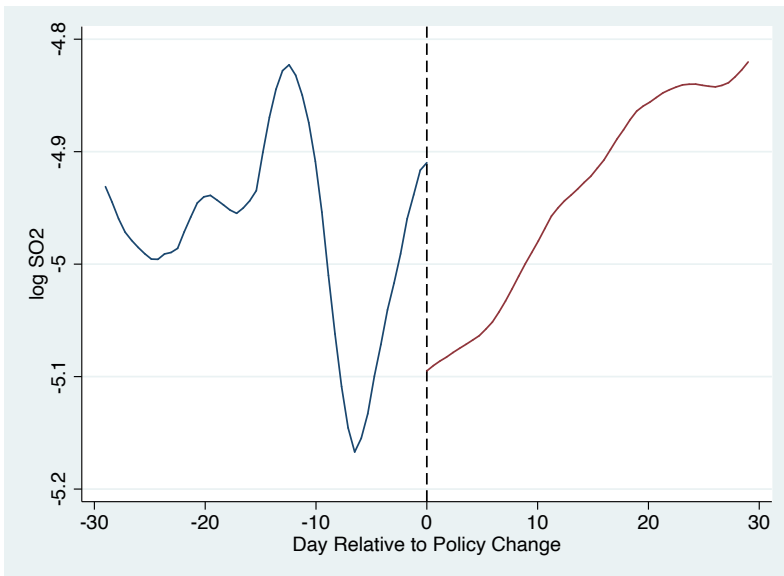


Figure 13: Fitted Log Sulfur Dioxide Concentrations in a Local Two-Month Window

It is crucial to emphasize that Figures 2–13 do not reflect the actual impact of the new gasoline pricing policy, as they display raw average concentrations without adjustments for weather and seasonal effects. These figures are intended to offer preliminary expectations regarding the policy's effects. A thorough empirical analysis that controls for weather and seasonality is essential for accurately assessing the policy's impact.

Empirical Results

This section presents the estimated coefficients (β_1), which represent the average effect of the gasoline subsidy reform on mean pollutant concentrations. These estimates are derived from the three time-series RD models specified earlier—specifically, models (1), (2), and (4)—depending on the specification used. In all tables presented in this section, the dependent variable is the pollution level, expressed in logarithmic form. The pollutants analyzed and presented in the tables below are carbon monoxide (CO), nitrogen dioxide (NO₂), nitrogen oxides (NO_x), nitric oxide (NO), ozone (O₃), and sulfur dioxide (SO₂). To enhance the reliability of the estimated standard errors, Newey-West standard errors are employed across all three specifications. These standard errors are adjusted to account for potential heteroskedasticity and autocorrelation in the residuals, with autocorrelation assumed to extend up to a maximum lag of 168 hours, equivalent to one week.

Table 4 presents the estimated average effect of the gasoline subsidy reform on mean pollutant concentrations from various polynomial models using the global polynomial RD specification described in Equation (1). The sample includes data from September 1, 2015, to July 31, 2017. The Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC) both select the 6th-order polynomial as the best-fitting specification across all pollutants.

Table 4
Impact of Gasoline Subsidy Reform on Mean Pollution Levels
Using the Global Polynomial RD

	CO	NO ₂	NO _x	NO	O ₃	SO ₂
Global Polynomial RD						
3 rd order polynomial time trend	0.168 (0.407)	-0.278 (0.373)	0.412 (0.674)	0.242 (0.592)	-0.420 (0.520)	-0.719 (0.450)
4 th order polynomial time trend	0.517 (0.376)	-0.081 (0.361)	0.969 (0.626)	0.257 (0.615)	-0.208 (0.526)	-0.825* (0.466)

Cont. Table 4
Impact of Gasoline Subsidy Reform on Mean Pollution Levels
Using the Global Polynomial RD

	CO	NO ₂	NO _x	NO	O ₃	SO ₂
5 th order polynomial time trend	0.516 (0.364)	-0.003 (0.337)	1.09* (0.590)	0.340 (0.582)	-0.262 (0.499)	-0.774* (0.453)
6 th order polynomial time trend	0.218 (0.330)	-0.145 (0.330)	0.672 (0.577)	0.224 (0.589)	-0.594 (0.433)	-0.754* (0.438)

*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.10$

The results indicate that none of the effects of the gasoline subsidy reform on pollutant concentrations are statistically significant at the five-percent level. This lack of statistical significance suggests that there is no robust statistical evidence to support the conclusion that the gasoline subsidy reform has had a meaningful impact on ambient air quality in Kuwait. To further validate these findings, it is prudent to confirm the results by applying the other two alternative time-series RD methodologies.

