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Improving Air Quality by Reformulating Gasoline: How California Got It Right

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Regulations intended to improve air quality by changing the composition of gasoline have resulted in significant improvements in air quality in Southern California.

Starting with the passage of the 1963 Clean Air Act, U.S. government agencies at the federal and state level have designed and implemented a significant number of policies to improve air quality. The Clean Air Act regulated six criteria pollutants (Ozone, particulate matter, NOx, SO_2, Carbon Monoxide and Lead), all of which are thought to have negative consequences for human health. Ozone is an odorless gas invisible to the human eye which, if found at ground level, has been linked to asthma, increased susceptibility to pneumonia and bronchitis, as well as damage to crops and natural vegetation. Studies have shown that even relatively small short-term increases in ambient ozone concentrations can result in a significant increase in deaths. Ozone is not directly emitted by any point source, but forms in the atmosphere through a set of complex chemical reactions. The formation of ozone requires two classes of man-made and naturally occurring chemicals that react in the atmosphere—volatile organic compounds (VOCs) and oxides of nitrogen (NO_x). The first reliable measurements of ambient ozone concentrations were made in 1965. The maximum one-hour ozone concentration for that year in the South Coast Air Basin was 0.58 ppm, which is roughly five times the currently allowable maximum hourly concentration set by the national ambient air quality standards. Figure 1 displays the history of eight-hour average concentrations for the South Coast Air Basin since 1973. Over this period, this measure of ozone concentrations has improved by 50%, which is an impressive achievement given the increases in population and income over this period. On the flip side, however, despite more than four decades of air quality regulation, many places continue to experience ambient concentrations of ozone that violate the standards set by the Environmental Protection Agency (EPA). While the South Coast Air Basin has experienced tremendous improvements in air quality, it is still in violation of the national eight-hour standard for more than 100 days out of the year.

In order to bring jurisdictions into compliance with federal regulation, a variety of novel policy tools at the federal and state level have been proposed and implemented. Discussion of any new regulation brings with it the question of how flexible or prescriptive it should be. More flexible regulation allows the regulated firm to choose how to meet a standard, while a more prescriptive approach specifies precisely what the firm must do to comply. In one particular set of gasoline regulations targeted at reducing ozone pollution, regulators have imposed both types of regulation: a performance standard, which allows the firms to choose how to meet an overall emissions standard,

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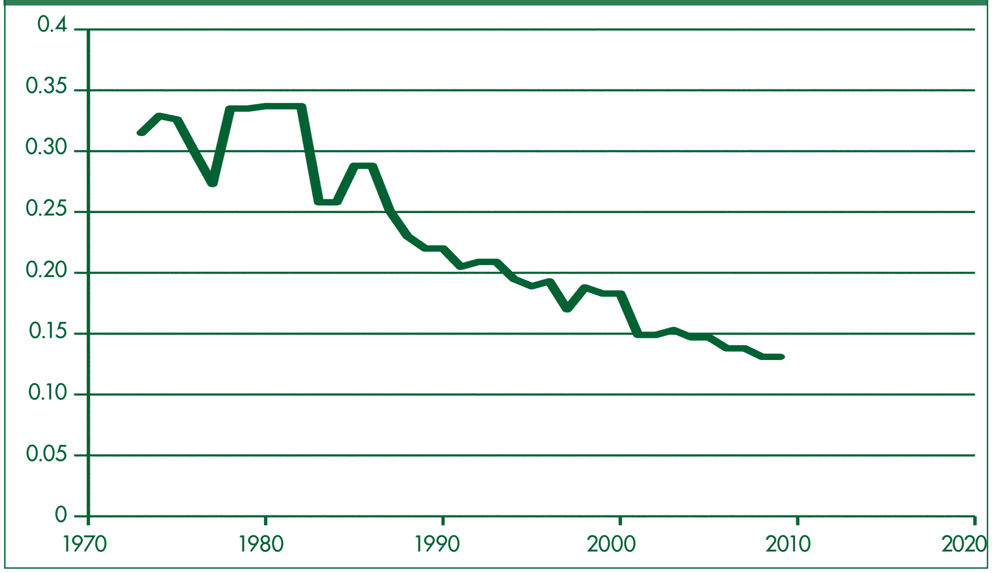
Figure 1. Average Eight-hour Ozone Concentrations (ppm) for the South Coast Air Basin



and a chemical content specification, which dictates the chemical composition of the gasoline. After years of experience with these regulations, the question is how have they performed in reducing ozone pollution?

The gasoline content regulations we study were designed to reduce the concentrations of ground level ozone. Since one cannot target emissions of ozone directly, these regulations attempt to reduce the emissions of the precursor pollutants. The regulations mostly target the emissions of VOCs, which include a large number of chemicals with varying degrees of ozone-forming potential. Some VOCs are almost 80 times more reactive than others.

