Evaluating a Discretionary Safety Valve: The Economic and Environmental Impacts of Waiving Fuel Content Regulations in Response to Supply Shocks

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Abstract

Given the uncertainty over compliance costs characterizing many public policies and regulations, economists have developed decision rules for choosing a price-based or quantity-based instrument – or a hybrid of the two approaches – to maximize net social benefits. While the vast majority of U.S. environmental and energy policy has focused on quantity-based regulation, a hybrid approach has become more common in recent years. For example, boutique fuel regulations dating to the 1990s – such as reformulated gasoline – established quantitative restrictions on pollutants in transportation fuels. Starting in 2005, the Environmental Protection Agency had the authority to issue a temporary waiver of these regulations in response to a fuel supply shock. In the first decade of this authority, EPA waived fuel content regulations 60 times, with nearly 90% of these waivers prompted by hurricane-related disruption of fuel supplies. This analysis examines the impacts of temporary waivers of regulations in response to shocks to production. Specifically, I explore how shocks affect local fuel markets and how waivers mitigate these shocks through analysis of daily, city-level fuel price data. These markets experience large increases, and quick declines in fuel prices, although it is difficult to discern these impacts from markets that do not seek regulatory waivers. The nature of these shocks – affecting many local markets at the end of the pipeline far from the natural disaster – serves as the basis for statistically identifying the impacts of waivers on air pollutant concentrations. I find that waiving reformulated gasoline regulations does not meaningfully impact ozone concentrations, but it appears to increase fine particulate matter concentrations by about 20% in the two months after a waiver has been issued.

Key words: instrument choice, regulatory waiver, fuel prices, air pollution

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1 Introduction

U.S. gasoline markets have been segmented based on fuel content regulations, creating so-called boutique fuel markets. With the promulgation in the 1990s of Environmental Protection Agency (EPA) regulations on reformulated gasoline Reid vapor pressure, oxygenated fuels, California cleaner burning gasoline, and the state boutique fuels the program, there are more than 45 different gasoline fuel blends sold in America (Chakravorty et al., 2008; Aldy, 2017). State policies also imposed limitations on the design and marketing of gasoline (Anderson and Elzinga, 2014).

While these air quality regulations are intended to improve air quality – primarily local ground-level ozone concentrations – they also create small Balkanized markets. The regulations impose significant and heterogeneous price impacts, with averages on the order of about 7 cents per gallon, reflecting both geographic isolation and imperfect competition (Sweeney, 2015; Brown et al., 2008). These regional markets are potentially less resilient to supply shocks because neighboring markets do not have regulation-compliant fuels to export to those experiencing a shock.

To address the concerns about the impacts of supply shocks to these markets, the 2005 Energy Policy Act granted EPA the authority to waive temporarily fuel content regulations. In the first year of this authority, EPA granted requests from 16 states for 31 waivers (Aldy, 2017). Most of the 2005 waiver requests reflected concerns about pipeline outages due to Hurricanes Katrina and Rita affecting downstream markets. For example, governors of the states of Iowa, Kentucky, Missouri, Nebraska, and Virginia were among the fourteen who requested waivers of fuel regulations in the fall of 2005 as a result of one (or both) of these hurricanes. Over 2005-2015, EPA granted 60 waivers, with 85 percent resulting from hurricane-related supply shocks.

In this paper, I use fuel content regulation waivers in response to hurricanes to identify the environmental benefits of these standards. By focusing on waivers for states at the end of pipelines, I can exclude potential confounding influences on air quality associated with hurricane damage, rescue operations, cleanup, and rebuilding. These end of pipeline states bear a supply shock from an exogenous event that does not influence local economic activity or pollution, except through the fuel supply and associated waiver of fuel content standards. Using difference-in-differences estimators, I find that waiving fuel content regulations have statistically negligible impacts on ozone concentrations, but appear to increase fine particulate concentrations by as much as 20 percent.

These results also serve as an extension of the analyses in (Auffhammer and Kellogg (2011); hereafter AK), which exploit the temporal discontinuities in the initial implementation of boutique fuel regulations to estimate the ozone concentration impacts of these standards. AK show that only the California boutique fuel (so-called CARB gasoline) yields a statistically significant reduction in ozone concentrations across difference-in-differences and regression discontinuity estimators. They explain the absence of ozone pollution reductions in California to the fact that many urban areas have ozone concentrations driven by nitrogen oxide precursors, not that VOC precursors targeted by boutique fuel regulations. Moreover, they find that California is more prescriptive in the specific VOC precursors that refiners must reduce in producing CARB gasoline, with a focus on those most prolific in facilitating ozone creation. As a part of this project, I have replicated their work, which is summarized in the appendix. By estimating the impacts on fine particulates, this study extends our understanding of how fuel content regulations affect air quality and, thus, public health.

This work provides air quality estimates that are important in their own right and as an input in evaluating policy options for mitigating the risks posed by fuel supply shocks. Estimating changes in pollutant concentrations as a result of waivers represents an alternative means for identifying the air quality benefits of fuel content regulations. The randomness of hurricane-related supply shocks (from refinery and/or pipeline outages) is unlikely to be correlated with other air quality policies; an issue AK investigate carefully in the context of their empirical approach, which shows that some of the apparent air quality benefits of reformulated gasoline likely reflect simultaneous implementation of major nitrogen oxide controls at power plants. Moreover, this randomness is unlikely to be correlated with local economic factors that could influence air quality.

The waivers represent a quick-moving policy response to supply shocks. Policymakers have few fast-acting tools at their disposal to address such shocks. Natural disaster-related shocks have prompted more policymaker decisions to tap the crude oil stored in the U.S. Strategic Petroleum Reserve than have foreign supply shocks. As a result, there has been some policy support for constructing product-based strategic reserves. Building and maintaining such reserves represent a potentially costly alternative to temporary modifications of regulations that create Balkanized fuel markets. This analysis could inform a welfare analysis of waivers as well as an assessment of the incremental net social benefits of product reserves. The next section describes the policy and economics of waiving fuels regulations. Section three examines the impacts of hurricanes on gasoline prices in an effort to infer the decision rule for issuing a regulatory waiver. Section four presents the empirical framework, data, and results for the impacts of regulatory waivers on air pollutant concentrations. The final section concludes with a discussion of policy implications and next steps.

2 Policy and Economics of Waiving Fuel Regulations

2.1 Fuel Content Regulations

Under the Clean Air Act, the Environmental Protection Agency (EPA) regulates the design of transportation fuels with the intent of reducing the emissions of volatile organic compounds (which facilitate the formation of ground-level ozone pollution), carbon monoxide, and hazardous air pollutants. The 1990 Clean Air Act Amendments granted EPA the authority to implement such fuel content regulations by targeting the most heavily polluted areas.

During the ensuing decade, EPA promulgated regulations on reformulated gasoline (RFG), Reid vapor pressure (RVP), oxygenated fuels, California cleaner burning gasoline, and the state boutique fuels the program. Each of these standards requires refiners to modify their gasoline – primarily by removing various volatile organic compounds – so that when it is used in cars and trucks, there are fewer pollutant emissions. The RFG standard imposes the greatest costs on fuel markets and is estimated to have the largest impact in reducing volatile organic compounds among this set of regulations. The RVP standard applies to the greatest number of counties among these regulatory instruments (Figure 1).

Implementing multiple, geographic-specific fuel content standards and providing state regulators the discretion to authorize specific fuel blends under the state boutique fuels program has resulted in more than 45 different gasoline fuel blends sold in America (Chakravorty et al., 2008; Anderson and Elzinga, 2014). This segmentation of U.S. gasoline markets through fuel content regulations has created what is typically referred to as boutique fuel markets.

The air quality regulations creating these boutique fuel markets are intended to improve air quality in those areas with the worst ozone and carbon monoxide pollution – the most serious non-attainment areas as designated by EPA under the Clean Air Act. However, these regulations have also Balkanized the American gasoline market, imposing significant and heterogeneous price impacts. For example, the reformulated gasoline standard increases gasoline prices on the order of about 7 cents per gallon, but this varies by more than a factor of two, reflecting both geographic isolation and imperfect competition in local fuel markets (Sweeney, 2015; Brown et al., 2008).

