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Abstract

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Reformulating Competition?
Gasoline Content Regulation and Wholesale Gasoline Prices[*]

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ABSTRACT

The 1990 Clean Air Act Amendments stipulated gasoline content requirements for metropolitan areas with air pollution levels above predetermined federal thresholds. The legislation led to exogenous changes in the type of gasoline required for sale across U.S. metropolitan areas. This paper uses a panel of detailed wholesale gasoline price data to estimate the effect of gasoline content regulation on wholesale prices and price volatility. In addition, we investigate the extent to which the estimated price effects are driven by changes in the number of suppliers versus geographic segmentation resulting from regulation. We find that prices in regulated metropolitan areas increase significantly, relative to a control group, by an average of 3.6 cents per gallon. The price effect, however, varies by ten cents per gallon across regulated markets and the heterogeneity across markets is correlated with the degree of geographic isolation generated by the discontinuous regulatory requirements.

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1. Introduction

Policy makers consider the trade offs in determining the optimal geographic size and scope of environmental regulations. U.S. transportation policies have used command-and-control standards to limit emissions rates, gasoline additives, and vehicle fuel economy, primarily at the national level. By setting regulations at a regional level, pollution sources with higher marginal damages (relative to marginal abatement costs) can be regulated more strictly than others. However, introducing a myriad of regulations may result in the segmentation of markets, allowing some firms to exercise market power and causing others to exit the market. This paper examines whether environmental policies aiming to improve environmental quality by reformulating gasoline had the unintended consequence of reformulating competition in this industry, as well.

The 1990 Clean Air Act Amendments (CAAA) stipulated minimum motor fuel content requirements in order to decrease air pollution in excessively polluted areas. Under the regulation, gasoline marketed in `non-attainment' areas must meet different emissions and formulation requirements depending on the type of air pollution violation.[1] Hence the implementation of the CAAA resulted in discrete and differential changes in the required formulation of gasoline across metropolitan areas, geographically segmenting once contiguous

[1] EPA classifies counties as `non-attainment' if air pollution levels exceed criteria limits. The main types of regulation are Federal Reformulated Gasoline, which was required for metropolitan areas with highest levels of ozone non-attainment, Reid Vapor Pressure requirements, and oxygenate requirements, for areas in non-attainment for ozone and carbon monoxide, respectively.

wholesale gasoline markets. By one estimate, the number of fuels in the United States proliferated from one type to over 17 types as a result of the regulation.[2]

Commensurate with the implementation of the gasoline content regulations, many metropolitan areas seemed to experience higher wholesale gasoline prices and greater price volatility. The timing and geographic location of apparently higher and more volatile prices often coincided with gasoline content regulation. This coincidence prompted several state and federal investigations into the link between gasoline content regulation and wholesale gasoline prices.[3] Economists and policy makers hypothesize that, in addition to potentially increasing marginal costs, gasoline content regulations may increase prices for two strategic reasons. First, wholesale prices and volatility may increase due to the segmentation of once integrated geographic markets. The patchwork gasoline requirements based on pollution thresholds create isolated metropolitan supply areas. This may increase the market power of suppliers by limiting arbitrage across markets. Increased market power may lead to higher price levels and higher volatility if limited arbitrage increases market power of incumbent suppliers in periods of relatively tight supply.[4] Second, producing reformulated fuel often involved large fixed cost investments.[5] Hence, many producers may have opted to exit the regulated markets, leading to a decrease in the number of competitors supplying regulated markets. Increases in market concentration through increased entry barriers to production may separately contribute to higher and more volatile gasoline prices in the regulated markets.

[2] See the U.S. Senate Committee on Governmental Affairs [24].
[3] See U.S. Energy Information Administration [21] and U.S. General Accounting Office [23].
[4] See U.S. Federal Trade Commission [22].
[5] See U.S. Energy Information Administration [20].

We use company-specific weekly wholesale prices for unbranded gasoline for selected distribution racks in the United States to estimate the price effect of gasoline content regulation and the extent to which the estimated price effect is driven by changes in the number of competitors versus geographic market segmentation. We use a treatment and control approach, pairing each regulated metropolitan area with an unregulated metropolitan area in close geographic proximity in order to estimate the price effect of gasoline content regulation. In addition, we compare the variance of price series across treated and untreated cities in order to examine the effect of content regulation on price volatility.

Our evidence shows that prices in regulated metropolitan areas increase significantly relative to the unregulated comparison markets. While the price effect of regulation is on average 3.6 cents per gallon, the spot estimate for the price effect of content regulation varies across regulated cities by approximately ten cents per gallon. We use the variation in the change in the number of competitors and the change in geographic isolation across the treated metropolitan areas to examine the extent to which each factor contributes to the city-specific increase in wholesale gasoline prices resulting from content regulation. The average effect of reduced competition is estimated at 0.1 cents per gallon. This implies that changes in the number of suppliers do not absorb all variation in price effect of regulation across cities, but do have some effect and in the direction that we expect. Our estimated residual differences in the price effect of regulation (are consistent with and) could be caused by variation in the degree of geographical isolation resulting from gasoline content regulation.

The paper proceeds as follows. The next section provides a brief discussion of the background on environmental regulation in gasoline markets. In Section 3, we discuss the related literature. Section 4 describes the data used. Section 5 describes the model, research design, and empirical results. The final section concludes and discusses the potential economic implications of these results for gasoline content regulation.

2. Background on Environmental Gasoline Content Regulation

The CAAA is a federal law through which the EPA regulates air emissions from stationary and mobile sources. The original Clean Air Act (of 1970) set air quality targets for every state. The 1990 amendments addressed issues such as acid rain, ground-level ozone, stratospheric ozone depletion, and air toxics. Recognizing the role of fuel-related emissions, the Act targets gasoline content (among other things) to reduce overall air pollution.

Regulations in the CAAA limit Reid Vapor Pressure, mandate minimum oxygen content and prescribe specific requirements relating to reformulated gasoline. Application of the regulations is not uniform; some content requirements are national, while others pertain only to non-attainment regions identified by the EPA (see Figure 1). States and regions not required to participate may still opt-in to the programs. Three regional programs aim to reduce fuel-related air pollution– the Oxygenated Gasoline Program, the Reid Vapor Pressure (RVP) Program, and the Federal Reformulated Gasoline (RFG) Program.[6] Minimum levels are mandated by the EPA, and the program allows regional regulators to impose more stringent standards through State

[6] See, for example, Muehlegger [14] for a thorough survey of gasoline content regulations and adoption timing across US counties and metropolitan areas.