One key feature of gasoline reformulation policy is that the stringency of regulations required by EPA varies quite drastically across states and counties. Further, some places have designed their own standards and boutique fuels, which in some cases are more stringent than those required by EPA. The earliest gasoline regulations were in the form of a performance standard, which targeted the Reid Vapor Pressure (RVP) of gasoline. RVP is measured in pounds per square inch and is a measure of how much of the VOCs evaporate from gasoline.

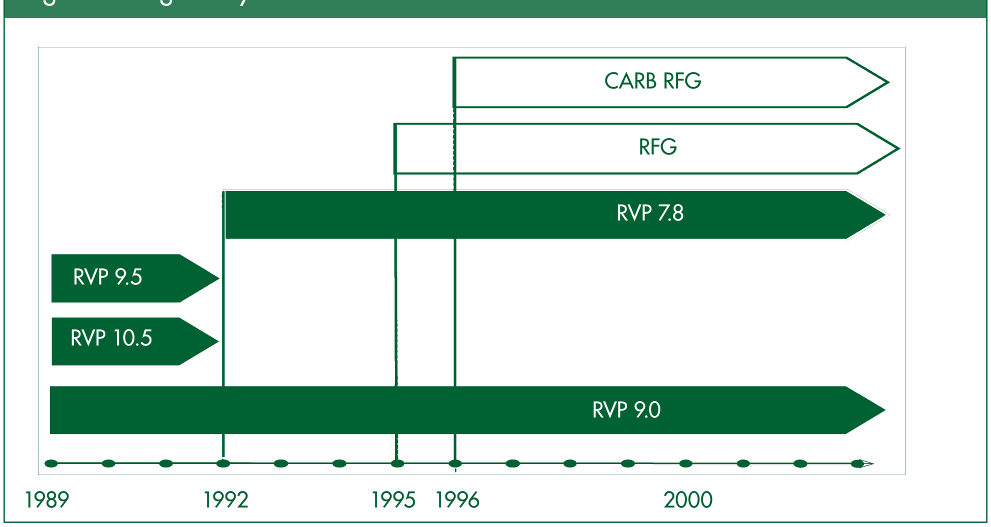
This regulation was implemented in two phases. Phase I, which lasted from 1989 through 1991, included differing degrees of stringency by place and month of the year, since ozone is largely a summertime problem. Phase II started in 1992 and imposed the most stringent of the phase I requirements on all states. Further, phase II tightened standards for areas in violation of the Clean Air Act ozone standards in southern states. This phase II regulation is still in place today, although in many areas these regulations were replaced by federal reformulated gas (RFG) or California Air Resources Board (CARB) standards. As of 1995, federal RFG was required in areas in severe non-attainment of the national ozone standard. RFG regulations are more stringent than those of RVP.

Two states, California and Arizona, have implemented even more stringent gasoline regulations. Most importantly, CARB gasoline imposes tighter VOC emissions standards *and* limits the concentrations of olefins and aromatic hydrocarbons, both of which are highly reactive in forming ozone. Figure 2 displays the sequence of these gasoline regulatory standards.

We exploit the sequential nature of this patchwork of regulations—which includes both more flexible (RVP and RFG) and more prescriptive (CARB) approaches, combined with a rich database of ambient ozone concentrations from across the country—to construct a careful comparison of how effective the different regulations were at achieving their stated goal.

Figure 3 depicts the time path of summer ozone concentrations in counties under different forms of regulation. Panel (a) compares the ozone concentrations in counties treated with a stringent RVP phase II standard to counties with a much more relaxed RVP standard. The introduction of the RVP phase II standard in 1992 does not appear to have substantially affected summertime ozone concentrations. Panel (b) suggests that the introduction of federal RFG in 1995 may have caused

Figure 2. Regulatory Timeline: 1996 – CARB RFG



slight improvements in ozone concentrations. However, panel (c) shows a substantial decrease in ozone concentrations in California around 1996, which is the year CARB gasoline was introduced in all California counties. It is not possible to determine from this graph alone whether the improvements in air quality can be attributed to CARB gasoline or to other confounding factors acting over the same time period. We therefore turn to statistics-based econometric methods to extract the impact of these regulations on air quality.

Specifically, we estimate the impacts of the gasoline regulations discussed above on ozone concentrations by collecting daily measurements of ambient ozone concentrations from hundreds of ozone monitors nationwide during 1989–2003. Further, we have collected a rich and spatially specific dataset of which regulations were in effect at what date. Due to the discrete nature with which these regulations were implemented, we can exploit a before and after comparison as well as a comparison across monitors.