Market Balkanization effectively reduces the elasticity of supply to every Balkanized jurisdiction, thereby increasing the price effect of local supply shocks. If a given reformulated gasoline market suffers a supply shock, the neighboring non-RFG markets do not have regulation-compliant fuel to export to the disrupted market.

2.2 Energy Supply Shocks and Safety Valves

Unanticipated energy price volatility can have quite significant macroeconomic impacts, adversely affecting business investment as well as household planning and consumption. As a result, such volatility can have important political implications. Energy price volatility has historically reflected geopolitical events around the world. But recently in the United States, natural disasters, policy design and implementation, and competition in markets have contributed to volatility in U.S. energy prices.

Environmental policy can influence the volatility of energy prices through a number of channels. For example, environmental regulations in markets characterized by little competition can reduce competitiveness. With fewer businesses participating in these markets, production shocks at one or more firms are likely to cause greater price swings. Moreover, implementing environmental policy through cap-and-trade systems, tradable performance standards, and tradable credit programs – all of which could be subject to even greater volatility than the world oil market (Aldy and Viscusi, 2014) could exacerbate fuel and electricity price volatility in retail markets. When short-term supply disruptions occur, environmental regulations can be quite costly without government intervention to relax the regulatory constraint.

Concerns about energy price volatility, especially that resulting from negative supply shocks, have motivated an array of policy responses. In response to the restrictions on oil production that dramatically increased oil prices in the 1970s, the U.S. government created the Strategic Petroleum Reserve – a public inventory that has held 500 to 700 million barrels of crude oil over most of the past three decades. The President has the discretion to tap the Strategic Petroleum Reserve to address an unexpected and significant shock to U.S. oil supplies.

Many state programs mandate the supply of electricity from renewable sources and implement these so-called renewable portfolio standards (RPS) through tradable credit systems. Some RPS programs establish rules that cap the prices of the tradable credits by allowing utilities to make alternative compliance payments in lieu of generating or contracting for renewable power. This prevents negative supply shocks in renewable power markets from significantly increasing utility costs and consumer prices. This is an illustration of a hybrid price-quantity instruments (Roberts and Spence, 1976) that can increase expected social welfare in the presence of uncertainty in regulatory compliance costs (Pizer, 2002). This so-called safety valve, common to many proposals for regulating greenhouse gas emissions (Aldy et al., 2010), establishes a transparent rule – a maximum allowance or credit price–at which the constraint set by the quantity regulation is relaxed and effectively converted into a price instrument.

In contrast, fuel content waivers reflected policymaker discretion in relaxing the regulatory constraint. In effect, when a waiver is issued, it permits firms selling fuel in the market covered by the waiver to market gasoline subject to conventional gasoline regulatory requirements. The waiver does not eliminate environmental regulations on fuel content, but it does break down the barriers to trade among conventional and more-stringently-regulated markets in the Balkanized fuel system.

The social welfare impacts of instituting a regulatory waiver option will depend on the relative changes in benefits and costs that would be realized in the event that the policymaker executes the option (Weitzman, 1974). The existing research on the environmental benefits foregone by relaxing the regulatory constraint suggests that there could be little downside to the regulatory waiver. While the intent of reformulated gasoline regulations is to mitigate emissions of ozone precursors, the EPA Regulatory Impact Analysis of the reformulated gasoline standard did not even estimate the impact of the rule on ozone concentrations or public health (Anderson and Rykowski, 1997). Subsequent empirical work shows that – outside of California – the impacts of reformulated gasoline and RVP regulations on ozone concentrations are statistical zeroes (Auffhammer and Kellogg, 2011). In the context of instrument choice and safety valves, its not that the marginal environmental damage function is not steep, it may not even differ from zero for many parts of the country. I explore this issue in detail in section 4 and in a replication of Auffhammer and Kelloggs work in the appendix.

The economic benefits of a waiver could be substantial in light of the significant fuel price spikes that occur during supply shocks to Balkanized markets. The implementation of the second phase of the RFG standard in Chicago illustrates the vulnerability of these Balkanized markets to supply shocks. The reformulated gasoline program transitioned to the second and more stringent phase in 2000 in areas with the worst ozone pollution. During the first year of the second phase, Chicago did not have significant inventories of regulation-compliant fuel when an important pipeline serving its market went out of service that spring. With a short supply of RFG gasoline, Chicago gasoline prices in June 2000 were some 50 cents higher per gallon than fuel sold in areas that were not exposed to the supply shock (Bulow et al., 2003).

Figure 2 illustrates the impacts of the spring 2000 Chicago supply shock. The figure presents the fuel prices for reformulated gasoline in the city of Dallas as a benchmark for the Chicago spike. Fuel prices under phase I of reformulated gasoline in the summer of 1999 through the winter conventional gasoline regulatory period (mid-September to mid-May) follow very similar trends in the two cities through April 2000. With the RFG-II requirements scheduled to take effect on May 15, the Chicago-Dallas differential expanded dramatically until July. Fuel prices in RFG markets near Chicago–such as St. Louis–increased in response to the demand pull from the Chicago market. The Chicago price spike resulted in fuel price increases an order of magnitude larger than the estimated cost to produce a gallon of reformulated gasoline (Sweeney, 2015).

3 Inferring a Decision Rule for a Discretionary Safety Valve: Fuels Regulations Waivers

3.1 Waiver Decision Rule

The statutory language in the 2005 Energy Policy Act authorizing fuel content regulatory waivers provides substantial discretion to EPA. The statute establishes conditions for temporarily waiving a rule (up to 20 days, subject to renewal), but leaves it to EPA staff on how to operationalize the process in cooperation with the Department of Energy, state government officials, and representatives of the petroleum industry. Since EPA had to implement this authority so quickly after the Energy Policy Act became law (Hurricane Katrina made landfall a few weeks after President Bush signed the bill), it did not have time to issue guidance or a rule-making on its implementation process. Based on conversations with government staff and industry experts, the decision by a state government to petition for a waiver and the decision by EPA to grant a waiver depends on assessments of the days of supply held in inventory available in the market affected by the shock. Put another way, they are determining if and when the tanks will go dry.

In contrast, an economist may focus on changes in fuel prices as a signal of the scarcity in a given market as well as a measure of the economic costs of a shock to a stringently regulated market. Indeed, the price of fuels in a market can represent information on a variety of factors that can influence the magnitude and duration of a shock – the supplies from refiners, the fuel in local inventory, the response by consumers to the news of the shock and rising fuel prices, the opportunities for regulation-compliant fuels to move from other markets into the one suffering the shock. As a result, the price of gasoline may serve as a more comprehensive statistic summarizing the local market than receiving updates on tank levels and pipeline flows from industry representatives. As the analysis below shows, fuel prices respond to shocks, but it is not clear that EPA responds to fuel price increases in making waiver decisions.

3.2 Preliminary Analysis of Waivers on Fuel Prices

Hurricanes that cause major damage to the refining and pipeline systems along the U.S. Gulf Coast have resulted in supply shocks and gasoline price spikes across the eastern half of the country. Figure 3 illustrates the experience of Richmond, Virginia in the aftermath of Hurricanes Katrina and Rita in 2005. The vertical lines reflect the dates that the two hurricanes made landfall and the gray shading is the duration of the regulatory waiver for that market. In the few days between Hurricane Katrina making landfall and Richmond receiving its waiver, the price of fuel shot up by more than 60 cents per gallon to about $3.15, and then remained around this level for a few days before slowing declining. The shock associated with Hurricane Rita caused another run-up in fuel prices — even as Richmond continued to operate under a regulatory waiver. These gasoline price spikes did not reflect the crude oil market, which had fairly level prices throughout that fall.

Figures 4–6 show a series of pairwise comparisons between three reformulated gasoline markets that received waivers that fall Richmond, St. Louis, and Houston and West Coast gasoline markets that are served by refineries and pipelines unaffected by Gulf Coast hurricanes. In Figure 4, Richmond gasoline prices over 2004 through late summer of 2005 are about 20 cents per gallon below those in San Diego (which uses CARB gasoline, similar in stringency to reformulated gasoline) and about 5 to 10 cents per gallon below those in Portland (which complies with low-volatility regulations). The shocks caused by the two hurricanes resulted in Richmond prices exceeding these West Coast comparables. Figure **??** tells a similar story for St. Louis, in comparison with CARB gasoline in San Francisco and low-volatility gasoline in Las Vegas. Likewise, Figure 6 shows the same phenomenon for Houston in comparison with CARB gasoline in Los Angeles and low-volatility gasoline in Seattle.