Implementation Plans. Note that the standards apply to all gasoline sold for use in the regulated region, but do not apply to fuel being transported for sale outside of the jurisdiction.

RVP measures a fuel's propensity to evaporate. Lowering RVP decreases at-the-pump pollutants such as volatile organic compounds (VOC). To reduce RVP, refiners eliminate the lightest components of the fuel, either by decreasing the volume of normal butane blended into gasoline, or by increasing the volume of normal butane rejected from motor gasoline. RVP regulations stipulate explicit content criteria. Since ground-level ozone pollution is exacerbated by high temperatures and sunlight, most RVP regulations are effective only in summer months.

The Oxygenated Gasoline Program provides explicit content criteria to reduce carbon monoxide (CO) emissions, a pollutant with particularly severe health effects for people with cardiovascular or respiratory diseases. The oxygenation process increases oxygen content which enables gasoline to burn more completely. To produce oxygenated gasoline, either ethanol or Methyl Tertiary-Butyl Ether (MBTE) is added to the product after refining.[7] Generally, refiners and distributors sell oxygenated gasoline during winter months, when CO emissions from mobile sources are highest. Also, since ethanol increases the RVP, oxygenation can be detrimental to reducing ozone pollution during summer months.

The RFG Program shares its targets with the other two programs. Like the RVP program, the RFG program aims to reduce ground-level ozone-forming pollutants and, similar to the oxygenate regulations, the RFG requirements combat CO emissions. RFG regulations stipulate

[7] MBTE is derived from natural gas and is used primarily in the Northeastern US, while ethanol is derived from renewable feed-stocks and is used mostly in the Midwestern states and California.

both content criteria (such as benzene content limits) and emissions-based performance standards for refiners.[8] While the required content changes must be done at the refinery level, refiners can meet these standards in the least-cost manner. The RFG program is in effect throughout the year and has winter (non-VOC Control Period) and summer (VOC Control Period) components. The Reformulated Gasoline Program is a major gasoline regulation; RFG gasoline constitutes one third of all gasoline sold in the U.S., and the EPA attributes a 17 percent reduction in emissions of VOC and other toxics to this program.

There were two phases of both RFG and RVP regulations, with increasingly stringent standards being imposed with time. Phase I of the RVP program began in the summer of 1989, reducing regional RVP limits. The second phase introduced a national RVP cap in the summer of 1992. In addition, Phase II set stricter standards in ozone non-attainment areas. The RFG program’s first phase began in January 1, 1995, forcing refiners to reduce VOC and nitrogen oxides emissions, and comply with content regulations for benzene and oxygenates. Phase II began January 1, 2000, and required even greater emissions reductions and content restrictions. RFG compliance was required initially in the nine worst ozone non-attainment (metropolitan) areas in the U.S.: Baltimore, Chicago, Hartford, Houston, Los Angeles, Milwaukee, New York City (including CT and NJ 'suburbs'), Philadelphia, and San Diego. Additional cities, such as Sacramento, were later reclassified as non-attainment and forced to shift from conventional to reformulated gasoline. Two types of RFG programs are in place: RFG North and “stricter” RFG South, where the geographic definition is given by the Mason-Dixon Line. California’s Air and Resources Board (CARB) administers the state’s gasoline content program. Beginning in 1992, Phase I imposed

[8] Between 1995 and 2000, both ethanol and MTBE were used in the RFG program; ethanol was used in 100 percent of RFG in Chicago and Milwaukee.

standards consistent with the federal RVP levels and slightly lower than federal oxygenate requirements. Phase II began in 1996 and is somewhat more strict than the national RFG program.[9]

The geographic scope of the RFG program may be attributed to the large number of opt-in areas. Table 1 lists of areas and adoption details for regions that opted into RFG programs.[10] As casual inspection suggests, the increasingly structured regulatory environment has increased the total variety of fuels available across the U.S.; according to a Senate Committee Report of 2002, the number of unbranded fuel types in the United States increased from 1 to 17 after content regulation (See Figure 2). This proliferation of disparate fuel regulations has segmented once contiguous wholesale gasoline markets. We will use the incidence of the RVP and RFG regulations to examine the extent to which gasoline content regulation has led to higher and more volatile wholesale gasoline prices by decreasing arbitrage between geographic markets and decreasing the number of suppliers within each market. Throughout the analysis, we focus on RVP and RFG regulations since, unlike the oxygenate requirement, they require changes in the gasoline content that cannot be achieved by adding components at the distribution rack ('splash blending'). They require different refining processes and thus constitute a significant barrier to arbitrage between regulated and unregulated markets as well as significant barrier to production entry.

[9] In addition to California, Arizona also adopted its own, stricter gasoline content regulation in the Phoenix area. Arizona's Cleaner Burning Gasoline (AZCBG) regulation started in June of 1998, replacing the RFG program (which Phoenix had opted into temporarily).

[10] For a more visual depiction of the regulatory geography of the various RFG, RVP, and oxygenate gasoline programs, see Figure 2 and Gardner [6]. Note that some areas that joined the RFG program, opted out either before the program took effect or shortly thereafter (see Table 1).

3. Related Literature

The consequences of environmental regulation for productivity, investment, and entry have been widely studied. Gray [8] finds that EPA regulations explain about 12 percent of the economic slowdown observed in U.S. manufacturing during the 1970s (Gray [8]). More specifically, pollution regulations have resulted in decreased productivity in electricity production (Gollop and Roberts [7]) and pulp and paper mills (Gray and Shadbegian [10]). Gray and Shadbegian [9] find that, in the pulp and paper mill industry, environmental investment at a plant crowds out productive investment. Finally Bushnell and Wolfram [3] find reductions in capital expenditures in the electricity industry as a result of increased enforcement of regulations.