There is an advantage of the regulations studied here, from a statistical perspective. Compared to standards for vehicle emissions control equipment which only produce effects slowly as the vehicle fleet turns over, the adoption of a gasoline content standard immediately affects all on-road vehicles. We therefore use our data to look for step changes in ambient ozone concentrations at the times and locations in which gasoline regulations were imposed. We use two methods.

First, we adopt a difference-in-difference (DD) estimation technique, which compares changes in air quality before and after the introduction of a policy to changes experienced in areas that did not adopt such a policy. Second, we exploit a regression discontinuity (RD) design that examines changes in ozone concentrations immediately before and after gasoline regulations came into

Figure 3a. RVP Summer Maximum Concentration Trends

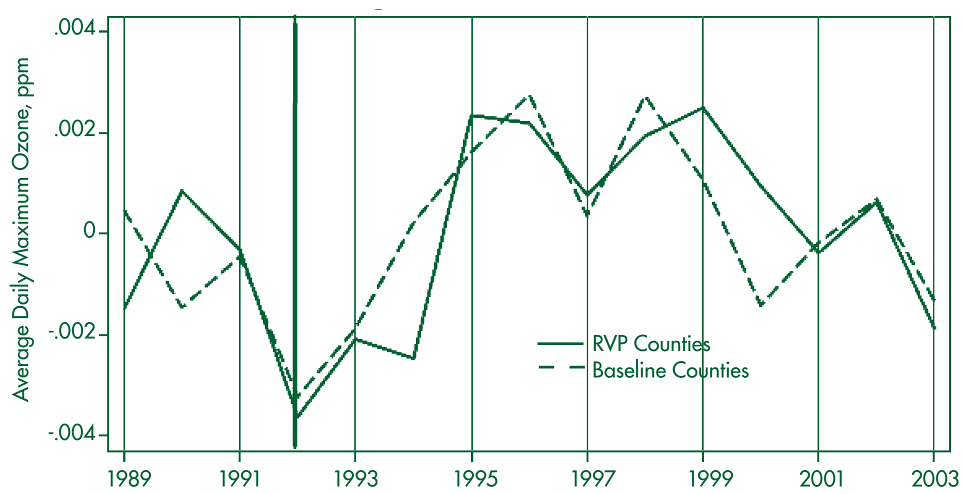


Figure 3b. RFG Summer Maximum Concentration Trends

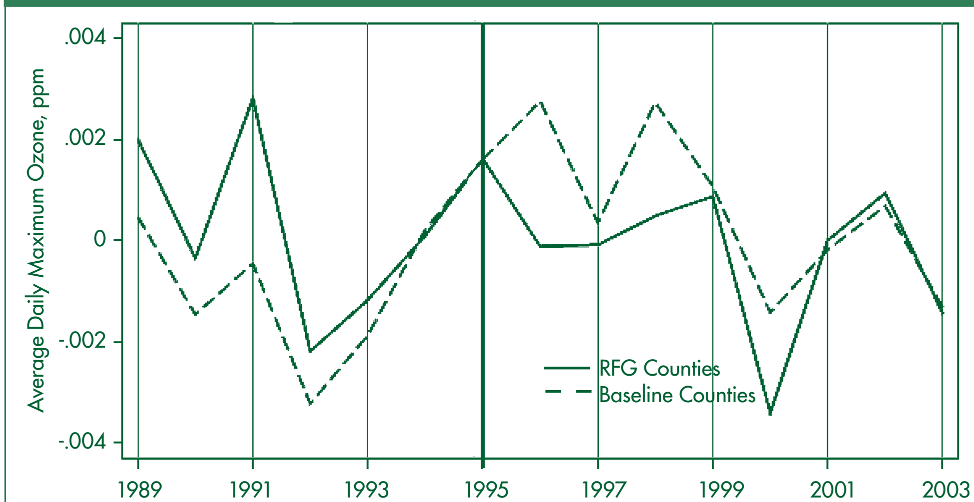
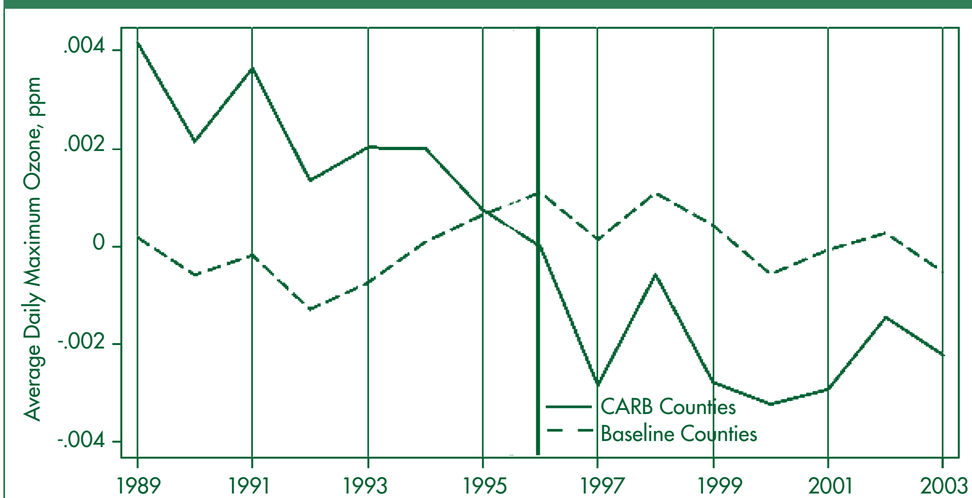