Figure 7 further illustrates this phenomenon in 2008 after Hurricanes Gustav and Ike, when reformulated gasoline markets in Baltimore, Louisville, and Richmond received waivers. The collapse of crude oil and refined petroleum product prices during the Great Recession in the fall of 2008 is also evident in this figure.

In these illustrations, and in analyses of other markets receiving waivers not shown here, virtually every market that suffered a hurricane-related shock and received a waiver experienced a large increase in fuel prices. On September 1, Richmonds gasoline price was 70 cents per gallon greater than the average for that date over 2000-2004, controlling for oil prices.

Some markets experienced price spikes and then declines before receiving a regulatory waiver. In some cases, this is a function of the additional strain that Hurricane Rita put on a stressed refinery and transport system, as well as delayed impacts of Hurricane Katrina.

The duration of high fuel prices in these shocked areas appears to be shorter than that for Chicago in 2000, although this is admittedly a small comparison set. While Figures 3–7 clearly show large price spikes relative to crude oil prices and to non-shocked western markets, it is difficult to discern the impact of the waiver. Did fuel prices slowly go down in these markets because of the waiver? Because of repairs to refineries and pipelines? Because of shipments from other, nearby markets? Its difficult to identify counterfactuals that would permit a parsing of the impacts of these various factors.

The decision rule for petitioning and receiving a waiver becomes even more difficult to identify when one evaluates the price impacts of markets that did not petition for a regulatory waiver. Table 2 presents several snapshots of fuel prices for five cities: Boston, Columbus, New York, Raleigh, and Richmond. These cities use either reformulated gasoline or low-volatility gasoline, but only Richmond received a regulatory waiver. Over August 15 through September 15, each of these cities experienced major price spikes, with gasoline prices 70 cents per gallon or more higher on September 5 than on August 15 and in comparison with the average for that date over the previous five years for each city. Of the four cities that did not receive a regulatory waiver, only Columbus had fuel prices that fell below Richmonds gasoline prices during at least some of this time period. This evidence is consistent with at least two phenomena. First, a physical shortage in Richmond contributing to an increase in fuel prices in that RFG market, which drew product from other east coast RFG markets causing all market prices to increase. Second, uncertainty about the extent and duration of the Hurricane Katrina damage may have caused many consumers to go fill up their cars and light trucks as a matter of precaution. This may have contributed to a spike in demand immediately after Katrina made landfall, resulting in higher prices.

4 Environmental Impacts of Waiving Fuel Regulations

4.1 Data

Waivers: I have compiled a dataset describing all EPA waivers of fuel content regulation since 2005. This includes dates, geographic coverage, and rationale for the waiver decision. Thus, I can identify and discern waivers due to a shock local to a market (e.g., Hurricane Katrina and Louisiana) from a shock affecting refining capacity or a pipeline distant from a given market (e.g., Hurricane Rita and Kentucky).

RVP, RFG, and CARB Regulations: Drawing from EPA-published information online, I have compiled a dataset that describes RVP regulation (Phases I and II), RFG regulation (Phases I and II), and CARB regulation in California. As with the waivers dataset, this includes date and geographic coverage information.

Air Quality: I use hourly air quality monitoring data from the EPA for ozone and fine particulate matter. Air quality monitor-days were included in the sample based on a two-step refinement. For a given monitor-day to be considered valid, at least nine hours of data need to have been recorded between 9am and 9pm by that monitor on that day. Then, for a given monitor-year to be considered valid, at least 75 percent of the monitor-days between June 1 and August 31 in that year need to have been valid. For ozone, I have focused on the daily maximum concentration and for fine particulate matter I have constructed the daily average concentration for a given monitor.

Weather: For each air pollution monitor-year, the closest weather station was identified using a spherical distance calculation. The daily weather observations from the closest weather station were used as the weather covariates for each air pollution monitor-day in that year. This includes information on temperature, precipitation, dew point, and wind speed. Using an imputation algorithm from AK, I have also imputed weather for some pollution monitor locations.

4.2 Empirical Framework

To estimate the impact of waivers on air pollutant concentrations, I implement a difference-in-differences estimator. In this framework, a waiver will treat one or more counties for the period of time covered by the waiver decision. An observation is at the level of an air pollution monitor, so for example, the impact of a waiver on ozone concentrations could be estimated by:

$$[O_3]_{it} = 1\{Waiver\}_{it} + \beta' X + FEs + \epsilon_{it}$$

where $[O_3]_{it}$ is the ozone concentration (either daily maximum or highest daily 8-hour average) on day t for ozone monitor i; the indicator function for the waiver takes a value of 1 for the dates that the county in which monitor i is located is covered by a waiver; the vector X includes a variety of other determinants of ozone concentrations (such as temperature and precipitation, per capita income of the county, and time trends interacted with an indicator for regulatory status); and an array of fixed effects intended to capture various unobservable phenomena that could confound identification. In the analyses presented below, I include Census region-by-year fixed effects (to account for regional trends in economic activity), day-of-week fixed effects (to account for differences in driving behavior and economic activity over the course of a week), and monitor-by-month fixed effects (to account for location-invariant factors, but permitting them to vary seasonally). In the analyses presented below, I also estimate how regulatory waivers affect fine particulate concentrations (PM-2.5).

Due to lags in the fuel supply chain, it may take several days or more for conventional gasoline to enter an area that was previously selling regulated fuel. It may take more time for that fuel to be distributed to fueling stations, and then more time until a consumer brings her car in to be filled up on the conventional gasoline. For these reasons, I have modified the representation of the regulatory waiver in the regression specifications. First, I make the indicator function take a value of 1 for a fixed period of time I experiment with 1-month and 2-month periods instead of simply the waiver period. Second, I interact this 1-month (or 2-month) waiver indicator with a linear time trend that starts at zero on the day that the waiver is issued and runs over the course of 30 (or 60) days.

In evaluating the impacts of a regulatory waiver on air quality, one may be concerned that the hurricane and the subsequent hurricane response could undermine statistical identification of the impact of the regulation on air pollution. For example, Louisiana received a waiver in the aftermath of Hurricane Katrina. The vast disruption caused by the hurricane and the large response, relief, and rebuilding efforts could have had a larger impact on air quality than the characteristics of the fuels sold at fill-up stations. As a result, I employ three samples in my analyses. One uses data from all states. A second sample excludes all data from the states of Louisiana, Mississippi, and Texas. In this second sample, I am focusing on waivers that occur at the end of the pipeline, in states like Kentucky, Iowa, Maryland, Missouri, Ohio, and Virginia. The third sample is further narrowed by eliminating all data from the states of Connecticut, New Jersey, and New York because of the waivers issued in response to Superstorm Sandy. This natural disaster affected the ability to use the local fuel transportation system and to access the bunkers in New York Harbor. In other words, a shock that occurred at the end of the pipeline. We remove these to address concerns about confounding effects in our third sample below.

This empirical strategy exploits the exogenous variation in regulatory status induced by natural disasters far away from the affected fuel market. The additional controls in the empirical models ensure that the waiver status indicator variable represents the causal impact of regulatory status on air pollutant concentrations. The monitor-by-month-of-year fixed effects address the seasonality in air pollutant concentrations especially ozone as well as location-specific factors that influence concentrations, coupled with the non-random timing of hurricanes over the course of a year. The Census region-by-year fixed effects account for the evolution in technological controls, improved compliance with national ambient air quality standards, and economic factors. Short-term factors that influence air pollutant concentrations are accounted for by the day-of-week fixed effects and weather controls.

4.3 Results

Table **??** presents the estimated impacts of fuel content regulation waivers on ozone concentrations. I specifically distinguish between waivers of low-volatility regulations (RVP_W) and waivers of reformulated gasoline regulations (RFG_W). The three samples that vary by state composition, described above, are employed in the first, second, and third triplet of models in Tables **??** and 4. Within each triplet, I estimate the average impact of these regulatory waivers during the month after the waiver date (Columns 1, 4, and 7), the impact over the first month that allows the effect to vary linearly with time from the waiver date (Columns 2, 5, and 8), and the impact over the two months after the waiver date, again allowing the effect to vary linearly with time from the waiver date (Columns 3, 6, and 9).