Furthermore, environmental regulations have deterred entry. In a study of the Portland cement industry, Ryan [18] found that Title V of the CAAA increased sunk entry costs, exacerbating industry concentration. In cases when the regulations affect only some firms (while others remain "grandfathered"), entry has been substantially deterred. These vintage-differentiated regulations have most notably affected entry by electricity generators (Nelson *et al.* [16]) but have had substantial consequences in many other industries, as well (Becker and Henderson [1]). Stavins [19] provides a general review of the impacts of these vintage-differentiated environmental regulations.

Environmental regulations are not necessarily harmful to some firms' profits. Firms may have strategic reasons for encouraging regulations (see Keohane *et al.* [13]) for a comprehensive discussion of this literature). Recently, Ryan [18] finds that in some markets, incumbent cement manufactures' profits increased as a result of regulation. In an oligopoly setting, firms may have incentives to induce strict environmental standards in order to raise their rivals' costs. Puller [17] examines these theoretical incentives of inducing regulation and cites examples of DuPont's support of the Montreal Protocol and Unocal's support of California's state-specific CARB gasoline content standards.

Despite the importance of understanding the impact of gasoline content regulation on wholesale gasoline prices, there are relatively few empirical studies on this topic. A handful of papers control for the impacts of gasoline content regulation while examining the impacts of merger activity during the late 1990's on wholesale gasoline prices (Chouinard and Perloff [5], Hastings and Gilbert [11]). However, these studies do not focus on the price effects of gasoline content regulation and the degree to which these price effects are generated by changes in the number of suppliers in each market or by increased geographic isolation.

A few recent studies have examined the relationship between gasoline content regulations and price volatility. Muehlegger [15] develops a structural model of refinery behavior to determine the degree to which recent price spikes resulted from (i) increased production costs versus (ii) incompatibility with the national reformulated gasoline standards. He finds evidence that these factors both contribute to the observed price volatility in California, Illinois, and Wisconsin. The paper uses price data aggregated by month, state, and gasoline formulation. In a related paper, Chakravorty and Nauges [4] examine the price effects of gasoline content regulation using state level averaged wholesale gasoline prices in a panel regression. They find evidence that, in some markets, gasoline content regulation resulted in higher wholesale prices. The aggregated data do not allow them to control for differential changes or shocks in wholesale prices across markets.

Using distribution rack level data, we are able to create treatment and control pairs of regulated and unregulated markets. This approach allows us to better control for differential regional changes in wholesale prices. In addition, the more detailed data allow us to control for the number of suppliers in each market, and estimate how changes in the number of suppliers as well as changes in geographic isolation affected wholesale prices. We can use these estimates to understand the relative value of geographic regulation expansion versus the possible secondary impact of regulation expansion on the number of suppliers in the market.[11]

4. The Data

The dataset we use as a basis for our econometric models consists of detailed, unbranded gasoline price and supplier information for gasoline distribution racks collected weekly by the Oil Price Information Service (OPIS). It includes all posted prices for each supplier for all formulations of gasoline sold at selected racks. We purchased these data for one year before and after the introduction of gasoline content regulation in each regulated geographic area. The data set also includes data from surrounding unregulated distribution racks. Thirty-one of the distribution racks in our data were located in jurisdictions (cities, counties or states) that enacted

[11] We are not able to estimate the entry decision for refiners into the reformulated fuels markets. We only know if a supplier posts prices at a particular distribution rack, however we do not know how much capacity each refiner decided to devote to reformulated fuels production. While it would be great to estimate the effects of fixed costs and regulated market size on entry decisions across refiner types in order to structurally simulate the effect on entry of expanded regulation geography, these data are not publicly available. They are collected by the Energy Information Administration, but are not accessible to researchers.

gasoline content regulations between 1995 and 2000. As outlined in Section 3, the regulations specify the RFG or RVP requirements for all gasoline used in the non-attainment region.

We divided the cities into Treatment and Control groups – treatment cities are those in which content regulations were introduced, and control cities had no content regulation. Each treatment city was matched with a control city in the same geographic region. Table 2 lists the treatment and control pairs. Recall that while the RFG and RVP regulations set content standards for all gasoline sold in the jurisdiction, suppliers in regulated areas may have continued to price and sell conventional gasoline for use outside of the region. In 20 of the 31 treatment cities, some suppliers continued to post prices for unbranded conventional gasoline after the regulation came into effect (see Table 2). We use prices for reformulated and conventional wholesale gasoline in regulated markets, as well as conventional prices in surrounding unregulated markets, in order to estimate the effects of regulation on wholesale gasoline prices and volatility.

The price variables extracted from the dataset are weekly averages, calculated as the mean of all prices posted for unbranded gasoline of the specified type (conventional, RFG, or RVP). In the statistical analysis that follows, we calculate two types of weekly prices differences: differences between the average regulated prices in the treatment city and the average conventional prices in the control city, and the differences between the average conventional prices in both the treatment and control cities. In all cases, the series consists of prices one year (52 weeks) before and after the regulations take effect. That is, each city pairing represents 104 weeks of price and supplier data. No weekly price was available for conventional and/or regulated gasoline for selected dates in eight of the 60 cities in our dataset. The price might have been unavailable because of supply limits (*i.e.*, no unbranded gasoline of the type was available for sale on that particular day[12]), or because of data collection problems.

Using the supplier-specific price data, we compile counts of the number of suppliers posting prices for each gasoline type in any given week. Table 3 displays the average supplier counts by distribution rack. Examining only the number of suppliers posting prices for conventional gasoline before and after the regulation date, the number of suppliers was the same or decreased in 39 out of 53 distribution racks. Similarly, the number of suppliers selling regulated gasoline declined in 24 out of 30 distribution racks selling gasoline with RFG or RVP content after a (own or neighboring) regional regulatory change, relative to the pre-regulation count.

5. Research Design, Statistical Model and Results

Our goal is to estimate the price effects of regulation, if any, and to determine if differences in the price effect of regulation across markets can be attributed to geographic isolation or increased supplier concentration. We match cities that were regulated (treated) with nearby cities that were not (controls) and use difference-in-difference approach on the time series of average prices in the cities. Both paired cities supply conventional gasoline before the regulation. After the regulation date, the regulated (treatment) city switches to the regulated gasoline blend, while the unregulated (control) city continues to supply conventional gasoline. As noted above, some suppliers in the treatment city may continue to sell conventional gasoline after the regulatory change, for sale outside of the regulated area.