Figure 3c. CARB Summer Maximum Concentration Trends



Note: The vertical axes display deviations of the ozone concentrations from their mean after the effects of weather have been statistically removed.

effect at a single monitor. The latter strategy does not utilize other "non-treated" monitors as controls, yet allows for tremendous flexibility and location specificity of the estimated effects.

Our main finding is that the effectiveness of gasoline regulations varies significantly with the degree of flexibility with which refiners are allowed to respond. The federal regulations (RVP and RFG) limit the total evaporation of VOCs from gasoline, without taking into account which VOCs are best at forming ozone. We find that these regulations, on average, have no economically or statistically significant effect on ambient ground-level ozone concentrations.

We argue that this result is likely due to the rational behavioral response of refiners to the federal standard: they minimize the cost of producing the required fuels by removing a VOC that is not strongly related to ozone formation. Refiners do not appear to reduce concentrations of the more highly reactive VOCs since this is more expensive and the federal regulation provides no incentive to do so.

California's gasoline regulations, however, strictly limit the VOCs most important in forming ozone, which prevents refiners from avoiding the costly abatement of these substances. We find that California has enjoyed a large improvement in ground level ozone concentrations: our estimates suggest that CARB gas reduced ground-level ozone concentrations by 16% in California's worst air quality area: the Los Angeles–San Diego area. We conduct a very conservative back-of-the-envelope calculation and show that the benefits outweigh the regulation's cost, based on its impacts on mortality alone.

These very different outcomes suggest a potential trade off when setting the degree of flexibility for environmental regulations. More flexible regulatory approaches, such as RVP and RFG, are designed to minimize the cost to producers to satisfy the regulation. Our analysis suggests this increased flexibility has resulted in lower environmental benefits. Recent literature on the effectiveness of pollution regulation suggests this trade off appears to not be limited to gasoline reformulation. Cap and trade systems, for example, have become increasingly popular, as they will reach a reduction of total emissions (cap) while allowing actual abatement to be distributed (traded) across heterogeneous firms to minimize the cost of meeting the emissions standard.

If, however, marginal benefits of emissions reductions differ across space (e.g., due to the distribution of the exposed population), standard permit-trading systems may not achieve the first-best welfare outcome. Fowlie (2009) finds that the benefits of a major U.S. NO_x cap-and-trade program were undercut because NO_x abatement was concentrated in low marginal damage areas rather than dense urban centers. She argues that less flexible regulation, which would have weighted emissions by local marginal damages, would have yielded a more desirable outcome.

In our study, the consequences of increased regulatory flexibility are severe. While the flexible RVP/RFG standards result in lower abatement costs than CARB gasoline (1–1.5 cents per gallon vs. 8–11 cents per gallon), the federal regulations appear to have no measurable effect, while California's regulation resulted in significant improvements in air quality. Anticipating firms' most probable response when implementing flexibility mechanisms in regulation is of first order importance, even in command-and-control regulation such as gasoline content standards. Regulators should weigh the benefits from increased flexibility against the reductions in compliance costs to regulated agents.

In the case of gasoline regulations aimed at reducing ozone emissions, the more flexible regulatory standard allowed refiners to implement the most cost-effective technique from their standpoint, but the goal of the regulation was not achieved. It has been the more prescriptive regulatory standard that was effective at actually reducing ozone concentrations, albeit at a higher compliance cost to the refiners. These outcomes highlight the need for environmental regulations to anticipate and mitigate the behavioral responses of the regulated entities when faced with a more flexible regulatory approach.

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For additional information, the authors recommend:

"Clearing the Air? The Effects of Gasoline Content Regulation on Air Quality." Auffhammer, Maximilian and Ryan Kellogg. 2009. UC Berkeley: Center for the Study of Energy Markets. Retrieved from: http://escholarship.org/uc/item/74s774zj.

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