The average effects over the first month for both types of regulatory waivers are statistically insignificant and small in magnitude (four of the six coefficient estimates for the RVP and RFG waivers represent less than a of 1 percent change in ozone concentrations). The models that allow the impacts to vary over the month after the regulatory waiver indicate that ozone concentrations may fall immediately after the waiver, but increase over the course of the month. The individual coefficient estimates on the indicator variable and the product of the indicator variable and the one-month time trend for each regulatory waiver are statistically significant at the 1 percent level (Columns 2, 5, and 8). When evaluated in combination, however, there is little evidence of statistically significant changes in ozone concentrations. Figure 8 illustrates the results for the reformulated gasoline regulatory waivers from the model presented in Column (8) of Table **??**. Ozone concentrations are about 2 parts per billion lower immediately after the waiver and statistically distinguishable from zero at the 5 percent level and they are about 2 parts per billion higher 30 days after the waiver and statistically distinguishable from zero at the 10 percent level. The near-term fall in ozone concentrations could reflect consumers reduction in demand in response to fuel price spikes. In future analysis, I will examine the change in driving in response to fuel prices using high frequency transportation count data (hourly counts of vehicles at traffic monitoring locations versus daily fuel prices) to assess this possibility. At most, the one-month analyses suggest that ozone concentrations could be about four percent higher one month after a waiver of the reformulated gasoline standard.

Extending the analyses to two months provides little evidence of a long-term impact of regulatory waivers on ozone concentrations (Table **??**, Columns 3, 6, and 9). The coefficient estimates for the RVP waivers are not statistically significant and, as we limit the sample moving from left to right, the evidence for RFG waiver impacts over two months also weakens. Figure 9 shows that ozone concentrations are very close to zero (about to 1 part per billion lower) during the 60 days after a reformulated gasoline waiver, with large confidence bounds.

In contrast to the ozone analyses, the fine particulate matter models illustrate statistically significant, large magnitude impacts of fuel content regulatory waivers on fine particulate matter concentrations. Table 4 presents the coefficient estimates for the model specifications as in Table **??**, except for the use of fine particulate matter concentrations as the dependent variable. While the estimated impacts for the RVP waiver are not robust across specifications, the results for the RFG waivers consistently show a statistically significant increase in fine particulate matter concentrations. The average impact over the month after the waiver date is a nearly 25 percent increase in fine PM concentrations (Columns 1 and 4). Figure 10 illustrates the results for the model presented in Column (5) of Table 4, which shows that concentrations are statistically different from zero about 10 days after a waiver date and increase as much as five micrograms per cubic meter 30 days after the waiver is issued. With average fine particulate matter concentrations of about 11 micrograms per cubic meter, these are quite large impacts. Figure 11 illustrates the results for the model presented in Column (6) of Table 4, which again shows a statistically significant increase in fine particulate matter concentrations throughout the 60-day window after the date of a waiver. The differences in the trend over time in Figures 10 and 11, however, suggests that a more flexible time specification should be explored (and will be in future work). Across both specifications, however, the average increase in fine particulate matter concentrations is about 20 percent.

These large fine particulate matter concentration impacts are preliminary and require additional analysis. First, the panel of monitors is smaller and changing over time, which could influence the results. Second, to the extent that long-distance pollutant transport occurs from a hurricane region to a market with the regulatory waiver occurs, this could influence the results. Third, the estimated impacts on concentrations are quite large given transportations share of fine particulate matter emissions nationally (about 10 percent in recent years). Additional analyses will examine the robustness of these findings.

5 Conclusions and Next Steps

The design and implementation of most fuel content regulations has resulted in a Balkanized patchwork of fuel markets more vulnerable to supply shocks. This analysis has examined how providing the regulator with a discretionary safety valve a time-limited waiver of stringent fuel content regulations can mitigate the impacts of supply shocks. Employing such discretion could have substantial economic benefits for fuel consumers by preventing price spikes or reducing prices after a spike but potentially with public health costs. Given the literature on accounting for the net social benefits of providing a safety valve to a quantity-based regulatory instrument, this paper provides a preliminary empirical examination of a discretionary safety valve in practice.

Major hurricanes affecting the refinery complexes and transportation systems in the U.S. Gulf Coast have contributed to significant gasoline price spikes throughout the eastern half of the United States. Regulators have often responded to such shocks by quickly waiving fuel content regulations, as EPA did within days of Hurricane Harvey making landfall in Texas in 2017. The waivers have been used in places with price spikes, but many other markets experienced similar price spikes without petitioning or receiving a regulatory waiver. The initial analysis of fuel markets suggests that a safety valve is merited in many cases the fuel price increases were about ten times greater than the average cost of compliance for reformulated gasoline but it is difficult to statistically identify the efficacy of the safety valve. Future work will attempt to further parse the impacts of shocks and waivers on the evolution of fuel prices in these markets.

These analyses also provide an independent assessment of the air quality benefits of fuel content regulations. The use of regulatory waivers serve as an alternative identification strategy for estimating the causal impacts of RVP and reformulated gasoline standards on ozone and fine particulate matter concentrations. The estimated ozone concentration impacts are statistically and economically small, consistent with the work by Auffhammer and Kellogg (2011). There is some weak evidence that concentrations would be as much as 4 percent higher about a month after a waiver is issued, which is similar to some of the statistically weak evidence in the difference-in-differences models of reformulated gasoline standards in AK. This work represents the first effort to use exogenous variation in fuel content regulation implementation to estimate the impacts of these rules on fine particulate matter. While additional work needs to be undertaken to ensure the robustness of the findings, these preliminary results suggest statistically significant, large magnitude increases on fine particulate matter concentrations of reformulated gasoline standard waivers.

This evaluation of discretionary safety valves can have important implications in related policy contexts. First, waiving fuel content regulations represent an alternative to constructing and operating refined petroleum product strategic reserves. Waiver authority would be an attractive alternative if it could mitigate supply shocks with greater net social benefits. Second, discretionary safety valves are used in a variety of other policy contexts, including some state renewable portfolio standards, the implementation of tariffs in U.S. trade policy, etc. Understanding the implementation and impacts of this discretionary approach to regulatory implementation could yield benefits in these other contexts.

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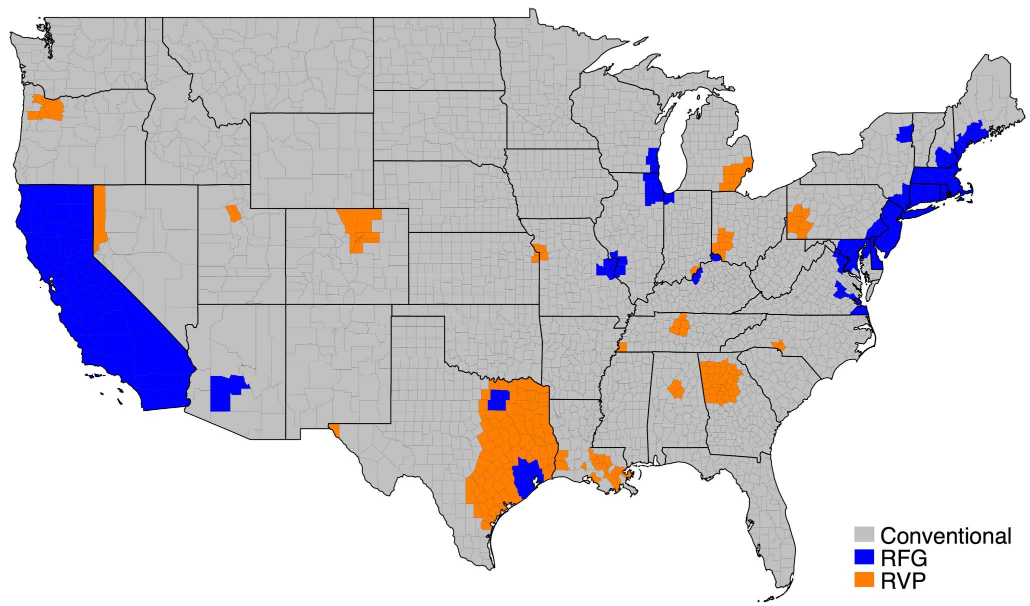
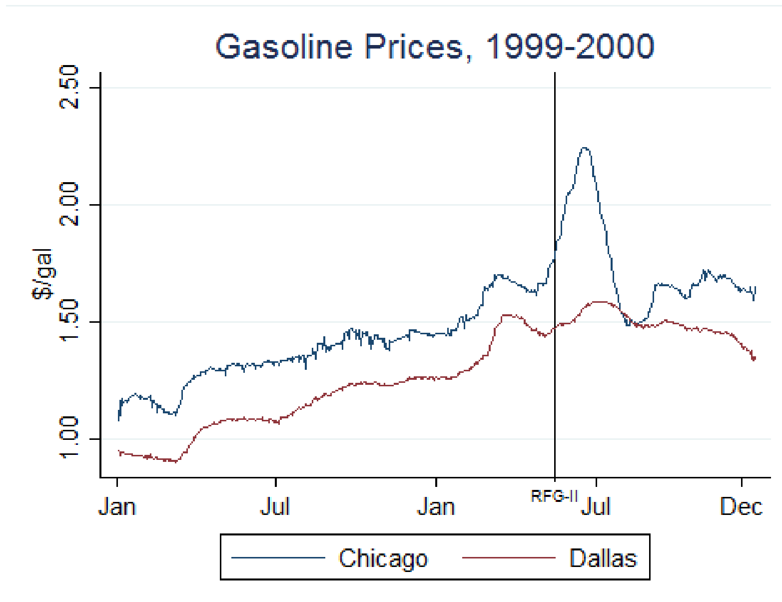
6 Figures and Tables