[12] Although no unbranded price was posted, the distribution rack may have had branded gasoline for sale.

Estimating the Effect of Regulation on Prices

The baseline reduced form econometric model for estimating the effect of regulation on prices consists of the following equation

$$Y_t \equiv P_{Treatment,t} - P_{Control,t} = \beta X_t + \varepsilon_t \qquad (1)$$

where Y is the difference between the average weekly price of gasoline in the treatment city ($P_{Treatment,t}$) and control city ($P_{Control,t}$) pairs, X_t is a matrix of explanatory variables and ε_t is an unobservable random variable.

In the baseline model, X_t =*[RFG RVP* N_C N_T *]*, where *RFG* is a dummy variable that equals one if the treatment city price is for RFG gasoline, zero otherwise; *RVP* is a dummy variable that equals one if the treatment city price is for RVP gasoline, zero otherwise; N_C represents the number of suppliers in the control city calculated from a count of refiners posting prices at the distribution rack for the gasoline type of interest; and N_T represents the number of suppliers calculated in the same way for the treatment city.

In terms of economic theory, an increase in N_T in the treatment city is expected to negatively affect the price differences between treated and untreated cities, all else equal. Conversely, an increase in N_C in the control city is expected to positively affect the price differences between treated and untreated cities. In the baseline model, the coefficients on *RFG* and *RVP* measure the average impact of regulation on the price differences between regulated and unregulated cities after controlling for the number of refiner-suppliers in the treated and control cities. A positive and significant estimate of the coefficient associated with the regulation dummies suggests that prices have increased on average in the regulated cities relative to nearby unregulated cities.[13]

Using a difference-in-difference approach, we find evidence of an effect for *RVP* and *RFG* on price of gasoline content regulation. In particular, we find that changes in the number of refiners do not absorb all of the variation in the price effect of regulation across cities. Residual differences in the price effect of regulation may be caused by variation in the degree of geographic isolation (for example, the distance to the nearest rack). Moreover, our results are consistent with hypotheses about the role of geographic isolation of regulated cities in explaining patterns of price differentials.

Results from the random effects estimation of equation (1) are presented in Table 4. The dependent variable in 4.1 is the difference between regulated and unregulated gasoline prices in the treated and control cities, respectively. The intercept is statistically insignificant, suggesting that controlling for the number of suppliers, average prices for conventional gasoline are statistically the same across treatment and control cities. The positive and statistically significant coefficients on the *RFG* and *RVP* dummy variables support the hypothesis that significant price differences correspond with the implementation of new gasoline content regulation. In particular, the introduction of *RFG* results in a significant 3.6 cents per gallon increase in average gasoline prices, while *RVP* regulation leads to a 1.1 cent increase.

[13] The potential problem of serial correlation has been taken into account since several observations in the post-treatment phase are included to model the change in prices over time (see Bertrand, Duflo and Mullainathan [2]).

Specification 4.1 also controls for the number of suppliers in both treatment and control cities. The number of suppliers in each market often depends on and varies with historically determined pipeline supply access and "terminalling" rights, regional mergers, as well as regional supply decisions for reformulated fuels. It is important to control for the number of refiner suppliers in each market, since the number of suppliers may influence price differences across markets. The coefficients on *RFG* and *RVP* dummies are statistically unaffected by the inclusion of supplier count variables, indicating that the introduction of the regulations and the market-level supplier count are reasonably independently identified. The coefficient on the control city supplier count is statistically significant and positive, while the coefficient on the treatment city supplier count is statistically significant and negative. Intuitively this implies that, more treatment city suppliers leads to lower prices and less price difference, while more control city suppliers exacerbates the price disparity by lowering the already-low conventional price.

The regression model in 4.2 provides a basis for a specification check for the results in 4.1 and estimates the effect of content regulation on the price difference of conventional gasoline sold in treated cities relative to conventional gasoline sold in unregulated cities. Since regulated cities may continue to supply conventional gasoline for sale outside of the regulated area, these conventional prices should be unaffected by the introduction of gasoline content regulations in part of the local supply area, once we control for changes in the number of suppliers. If conventional prices in the regulated markets are significantly different than conventional prices in the unregulated control markets after the regulation is implemented, controlling for the number of suppliers, we may be concerned that there are other market structure changes for which we have not accounted that are causing increases in prices and are coincident with the introduction of the regulation requirements. The regression model in 4.2 adds to the data series in 4.1 the price difference between conventional prices in the treatment and control cities, denoted by Y^{Conv}

$$Y^{Conv}{}_t \equiv P^{conv}{}_{Treatment,t} - P^{Conv}{}_{Control,t} = \beta^* X^*{}_t + \varepsilon^*{}_t \qquad (2)$$

where now the matrix X^* includes N_T and N_C , as in (1), but also an "Artificial" *RFG* dummy that equals one if the treatment city price is for conventional gasoline, and a *RFG* regulation is in effect for other fuel types in the city, zero otherwise; and an "Artificial" *RVP* dummy defined similarly for the RVP cities.

The results for this formulation appear in column 4.2. The 'Artificial' *RFG* and *RVP* dummies are statistically insignificant. The addition of these variables does not appear to significantly affect the estimated price effect of *RFG* or *RVP*, nor does it affect the estimated effect of the number of suppliers on average wholesale prices. These results imply that the introduction of regulations significantly increased the price of wholesale gasoline in regulated markets.

Effect of Regulation of Price Volatility

While *RFG* and *RVP* regulation significantly increase the average price of wholesale gasoline, we do not find evidence that they increase price volatility in regulated markets. Table 5 presents regression results of the estimated standard deviation in the wholesale price difference between treatment and control cities on the number of suppliers and the introduction of reformulated fuels requirements. The standard deviation in the price difference between the treatment and control city is calculated for the before-regulation period and the after-regulation period for each city-pair. This yields two observations on the standard deviation in relative retail prices for each city pair. This panel of standard deviations is then regressed on the number of suppliers and an indicator for the regulation type. The regression results show no statistically significant impact of regulation on relative wholesale price volatility for reformulated gasoline. However, we do find evidence that conventional gasoline prices in the treatment cities were significantly less volatile after the implementation of the policies.