Table 5 presents the results of the local linear RD specification outlined in Equation (2). The analysis uses bandwidths corresponding to a two-month window, a three-month window, and a four-month window, thereby limiting the sample to observations within 30, 45, and 60 days, respectively, before and after the gasoline price increase date.

Table 5
Impact of Gasoline Subsidy Reform on Mean Pollution Levels
Using the Local Linear RD

	CO	NO ₂	NO _x	NO	O ₃	SO ₂
Local Linear RD						
Two-month window	-0.160** (0.068)	0.163** (0.075)	0.276*** (0.089)	0.002 (0.085)	-0.018 (0.120)	-0.058 (0.091)
Three-month window	-0.189** (0.078)	0.025 (0.082)	0.060 (0.113)	-0.191* (0.105)	0.091 (0.124)	-0.002 (0.092)
Four-month window	-0.217*** (0.080)	-0.119 (0.109)	-0.133 (0.150)	-0.374*** (0.139)	0.245* (0.137)	0.082 (0.086)

*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.10$

The local linear RD estimations provide robust evidence of a consistent decline in carbon monoxide concentrations across all estimation windows, strongly suggesting that the gasoline subsidy reform had a significant impact on reducing carbon monoxide levels. However, the results for other pollutants exhibit greater variability, with patterns differing across the selected time windows. This variability underscores the critical influence of the estimation window in shaping the observed outcomes for the other five pollutants. For instance, while the four-month window reveals statistically significant reductions in nitric oxide levels, no significant reduction is observed in the two-month window, and only weak reductions at the 10 percent significance level are detected in the three-month window. Conversely, the two-month window presents strong statistical evidence of increased nitrogen dioxide and nitrogen oxides levels, indicating a deterioration in air quality; however, this effect diminishes in the subsequent windows.

A key concern with these findings is the potential bias arising from the omission of controls for daily and weekly patterns and seasonality in this local linear RD specification. The timing of the gasoline price increase—implemented at the beginning of September—coincides with substantial seasonal changes, such as the end of summer. For example, the typical rise in vehicle ridership between August and September, as citizens and residents return from summer travel and students resume school, could lead to higher traffic congestion, potentially skewing the analysis. Without month fixed effects, the RD estimates confound the gasoline reform with seasonal patterns, resulting in biased policy effects.

Therefore, while the local RD analysis provides strong evidence of a reduction in carbon monoxide levels following the gasoline subsidy reform, the results for other pollutants are either not statistically significant or highly sensitive to the choice of estimation window, lacking robustness across the short time frames examined. The omission of controls for seasonal factors likely introduces bias into these estimates, complicating the interpretation of the reform's true impact on air pollution. To obtain more reliable estimates of the reform's effects, it is crucial to focus on the results from the preferred specification, the two-step augmented local linear RD method. This method accounts for time-fixed effects while maintaining a narrow local estimation window around the policy implementation date. The results of this more refined analysis are presented in Table 6.

Table 6
Impact of Gasoline Subsidy Reform on Mean Pollution Levels Using
the Two-Step Augmented Local Linear RD

	CO	NO ₂	NO _x	NO	O ₃	SO ₂
Two-step Augmented Local Linear RD						
Two-month window	-0.007 (0.069)	0.190** (0.082)	0.337*** (0.098)	0.060 (0.125)	0.059 (0.087)	-0.086 (0.093)
Three-month window	0.014 (0.085)	0.097 (0.073)	0.167 (0.107)	-0.047 (0.116)	0.028 (0.078)	-0.043 (0.104)
Four-month window	0.022 (0.080)	-0.025 (0.091)	0.012 (0.131)	-0.156 (0.121)	0.150* (0.085)	0.103 (0.103)

*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.10$

The two-step augmented RD method, which adjusts for time-fixed effects contrasts with the initial local RD analysis by finding no statistically significant reduction in carbon monoxide levels across any of the examined windows. This suggests that the previously observed reduction in carbon monoxide may not hold once seasonal effects and other time-related patterns are properly controlled for. Similarly, nitric oxide and sulfur dioxide do not exhibit any consistent or significant effects across the various windows.