Figure 1: Geographic Heterogeneity in Fuel Content Regulations



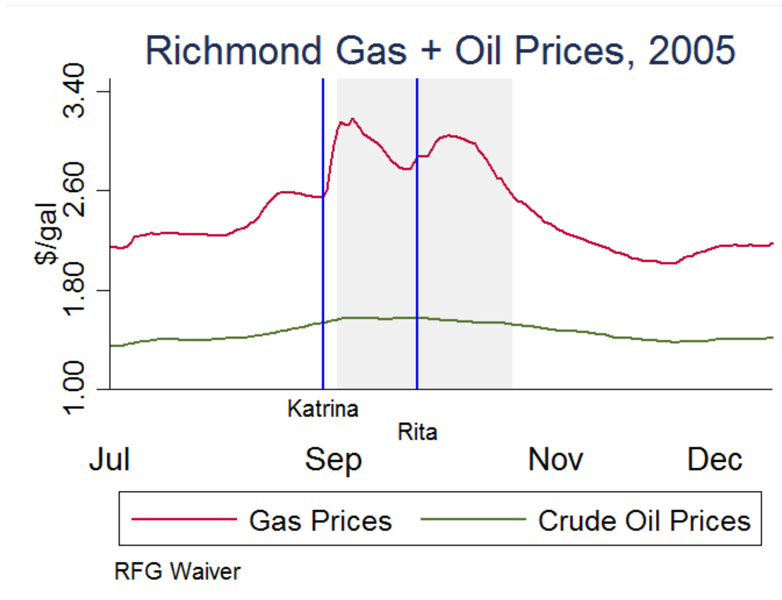
Notes: Produced by the author based on EPA regulatory implementation in 2015. Californias CARB gasoline satisfies the standards for the federal reformulated gasoline (RFG) standard, and is labeled RFG in the map. Counties required to meet the RFG standard must also satisfy requirements for Reid Vapor Pressure (RVP).

Figure 2: Illustration of the RFG-II Supply Shock in Chicago, 2000



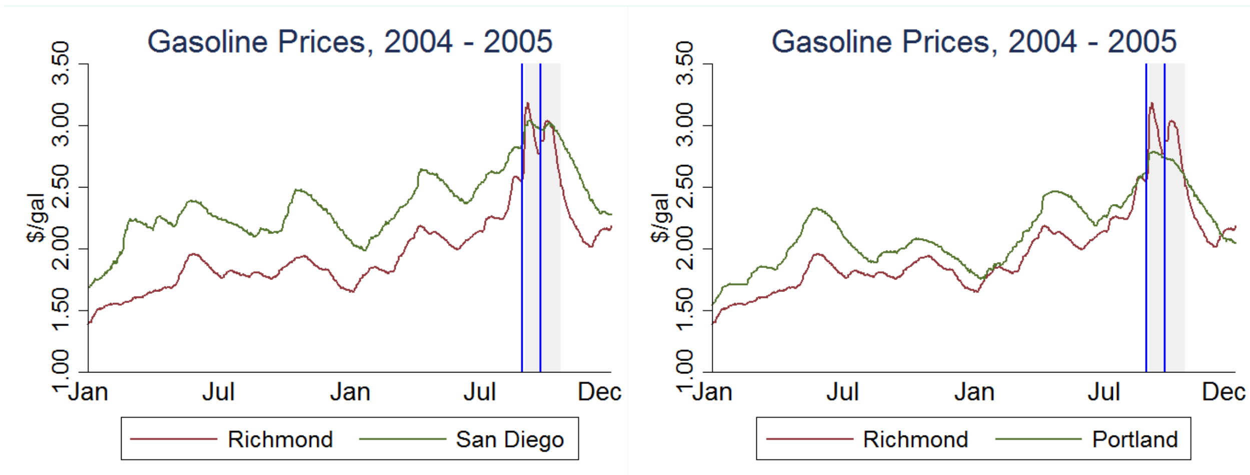
Notes: Nominal prices, based on city-wide daily average all-grades of unleaded gasoline. Data source: Oil Price Information Service.

Figure 3: 2005 Katrina-Rita Fuel Shock: Richmond RFG Market and WTI Crude Oil Prices



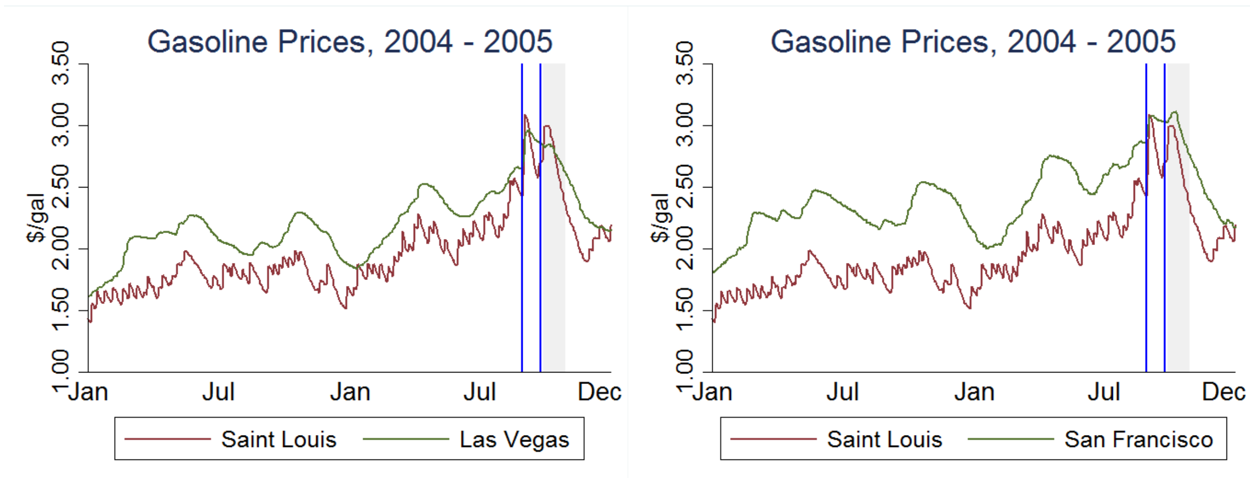
Nominal prices, based on city-wide daily average all-grades of unleaded gasoline, and closing daily spot prices for West Texas Intermediate crude oil at Cushing, Oklahoma. The two vertical lines refer to the dates of Hurricanes Katrina and Rita making landfall. The gray shading represents the period of Richmonds RFG waivers. Data sources: Oil Price Information Service and the Energy Information Administration.