Investigating the Effects of Geographic Isolation

The results in Table 4 indicate that regulation leads to the rise in relative wholesale prices. However, it is not clear what causes this price increase. For example, the price increases may be consistent with an increase in the marginal cost of producing the reformulated fuels, or increased market power due to geographic isolation. If the increase in prices was caused by an increase in marginal production costs, we would expect the estimated price effect to be uniform across regulated markets. If instead the price increase, or a portion of the price increase, were due to geographic market segmentation, we might expect heterogeneous price effects of regulation across markets as well as a positive relationship between the market-specific price effect and the degree of geographic isolation.

To analyze whether the regulation effects are differential, and therefore not just due to a difference in marginal cost, we model a reduced form specification interacting regulation dummies and treatment city fixed effects. Extending the regression presented in Table 4, column 4.1, the estimated price effect of each type of regulation city-by-city is presented in Table 6. The spot estimates for the price effect of *RFG*, for example, vary greatly across the affected markets. The estimates are positive in most cases, and statistically significant in many of the markets. There is a large spread in the spot estimates for *RFG*, ranging from a negative and significant three cents per gallon (Paulsboro, NJ) to a positive and significant seven cents per gallon (Hammond, IN). This large, ten-cent range of price effects suggests that marginal production costs alone cannot explain the average price effect of gasoline content regulation.

In Table 7, we present results from investigating the relationship between the degree of geographic isolation and the price effect of gasoline content regulation. We measure geographic isolation, for each regulated city, based on the number of potential trading partners and the inverse of the distance to those trading partners both before and after regulation. The variable 'Proximity Measure' is equal to the sum of the inverse distances between a city and every distribution rack (city) with which it could potentially trade. The variable 'Potential Partner Count' is the total number of distribution racks with which a city could potentially trade. To be specific, if a city is unregulated and can therefore sell conventional gasoline, then that city could potentially trade gasoline supply with any other city in the United States. If a city is required to sell only *RFG* then it can only trade with other cities who sell *RFG*.[14] When gasoline content regulation is introduced, it geographically segments markets. It does so in two ways. It first

[14] For RFG North, this includes any RFG selling distribution rack. However, for RFG South, this includes only cities that sell gasoline that meets the more stringent RFG South specifications. Recall that RFG South can be sold in RFG North areas, but not vice-versa.

decreases the total number of supply markets for each type of fuel, and it also in many cases increases the geographic distance between markets supplying the same type of fuel. These two variables ‘Potential Partner Count’ and ‘Proximity Measure’ capture these two types of market segmentation in a simple, reduced form manner. They change discretely with the introduction of gasoline content regulation, and change differentially across markets with the degree of geographic isolation and market segmentation caused by the regulation. For a more formal and structural analysis of arbitrage, geographic isolation and market integration using the fuel requirements to identify the structural parameters of interest, see Hastings and Villas-Boas [12].

If geographic isolation causes the differential price impact of content regulation, then we would expect the coefficients on both Proximity Measure and Potential Partner Count to be negative and significant. As the distance between a city and its potential trading partners increases, then the proximity measure decreases and we would expect price effects of regulation to increase. Similarly, we expect that if the number of trading partners decreases, the price effect should increase. In specification 7.1, we include only the Potential Partner Count variable and find that an inverse relationship between trading partners and price. When including both measures in 7.2, we find similar results: while both coefficients are negative, as predicted, only the coefficient on Potential Partner Count is significant. The results in Table 7 lend support to the hypothesis that market segmentation—caused by the discontinuous design of gasoline content regulation—may have led to the price increases that are not attributable to increased marginal costs of production.

Note that the estimates in Table 7 provide a basis for comparing the relative price effects of market segmentation versus decreased number of suppliers. The estimated effect of a decrease in the number of suppliers in a regulated city is about 1 cent per gallon per supplier. This is ten times the spot estimate of the effect of the number of trading partners. Hence, an increase of ten in the number of trading partners would just offset the price effect of a decrease of one in the number of suppliers. While a structural estimation would give a fuller picture of the trade off between supplier concentration within a distribution rack and geographic concentration of potential arbitrage partners, these reduce form estimates suggest that regulators should carefully consider the secondary impact on refiner concentration of geographic expansion of gasoline content regulation. If regulation expansion would lead to increased refiner entry into regulated markets, then competition would benefit both from an increase in the number of suppliers and an increase in the continuity between potential arbitrage markets. However, if regulation expansion would cause increased exit by marginal refiners due to high fixed entry costs, then gasoline content regulation reform could lead to increased price distortions.

6. Conclusions

This paper uses highly detailed company-specific weekly wholesale prices for unbranded gasoline for distributions rack in the United States to estimate i) the price effect of gasoline content regulation, and ii) the extent to which the estimated price effect is driven by changes in the number of competitors versus geographic market segmentation. The reduced form evidence shows that prices in ‘treated’ metropolitan areas increased significantly relative to their ‘untreated’ counterparts. While the price effect of regulation is on average 3.6 cents per gallon, the spot estimate for the price effect of content regulation varies across regulated cities by approximately ten cents per gallon.

Using the variation in the change in the number of competitors and the change in geographic isolation across the treated metropolitan areas, we find evidence that both of these factors contribute to city-specific increases in wholesale gasoline prices. The changes in the number of suppliers in treated and in nearby untreated cities do not absorb all the variation in the price effect of regulation across cities but does have some effect, and in the direction we expect. We find evidence that residual differences in the price effect of regulation could be caused by variation in the degree of geographic isolation to potential partners. The estimated effect of a decrease in the number of suppliers in a regulated city is about ten times the spot estimate of the effect of the number of trading partners.

In terms of economic implications, these reduced form estimates provide a basis for concluding that the secondary impact of geographic expansion of gasoline content regulation on refiner concentration may be an important issue for regulators to consider. If regulation expansion leads to increased refiner entry into regulated markets, then competition would benefit both from an increase in the number of suppliers and an increase in the continuity between potential arbitrage markets. However, if regulation expansion causes increased exit by marginal refiners due to high fixed entry costs, then gasoline content regulation reform may lead to increased price distortions. In determining the optimal scope (and scale) of environmental policy, optimal policy takes into consideration more than just the geographic differences in marginal damages and the “direct” marginal costs of abating pollution; as we find it this paper, these regulations also have implications on firms’ ability to exercise market power and on their entry decisions.