Moreover, the results in Table 6 provide statistical evidence of an increase in nitrogen dioxide and nitrogen oxides levels within the two-month window, with significance at the five percent and one percent levels, respectively. Ozone levels also show an increase in the four-month window, although this result is only significant at the ten percent level. While these findings suggest a negative environmental impact from these key transportation pollutants, no significant changes are observed in the other windows.

Given the limited size of these windows and the absence of consistent statistically significant results across all three small estimation windows, it can be concluded that the gasoline pricing policy did not exert a substantial impact on pollution levels. Moreover, the statistically significant estimates that do exist suggest a deterioration in pollution concentrations. Consequently, the preferred specification—the two-step augmented local linear RD method—indicates no improvement in ambient air quality in Kuwait following the gasoline price increase policy.

To further assess the robustness of the preferred estimates presented in Table 6, diesel and kerosene prices were included as controls in Equation (3) because these prices began fluctuating on a monthly basis starting in January 2015. In Kuwait, more than 92% of all vehicle types operate on gasoline. Diesel fuel is used by some commercial and industrial vehicles, such as buses, trucks, and heavy-load vehicles (The General Department of Traffic, 2016). Additionally, monthly oil production was added as a control in Equation (3), given Kuwait's oil-dependent economy and the significant role of oil as a major pollution source in the country. The results in Panel A of Table 7 closely align with the main results in Table 6, suggesting that the preferred model successfully captures influences on air quality beyond the impact of the gasoline subsidy reform. Furthermore, the government introduced changes to water and electricity prices across different economic sectors, with the commercial sector being the first to face the new prices on May 22, 2017. Panel B of Table 7 presents the results of the two-step augmented RD model, excluding observations from May 22, 2017, onward to ensure that the new water and electricity prices do not influence the findings. The results in Panel B of Table 7 confirm the main findings in Table 6, as the outcomes remain consistent.

Because air pollutants may co-move due to shared emission sources and common meteorological influences, and because the baseline analysis estimates the effects for each pollutant separately, the main results are further corroborated using a multivariate robustness check. Although the baseline regressions employ Newey-West standard errors to address within-pollutant autocorrelation and heteroskedasticity, this adjustment does not account for dependence across pollutants. To the extent that serial correlation reflects persistent unobserved factors (e.g., traffic volume), that affect all pollutants, the Newey-West estimator may partially capture their shared structure. Nevertheless, such factors may also induce contemporaneous correlation across pollutants. A multivariate Seemingly Unrelated Regressions (SUR) system is used to address this issue by jointly modeling all six pollutants while allowing for cross-equation error correlation. This SUR framework combines the results of the second-stage models from the baseline two-step augmented RD design, preserving its structure while clustering standard errors at the calendar-week level. The results are presented in Table 7, Panel C.

Relative to the single-equation estimates in Table 6, the few initially significant results are attenuated. In the two-month window, the estimated increases for nitrogen dioxide and nitrogen oxides remain modestly significant only at the ten

percent and five percent levels, respectively. The increase in ozone, which was significant at ten percent level in the four-month window in Table 6, becomes statistically insignificant. Collectively, these system-wide results reinforce the primary conclusion that the reform did not produce broad-based improvements in ambient air quality.

Table 7
Robustness Checks of the Main Results Using the Two-Step
Augmented Local Linear RD