Figure 4: 2005 Katrina-Rita Fuel Shock: Comparing the Richmond RFG Market to the San Diego CARB and Portland RVP Markets



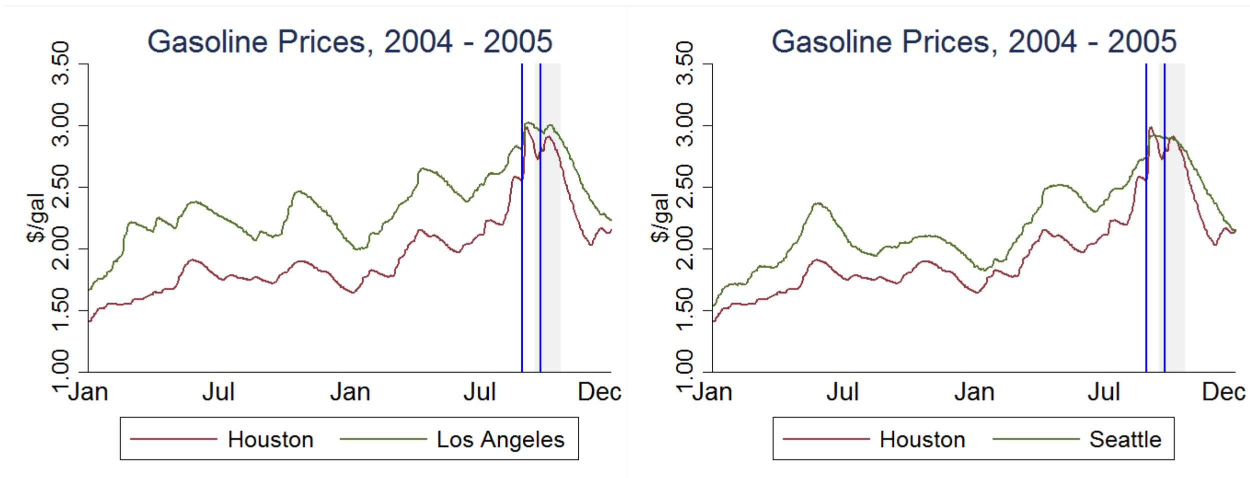
Notes: Nominal prices, based on city-wide daily average all-grades of unleaded gasoline. The two vertical lines refer to the dates of Hurricanes Katrina and Rita making landfall. The gray shading represents the period of Richmonds RFG waivers. Data source: Oil Price Information Service.

Figure 5: 2005 Katrina-Rita Fuel Shock: Comparing the St. Louis RFG Market to the San Francisco CARB and Las Vegas RVP Markets



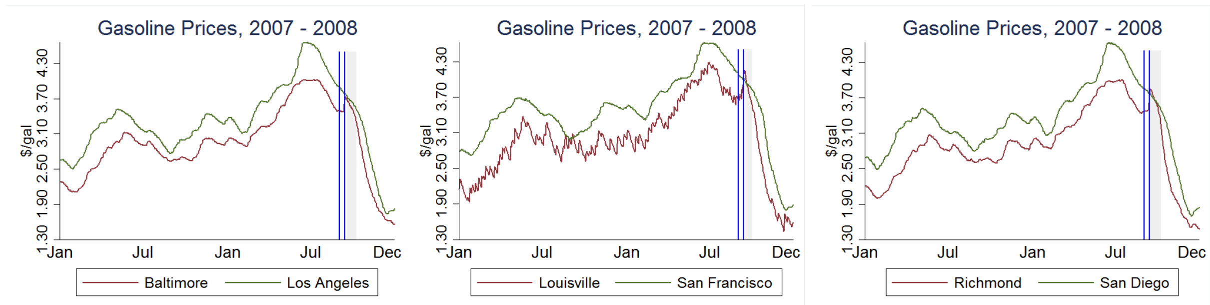
Notes: Nominal prices, based on city-wide daily average all-grades of unleaded gasoline. The two vertical lines refer to the dates of Hurricanes Katrina and Rita making landfall. The gray shading represents the period of Houston's RFG waiver. Data source: Oil Price Information Service.

Figure 6: 2005 Katrina-Rita Fuel Shock: Comparing the Houston Market to the Los Angeles CARB and Seattle RVP Markets



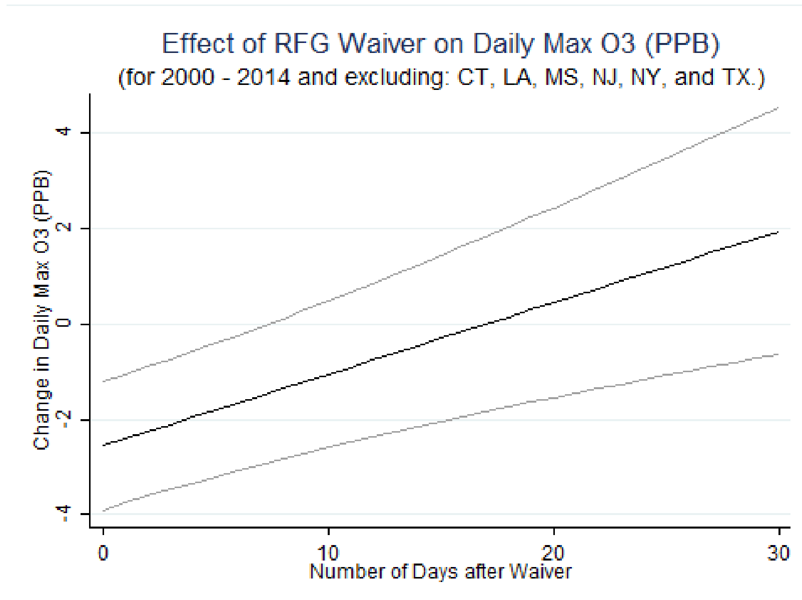
Notes: Nominal prices, based on city-wide daily average all-grades of unleaded gasoline. The two vertical lines refer to the dates of Hurricanes Katrina and Rita making landfall. The gray shading represents the period of Saint Louiss RFG waiver. Data source: Oil Price Information Service

Figure 7: 2008 Gustav-Ike Fuel Shock: Baltimore, Louisville, and Richmond RFG Markets



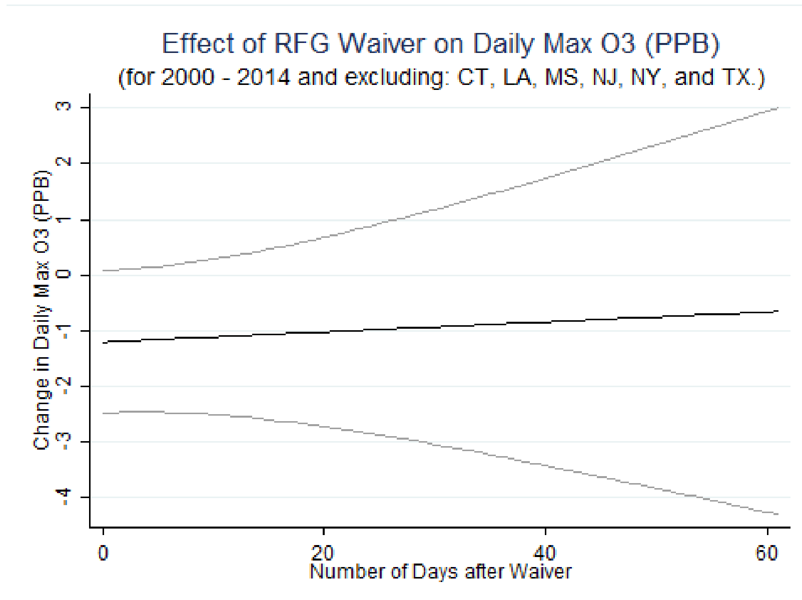
Notes: Nominal prices, based on city-wide daily average all-grades of unleaded gasoline. The two vertical lines refer to the dates of Hurricanes Gustav and Ike making landfall. The gray shading represents the period of each citys RFG waiver. Each Californian comparison city uses CARB gasoline during this time period. Data source: Oil Price Information Service.