Future research will use these data and the underlying source of variation generated by regulation, and the variation in refineries due to exogenous events, to estimate the parameters of a structural model of arbitrage that incorporates both internal number of refiners, and the distance to next potential arbitrage markets.

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Table 1: Areas that Opted-Into RFG Program

State	Counties	Opt-in Date	Opt-out date
Arizona	Phoenix Metro counties	July 3, 1997	June 10, 1998*
Connecticut	Remainder of state	January 1, 1995	
District of Columbia	All counties	January 1, 1995	
Kentucky	Cincinnati-Hamilton and Louisville counties	January 1, 1995	
Massachusetts	All counties	January 1, 1995	
Maryland	Washington DC counties, Kent, Queen Anne's	January 1, 1995	
Maine	Hancock, Waldo	January 1, 1995	August 7, 1996**
Maine	Knox-Lincoln, Lewiston-Auburn, Portland	January 1, 1995	March 10, 1999
Missouri	St. Louis metro counties	June 1, 1999	
New Hampshire	South Eastern Counties	January 1, 1995	
New Jersey	Remainder of state	January 1, 1995	
New York	Essex and Dutchess counties	January 1, 1995	
New York	Albany area, Buffalo area, Jefferson counties	January 1, 1995	August 7, 1996**
Pennsylvania	Western part of state	January 1, 1995	August 7, 1996**
Rhode Island	All counties	January 1, 1995	
Texas	Dallas-Fort Worth counties	January 1, 1995	
Virginia	Norfolk, Richmond, Washington DC counties	January 1, 1995	

* Replaced with AZCBG, **Submitted opt-out request before January 1, 1995, so was never regulated.

Table 2: Treatment and Control Cities

	Cities				Regulation		Conventional in
PADD	Treatment		Control		Type	Date	Treatment?[1]
5	Albany	NY	Utica	NY	RFG	from Jan 1,1995	yes
1	Baltimore	MD	Harrisburg	PA	RFG	from Jan 1,1995	yes
1	Baltimore	MD	Philadelphia	PA	RFG	from Jan 1,1995	no
1	Buffalo	NY	Rochester	NY	RVP	Dec 1994-Jan 1995	no
2	Chicago	IL	Rockford	IL	RFG	from Jan 1,1995	yes
2	Covington	KY	Cincinnati	OH	RFG	from Jan 1,1995	yes
2	Covington	KY	Dayton	OH	RFG	from Jan 1,1995	yes
2	Covington	KY	Lebanon	OH	RFG	from Jan 1,1995	yes
3	Dallas	TX	Austin	TX	RFG	from Jan 1,1995	yes
3	Dallas	TX	Oklahoma City	OK	RFG	from Jan 1,1995	yes
3	Dallas	TX	Waco	TX	RFG	from Jan 1,1995	yes
2	Detroit	MI	Flint	MI	RVP	June-Sept 96/97	no
2	Detroit	MI	Lansing	MI	RVP	June-Sept 96/97	no
2	Detroit	MI	Toledo	OH	RVP	June-Sept 96/97	no
3	El Paso	TX	Odessa	TX	RVP	May-Sept 95/96	no
3	El Paso	TX	Tucson	AZ	RVP	May-Sept 95/96	no
1	Fairfax	VA	Harrisburg	PA	RFG	from Mar 1,1995	yes
1	Fairfax	VA	Roanoke	VA	RFG	from Mar 1,1995	yes
3	Fort Worth	TX	Austin	TX	RFG	from Jan 1,1995	no
3	Fort Worth	TX	Oklahoma City	OK	RFG	from Jan 1,1995	no
3	Fort Worth	TX	Waco	TX	RFG	from Jan 1,1995	no
2	Hammond	IN	Indianapolis	IN	RFG	from Jan 1,1995	yes
3	Houston	TX	Austin	TX	RFG	from Dec 1,1994	yes
3	Houston	TX	San Antonio	TX	RFG	from Dec 1,1994	yes
3	Houston	TX	Waco	TX	RFG	from Dec 1,1994	yes
2	Kansas City	KS	Topeka	KS	RVP	June-Sept 97/98	yes
5	Los Angeles	CA	Las Vegas	NV	RFG	from Dec 1,1994	no
5	Los Angeles	CA	San Francisco	CA	RFG	from Dec 1,1994	no
5	Los Angeles	CA	San Jose	CA	RFG	from Dec 1,1994	no
2	Louisville	KY	Cincinnati	OH	RFG	from Jan 1,1995	yes
2	Louisville	KY	Lexington	VA	RFG	from Jan 1,1995	yes
1/2[2]	Midland	PA	Youngstown	OH	RVP	May-Sept 98/99	yes
2	Milwaukee	WI	Madison	WI	RFG	from Jan 1,1995	yes
1	Newark	NJ	Macungie	PA	RVP	from Mar 1,1995	no
1	Newark	NJ	Scranton	OH	RVP	from Mar 1,1995	no
1	Newburgh	NY	Albany	NY	RFG	from Jan 1,1995	yes
1	Norfolk	VA	Raleigh	NC	RFG	from Jan 1,1995	yes
1	Norfolk	VA	Roanoke	VA	RFG	from Jan 1,1995	yes
2	Olathe	KS	Topeka	KS	RVP	June-Sept 97/98	yes
1	Paulsboro	NJ	Sinking Springs	PA	RFG	from Dec 1,1995	no
1	Philadelphia	PA	Harrisburg	PA	RFG	from Mar 1,1995	no
1	Philadelphia	PA	Macungie	PA	RFG	from Mar 1,1995	no
5	Phoenix	AZ	Tucson	AZ	RVP	May-Sept 95/96	no
1/2[2]	Pittsburgh	PA	Youngstown	PA	RVP	May-Sept 98/99	yes
1	Portland	ME	Bangor	ME	RFG	from Jan 1,1995	yes
1	Richmond	VA	Raleigh	NC	RFG	from Jan 1,1995	no
1	Richmond	VA	Roanoke	VA	RFG	from Jan 1,1995	yes
1	Springfield	MA	Albany	NY	RFG	from Oct. 1,1996	no
2	St. Louis	MO	Decatur	IL	RFG	from June 1,1999	yes
2	St. Louis	MO	Indianapolis	IN	RFG	from June 1,1999	yes
2	Wood River	IL	Decatur	IL	RVP	June-Sept 95/96	yes
2	Wood River	IL	St. Louis	MO	RVP	June-Sept 95/96	yes

[1] At least one supplier in the Treatment city continued to post prices for conventional gasoline after the regulation date.