	CO	NO ₂	NO _x	NO	O ₃	SO ₂
Panel A: Including Diesel Prices and Oil Production Levels						
Two-month window	-0.002 (0.070)	0.190** (0.085)	0.338*** (0.104)	0.059 (0.134)	0.064 (0.086)	-0.097 (0.101)
Three-month window	0.005 (0.086)	0.084 (0.076)	0.166 (0.110)	-0.036 (0.124)	0.025 (0.077)	-0.075 (0.114)
Four-month window	0.012 (0.080)	-0.036 (0.093)	0.017 (0.133)	-0.123 (0.124)	0.135* (0.081)	0.098 (0.113)
Panel B: Excluding Observations After Water and Electricity Price Changes						
Two-month window	-0.006 (0.068)	0.191** (0.083)	0.332*** (0.100)	0.050 (0.124)	0.060 (0.087)	-0.085 (0.096)
Three-month window	0.012 (0.086)	0.105 (0.072)	0.179* (0.103)	-0.039 (0.111)	0.025 (0.077)	-0.050 (0.108)
Four-month window	0.022 (0.080)	-0.023 (0.091)	0.009 (0.130)	-0.162 (0.118)	0.150* (0.085)	0.103 (0.106)
Panel C: Multivariate Regression Across Pollutants						
Two-month window	-0.007 (0.065)	0.190* (0.114)	0.337** (0.147)	0.060 (0.175)	0.059 (0.133)	-0.086 (0.104)
Three-month window	0.014 (0.089)	0.097 (0.083)	0.167 (0.116)	-0.047 (0.132)	0.028 (0.102)	-0.043 (0.112)
Four-month window	0.022 (0.088)	-0.025 (0.095)	0.012 (0.134)	-0.156 (0.130)	0.150 (0.106)	0.103 (0.106)

*** $p \leq 0.01$, ** $p \leq 0.05$, * $p \leq 0.10$

Conclusion

This study presents a rigorous empirical analysis of Kuwait's 2016 gasoline price reform, assessing its impact on ambient air quality using advanced time-series regression discontinuity methodologies. The reform, representing the first upward adjustment in gasoline subsidies since 1998, introduced price increases ranging from 42% to 83%. The findings highlight a complex and nuanced relationship between these fuel price hikes and local pollution levels. Contrary to expectations that higher gasoline prices would lead to reduced emissions through decreased fuel consumption, the analysis does not identify consistent or statistically significant improvements in air quality across six key local pollutants: carbon monoxide, nitrogen oxides, nitrogen dioxide, nitric oxide, ozone, and sulfur dioxide. In certain estimation windows, some pollutants even exhibit increased concentrations, raising concerns about potential unintended consequences, though these results are not uniformly robust across all models and time frames. These findings underscore that price mechanisms alone may be insufficient to achieve meaningful reductions in local air pollution, particularly in contexts where alternatives to private vehicle use are limited and effective environmental policies are lacking.

The interplay between demand- and supply-side dynamics may help explain this paradox. On the demand side, behavioral responses—such as consumers switching to older, less fuel-efficient vehicles, opting for lower-grade gasoline, or the industrial, agricultural, and residential sectors adopting higher-emitting energy sources and practices—could undermine the expected environmental benefits. On the supply side, possible shifts in refining practices, increased oil exports due to reduced local fuel demand, and delayed adoption of cleaner technologies in favor of cost-saving measures might further dilute the potential gains from the reform.

Kuwait's gasoline price reform represents a significant policy effort; however, its limited impact on ambient air quality underscores the challenges of relying solely on price-based measures for environmental improvements. The muted effects highlight the need for a comprehensive policy framework that extends beyond subsidy reforms. Expanding public transportation infrastructure, promoting awareness campaigns, incentivizing fuel-efficient driving, and encouraging reduced vehicle usage are essential for reshaping entrenched mobility patterns. Integrated urban planning can also address structural drivers of vehicle dependency, such as long commutes to job opportunities and business centers. Investments in compact urban development, including affordable housing near economic hubs

and the integration of jobs and services with public transportation, can foster a more sustainable and interconnected urban environment, significantly reducing transportation-related emissions.

Furthermore, introducing market-based instruments, such as carbon taxes and cap-and-trade systems, across sectors contributing to pollution can play a pivotal role in improving environmental quality by creating economic incentives to reduce emissions. Aligning these efforts with investments in renewable energy infrastructure can amplify environmental benefits while supporting broader energy transition goals. Policymakers must consider the complex interplay of Kuwait's economic, social, and environmental conditions, tailoring interventions to its regional context to maximize effectiveness. By addressing potential unintended consequences—such as pollution displacement or implementation inefficiencies—through a nuanced and adaptive policy approach, Kuwait can develop more effective and sustainable solutions to improve air quality.

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Shamlan Waleed Albahar is an Assistant Professor of Economics at the College of Business Administration, Kuwait University. He received his Ph.D. in Economics from the University of California, Santa Barbara. His research interests include environmental economics, natural resource economics, and energy economics, as well as the study of market failures associated with command-and-control policies across various areas of economics. (shamlan.albahar@ku.edu.kw)

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