Figure 8: Impact of RFG Waiver on Daily Maximum Ozone Concentrations, One-Month Post-Waiver Analyses



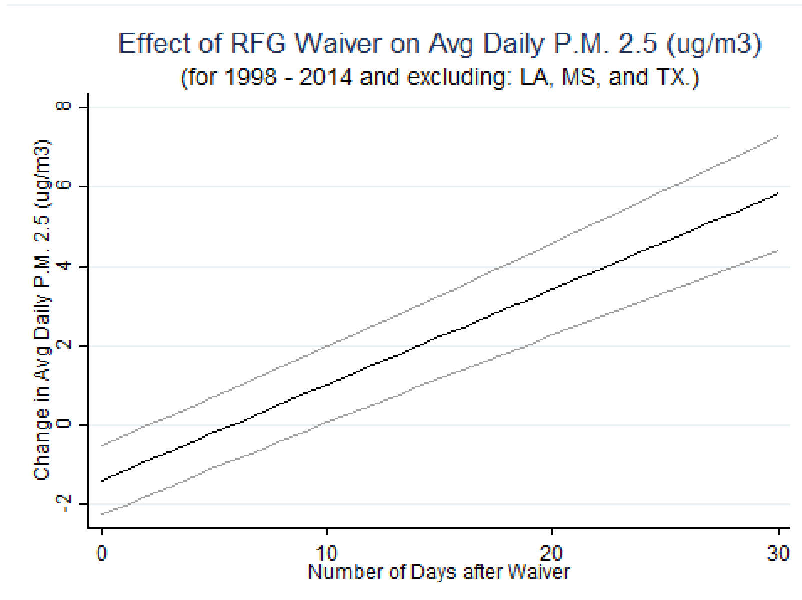
Notes: Based on results in Column (8) in Table **??**. Sample includes all ozone monitors over 2000-2014, except for those in Connecticut, Louisiana, Mississippi, New Jersey, New York, and Texas. The light-shaded lines represent the 95 percent confidence interval.

Figure 9: Impact of RFG Waiver on Daily Maximum Ozone Concentrations, Two-Month Post-Waiver Analyses



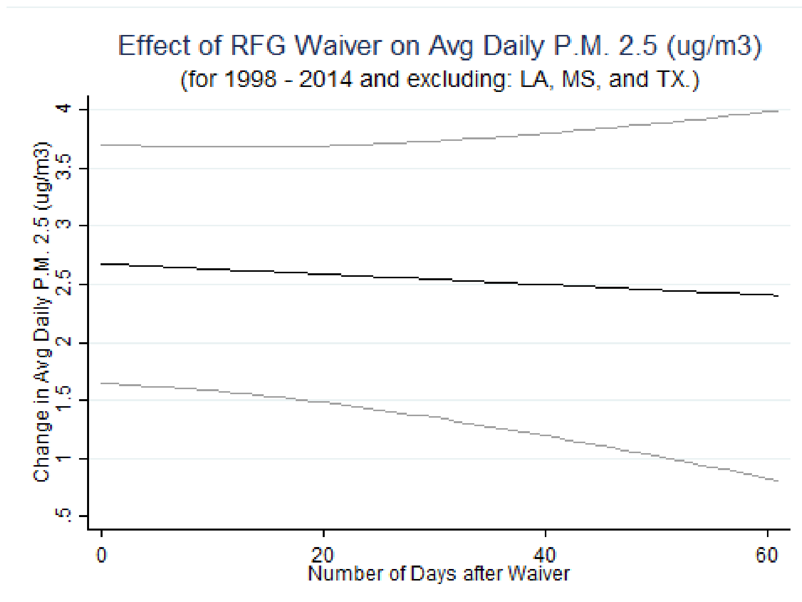
Notes: Based on results in Column (9) in Table **??**. Sample includes all ozone monitors over 2000-2014, except for those in Connecticut, Louisiana, Mississippi, New Jersey, New York, and Texas. The light-shaded lines represent the 95 percent confidence interval.

Figure 10: Impact of RFG Waiver on Daily Average PM-2.5 Concentrations, One-Month Post-Waiver Analyses



Notes: Based on results in Column (5) in Table 4. Sample includes all PM-2.5 monitors over 1998-2014, except for those in Louisiana, Mississippi, and Texas. The light-shaded lines represent the 95 percent confidence interval.

Figure 11: Impact of RFG Waiver on Daily Average PM-2.5 Concentrations, Two-Month Post-Waiver Analyses



Notes: Based on results in Column (6) in Table 4. Sample includes all PM-2.5 monitors over 1998-2014, except for those in Louisiana, Mississippi, and Texas. The light-shaded lines represent the 95 percent confidence interval.

Table 1: EPA Fuel Content Regulation Waivers, 2005-2014

Reason	N	States	Regulations
2005 Katrina/ Rita	30	Alabama, Arizona, California, Florida, Georgia, Iowa, Kentucky, Louisiana, Mississippi, Missouri, Nebraska, Texas, Virginia	RFG, RVP, low-sulfur diesel, Texas low-emission diesel
2008 Gustav/ Ike	14	Alabama, Arizona, DC, Florida, Georgia, Kentucky, Louisiana, Maryland, North Carolina, Ohio, Tennessee, Texas, Virginia	RFG, RVP, low-sulfur diesel, AZ cleaner burning gasoline
2012 Isaac	2	Alabama, Florida, Georgia, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee	RVP
2012 Sandy	5	Alabama, Connecticut, Delaware, DC, Georgia, Maryland, Massachusetts, Mississippi, New Hampshire, New Jersey, New York, North Carolina, Pennsylvania, Rhode Island, South Carolina, Tennessee, Virginia	RFG, low-sulfur diesel
Other	9	Florida, Illinois, North Carolina, North Dakota, Pennsylvania, Tennessee	RVP

Notes: Waiver information compiled from EPAs fuel regulation waiver website, https://www.epa.gov/enforcement/fuel-waivers

There were no waivers in 2015 and three waivers in the fall of 2016.

In the August-September 2017 period, EPA issued a number of waivers in response to Hurricanes Harvey, Irma, and Maria

Table 2: Fuel Prices for a Smple of East Coast and Midwest Cities, 2005

City	Fuel Regulation	August 15	September 1	September 5	September 15
Boston	RFG	$2.59	$3.07	$3.30	$3.10
		(+0.22)	(+0.60)	(+0.80)	(+0.62)
Columbus	RVP	$2.51	$3.08	$2.95	$2.76
		(+0.43)	(+0.88)	(+0.73)	(+0.54)
New York	RFG	$2.73	$3.09	$3.40	$3.24
		(+0.25)	(+0.49)	(+0.79)	(+0.64)
Raleigh	RVP	$2.56	$3.15	$3.19	$2.95
		(+0.38)	(+0.86)	(+0.89)	(+0.65)
Richmond	RFG	$2.53	$2.97	$3.13	$2.91
		(+0.36)	(+0.69)	(+0.85)	(+0.64)

Each row presents average city gasoline price and, in parentheses, the change in the gasoline price excluding crude oil price relative to the 2000-2004 average

Richmond was the only city in this table to receive a waiver of its fuel regulation requirements.

Data Source: Oil Price Information Service.

Table 3: Impacts of Fuel Content Regulatory Waivers on Ozone Concentrations, 2000-2014

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
1{RVP_W+1mth}	0.321	-2.823**		0.320	-2.234**		0.330	-2.311**	
	(0.199)	(0.511)		(0.224)	(0.520)		(0.224)	(0.517)	
1{RVP_W+1mth}xtime		0.200**			0.163**			0.169**	
		(0.0266)			(0.0260)			(0.0257)	
1{RFG_W+1mth}	0.611	-6.560**		-0.0715	-1.956*		-0.236	-2.558**	
	(0.429)	(1.034)		(0.483)	(0.840)		(0.444)	(0.717)	
1{RFG_W+1mth}xtime		0.457**			0.123**			0.150**	
		(0.0667)			(0.0372)			(0.0374)	
1{RVP_W+2mth}			-0.335			-0.296			-0.295
			(0.282)			(0.318)			(0.318)
1{RVP_W+2mth}xtime			0.0151*			0.00313			0.00296
			(0.00699)			(0.00791)			(0.00792)
1{RFG_W+2mth}			-1.417**			-1.259*			-1.206
			(0.493)			(0.595)			(0.677)
1{RFG_W+2mth}xtime			0.0637**			0.0305			0.00903
			(0.0150)			(0.0229)			(0.0287)
R^2	0.552	0.552	0.552	0.578	0.578	0.578	0.576	0.576	0.576
N	2.49m	2.49m	2.49m	2.18m	2.18m	2.18m	2.07m	2.07m	2.07m
Sample	All States	All States	All States	Excludes LA, MS, TX	Excludes LA, MS, TX	Excludes LA, MS, TX	Excludes LA, MS, TX CT, NJ, NY	Excludes LA,MS,TX CT, NJ, NY	Excludes LA,MS,TX CT, NJ, NY

* p<0.05 ** p<0.01. All models include monitor-month, Census-region-by-year, and day-of-week fixed effects; county per capita income; polynomials in temperature and precipitation; and linear time trends by regulatory status. Standard errors clustered by monitor.