[2] Midland and Pittsburg are located in PADD 1, Youngstown is located in PADD 2

Table 3: Supplier Counts by City, Before and After Regulation

	average # of suppliers[1]				average # of suppliers[1]		
	Conventional		RFG or RVP		Conventional		RFG or RVP
	Before	After[2]	After[2]		Before	After[2]	After[2]
Albany	6.9	7.5	1.3	Newark	8.85	-	7.2
Austin	6	5.75	-	Newburgh	3	2.67	2.67
Baltimore	9.3	4	9.3	Norfolk	14	8.54	13.67
Bangor	1.96	1	-	Odessa	1	1	-
Buffalo	1	-	1	Oklahoma City	10	10.1	-
Chicago	8.5	4	5	Olathe	5	4.47	2.5
Cincinnati	6	5.75	1	Paulsboro	2.38	-	1.96
Covington	4	4	3.69	Philadelphia	2.55	2	-
Dallas	6.8	3.5	8.6	Phoenix	4.45	-	4
Dayton	6	6	-	Pittsburgh	6.75	7.08	6.1
Decatur	1.2	1.6	-	Portland	5.6	2.96	4.8
Detroit	9.2	-	8.6	Raleigh	2.83	2.9	-
El Paso	4.34	-	4.13	Richmond	15	13.03	13.31
Fairfax	7.45	1.65	11.7	Roanoke	11.4	16.9	-
Flint	3.75	3.5	-	Rochester	6	6.5	-
Fort Worth	6.8	3.5	8.6	Rockford	7	6.6	-
Hammond	6.25	5.96	4.25	San Antonio	8	7.7	-
Harrisburg	5.83	6.3	-	San Francisco	7	5	-
Houston	7	2.33	9.5	San Jose	7	5.5	-
Indianapolis	10	8.8	-	Scranton	4.75	4.33	-
Kansas City	10	9.4	5	Sinking Springs	1	2.12	-
Lansing	2.75	2.5	-	Springfield	0	-	1
Las Vegas	2	2	-	St. Louis	5.7	5.79	3.7
Lebanon	10	11	-	Toledo	8.1	8	-
Lexington	5	5	-	Topeka	8.3	8.3	-
Los Angeles	6	-	5	Tuscon	5	5	-
Louisville	9.94	9.46	6.58	Utica	3.9	3.9	-
Macungie	4.9	5.2	-	Waco	6	5.75	-
Madison	8.23	8.67	-	Wood River	4.5	4.44	3
Midland	1.85	1.8	1.68	Youngstown	3.8	4	-
Milwaukee	8	6.67	3.6				

[1] Suppliers counts were calculated as the average number of suppliers appearing consistently in the dataset for the year-long before- and after-regulation periods. Suppliers appearing fewer than 12 times in the year were omitted from this count, but remain in the full dataset used in further analyses.
[2] For a city in the treatment group, "After" supplier count reflects the average number of suppliers in the area after the regulation came into effect. For a city in the control group, "After" supplier count reflects the average number of suppliers in the area after the regulation was enacted in the nearby city with which it was pairs (see Table 1 for pairings).

<u>Table 4: Random Effects Regression of Average Treatment with AR(1) disturbances</u>

Dependent Variable: Gasoline Price in Treatment City - Gasoline Price in Control City (cents per gallon)

		Models			
		4.1		4.2	
Price Difference	*before regulation*	conv - conv		conv - conv	
	after regulation	reg - conv		reg-conv & conv-conv	
RFG dummy		3.539	**	3.591	**
		(0.166)		(0.143)	
RVP dummy		1.083	**	1.118	**
		(0.216)		(0.185)	
"Artificial" RFG dummy				0.137	
				(0.197)	
"Artificial" RVP dummy				-0.532	
				(0.289)	
# of Suppliers in Control City		0.110	*	0.085	*
		(0.055)		(0.038)	
# of Suppliers in Treatment City		-0.135	**	-0.098	**
		(0.048)		(0.035)	
Constant		0.077		-0.085	
		(0.451)		(0.327)	
Auto-correlation (rho)		0.759		0.767	
# of Observations		5190		8098	

Note: Values in parentheses are standard errors. * and ** represent statistical significance at the 5 and 1 percent levels, respectively.

Table 5: Random Effects Regression of Volatility with AR(1) disturbances

Dependent Variable: Std. Dev of Difference of Gasoline Price in Treatment and Control Cities

Price Difference	*before regulation*	conv-conv
	after regulation	reg-conv
RFG dummy		0.441
		(0.260)
RVP dummy		-0.577
		(0.302)
# of Suppliers in Control City		-0.106 **
		(0.034)
# of Suppliers in Treatment City		-0.047
		(0.031)
Constant		2.623 **
		(0.296)
R-squared		0.165
# of Observations		103

Note: Values in parentheses are robust standard errors. * and ** represent statistical significance at the 5 and 1 percent levels, respectively.

Table 6: Random Effects Regression with AR(1) disturbances and City Fixed Effects

Dependent Variable: Regulated Gasoline Price in Treatment City - Conventional in Control City

		Estimate	Standard Error
RFG dummy		1.165	0.924
RVP dummy		0.614	0.357
RFG dummy interacted with	Baltimore	0.879	1.120
	Buffalo	2.510	1.400
	Chicago	6.105**	1.229
	Covington	5.652**	1.028
	Dallas	2.295*	1.089
	Fairfax	1.447	1.213
	Fort Worth	1.795	1.034
	Hammond	6.857**	1.237
	Houston	4.202	1.104
	Los Angeles	0.296	1.116
	Louisville	4.985**	1.072
	Milwaukee	6.386**	1.225
	Newark	-2.149*	1.074
	Newburgh	0.531	1.246
	Norfolk	3.106**	1.139
	Paulsboro	-2.997*	1.239
	Philadelphia	-1.079	1.085
	Portland	0.619	1.257
	Richmond	3.008	1.117
	Springfield	0.868	1.594
	St. Louis	3.366**	1.075
RVP	ElPaso	1.372*	0.600
	Kansas City	1.244	0.836
	Midland	0.435	1.002
	Olathe	1.051	0.806
	Pittsburgh	-0.836	0.775
	Tuscon	0.629	0.787
	Wood River	0.582	0.618
# of Suppliers in Control City		0.069	0.053
# of Suppliers in Treatment City		-0.105	0.060
Constant		0.133	0.485
Auto-correlation (rho)		0.728	
# of Observations		5190	

Note: * and ** represent statistical significance at the 5 and 1 percent levels, respectively. The omitted cities are Albany NY for RFG interactions and Detroit MI for RVP interactions.

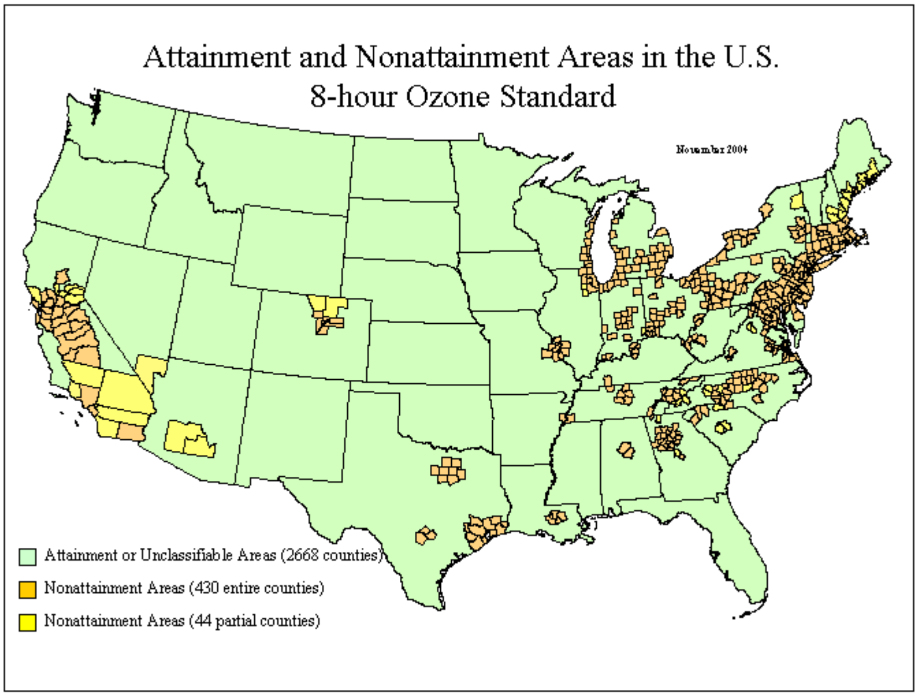
Table 7: Random Effects Regression with AR(1) disturbances with Proximity Measures

Dependent Variable: Regulated Gasoline Price in Treatment City - Conventional in Control City

	Model	
	7.1	7.2
Proximity Measure		-1.167
		(0.974)
Potential Partner Count	-0.009 **	-0.008 **
	(0.000)	(0.001)
# of Suppliers in Control City	0.160 **	0.163 **
	(0.058)	(0.056)
# of Suppliers in Treatment City	-0.098 *	-0.098 *
	(0.049)	(0.048)
Constant	2.750 **	2.803 **
	(0.456)	(0.442)
Auto-correlation (rho)	0.761	0.757
# of Observations	5190	5190

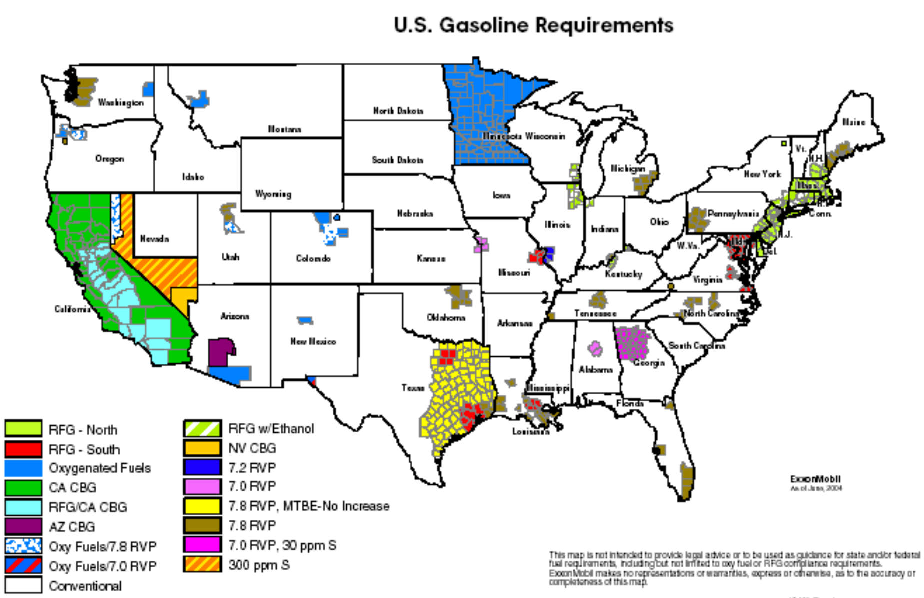
Note: Values in parentheses are standard errors. * and ** represent statistical significance at the 5 and 1 percent levels, respectively. "Proximity Measure" is the sum of the inverses of distances between treatment city and cities with similar content requirements. "Potential Partner Count" is the total number of cities with content requirements similar to the treatment city.

Figure 1



Source: http://www.epa.gov/oar/oaqps/greenbk/naa8hrgreen.html

Figure 2



Source: Gardner (2004)