Table 4: Impacts of Fuel Content Regulatory Waivers on Fine Particulate Matter Concentrations, 1998-2014

	(1)	(2)	(3)	(4)	(5)	(6)
1{RVP_W+1mth}	1.258**	-0.112		0.608*	-0.0263	
	(0.280)	(0.529)		(0.305)	(0.557)	
1{RVP_W+1mth}xtime		0.0854**			0.0405	
		(0.0263)			(0.0252)	
1{RFG_W+1mth}	2.296**	-3.161**		2.435**	-1.390**	
	(0.321)	(0.580)		(0.388)	(0.462)	
1{RFG_W+1mth}xtime		0.340**			0.241**	
		(0.0340)			(0.0193)	
1{RVP_W+2mth}			1.294**			0.672
			(0.342)			(0.366)
1{RVP_W+2mth}xtime			-0.0218**			-0.0170*
			(0.00695)			(0.00792)
1{RFG_W+2mth}			1.929**			2.677**
			(0.418)			(0.534)
1{RFG_W+2mth}xtime			-0.00495			-0.00448
			(0.00611)			(0.0102)
R^2	0.382	0.382	0.382	0.397	0.397	0.397
N	0.70m	0.70m	0.70m	0.58m	0.58m	0.58m
Sample	All States	All States	All States	Excludes LA, MS, TX	Excludes LA, MS, TX	Excludes LA, MS, TX

* $p<0.05$ ** $p<0.01$. All models include monitor-month, Census-region-by-year, and day-of-week fixed effects; county per capita income; polynomials in temperature and precipitation; and linear time trends by regulatory status. Standard errors clustered by monitor.

7 Appendix A. replication of Auffhammer and Kellogg (2011)

The original A&K dataset (filename AER20090377_FinalData.dta) contains approximately 5.2 million observations over the years 1989-2006. Of these, 4,658,488 observations were matched to weather data without imputation (and do not have any of temperature max, temperature min, snow, or rain missing; these observations represent about 89.64 percent of the total). There are 531,161 observations with imputed weather data (approximately 10.22 percent of the total). After imputation, there are 8,820 observations with at least one of temperature max, temperature min, snow, or rain missing (these observations represent about 0.17 percent of the total).

Our full ozone dataset contains about 8.6 million observations over the years 1990-2016. Of these, 4,969,171 observations were matched to weather data without imputation (and do not have any of temperature max, temperature min, snow, or rain missing; these observations represent about 58.01 percent of the total). There are 3,596,166 observations with imputed weather data (approximately 41.99 percent). After imputation, there are 2,370,213 observations with at least one of temperature max, temperature min, snow, or rain missing (these observations are about 27.67 percent of the total).

These three categories of observation counts (matched without imputation; imputed; and missing weather after imputation) for the years 1990-2006 are as follows:

	Matched	Imputed	Unmatched
A& K Original Data	4,460,113 (89.78%)	500,596 (10.08%)	8,178 (0.16%)
Our Data	3,307,499 (55.78%)	1,677,261 (28.29%)	944,577 (15.93%)

If we match our ozone dataset to the (full) A&K dataset on a monitor-day basisand ignore missing weatherwe match about 95.50 percent of the observations in the A&K dataset. Of the unmatched observations, over 98 percent are in the year 1989 (a year which is not represented in our dataset). Most of the remaining unmatched observations are spread among eight monitors.

If we again consider only the years 1990-2006 (the years for which both datasets have observations), we see the following monitor counts:

	All Observations	Drop Missing Weather
A& K Original Data	1,924 monitors	1,916 monitors
Our Data	1,928 monitors	1,659 monitors

For these same yearsand ignoring missing weatherthere are 167,372 monitor-months in the A&K dataset. Our dataset matches 167,220 of these monitor-months based on FIPS county code, monitor ID, and year/-month combination (approximately 99.91 percent). Similar to the monitor-day comparison above, if we total the observations for each monitor-month and then compare across the datasets, there is nearly complete overlap. There are 16 monitors that have more than one observation difference in the monthly counts (that is, 16 monitors with at least one monthly count where the A&K count exceeds our count by more than one).

If we again take the years 1990-2006, but then drop observations with missing weather from both datasets, we match 136,551 of 167,312 monitor-months in the A&K dataset (about 81.61 percent). If we total the observations for each monitor-month and compare across the datasets, there are 15,498 monitor-months for which there is a 31-day observation difference (where there are 31 more observations in these monitor-months in the A&K dataset as compared to our dataset), and 10,389 monitor-months for which there is a 30-day observation difference.

For the years 1990-2006 with missing weather data dropped, our sample size is about 81.47 percent of A&Ks. This ratio does not change substantially when integrating sample size reductions for other reasons, such as restricting observations to the summer months and requiring all monitor-days to have at least nine hourly observations between 9am and 9pm.

The source for our weather data is NOAA's Daily Global Historical Climatology Network for 1990-2015, which is composed of weather stations across the world that collect measurements on a host of indicators (as noted above, we use temperature max, temperature min, rain, and snow).

These data can be accessed at: https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/.
The associated readme file is at: https://www1.ncdc.noaa.gov/pub/data/ghcn/daily/readme.txt.

The table below presents two sets of regressions using the A&K difference-in-differences methodology (that is, all regressions use the same A&K Stata do-file). The first four columns show results using the original A&K dataset. These correspond to the columns labeled 1, 2, 4, and 5 in Table 2 in the A&K paper. The final four columns show results from a restricted A&K dataset that includes only those monitor-dates for which our dataset does not have missing weather (after imputation). That is, we find all combinations of monitor and date in our dataset for which there are temperature max, temperature min, snow, and rain valuesregardless of whether these values were imputedand then restrict the A&K dataset to use only these specific monitor-date combinations.

Table 5: Comparison of Original A&K Differences in Differences Regressions and "Restricted" Dataset Regressions

ln(max O_3)	Original-1	Original-2	Original-4	Original-5	Restricted-1	Restricted-2	Restricted-4	Restricted-5
[1em] 1{RVP-I}	0.016	0.013	0.001	0.004	0.026*	0.015	0.000	0.008
	(0.016)	(0.015)	(0.016)	(0.018)	(0.013)	(0.015)	(0.016)	(0.016)
1{RVP-II}	-0.007	-0.011	-0.012	-0.012	-0.001	-0.005	-0.009	-0.012
	(0.008)	(0.007)	(0.009)	(0.011)	(0.009)	(0.008)	(0.009)	(0.012)
1{RFG}	-0.029**	-0.030**	-0.036**	-0.019	-0.029**	-0.026*	-0.036**	-0.026
	(0.009)	(0.007)	(0.011)	(0.012)	(0.010)	(0.008)	(0.011)	(0.013)
1{Carb}	-0.095**	-0.090**	-0.065**	-0.064**	-0.066**	-0.064**	-0.054*	-0.071**
	(0.013)	(0.011)	(0.019)	(0.020)	(0.014)	(0.012)	(0.022)	(0.024)
County Income			-0.22	-0.30			0.046	0.010
			(0.240)	(0.240)			(0.248)	(0.240)
Weather Vars		✓	✓	✓		✓	✓	✓
Linear Trend			✓				✓	
Quadratic Trend				✓				✓
N	1.1m	1.1m	1.1m	1.1m	0.87m	0.87m	0.87m	0.87m
R^2	0.02	0.26	0.26	0.26	0.02	0.27	0.27	0.27
Sample	Original A&K Data-set				Restricted A&K Data-set			

* p<0.05 ** p<0.01