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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 US 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. 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 cents/gal. The price effect, however, varies by 8 cents/gal across regulated markets and the heterogeneity across markets is correlated with the degree of geographic isolation generated by the discontinuous regulatory requirements.

JEL classification: L13; L51; Q50

Keywords: Environmental content regulation; Gasoline wholesale prices

1. Introduction

The theory of environmental policy suggests that when setting environmental standards, the government regulator will optimize social welfare by equating marginal external damages and marginal abatement costs. When damages and costs vary spatially, the theory suggests that spatially differentiated standards are appropriate [15,5]. However, spatially differentiated standards have the potential to segment markets that might be integrated under a uniform standard. Segmentation, in turn, may give firms that supply isolated markets the ability to exercise market power. Such secondary effects of spatially differentiated standards on market competition and efficiency may counteract potential benefits of moving from a system with uniform standards to one with spatially differentiated standards. The literature on fiscal federalism discusses the

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optimal geographic size and scope of government policies given the market forces that can lead to efficiency gains or losses as a function of federal versus local policy implementation (e.g. [17,14]).

Historically, US transportation policies have used command-and-control standards to limit emissions rates, gasoline additives, and vehicle fuel economy, primarily at the national level. More recently, the US Environmental Protection Agency (EPA) introduced gasoline content regulations aimed at specific cities with poor air quality, and allowed flexibility in how different areas met those requirements. The policies segmented once contiguous fuel markets and therefore may have had a secondary impact on market structure. This paper examines whether environmental policies aiming to improve environmental quality by reformulating gasoline may have significantly altered competition 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 changes in the required formulation of gasoline across metropolitan areas and geographically segmented once contiguous wholesale gasoline markets. By 2004, industry analysts estimated that the number of fuels in the United States proliferated from one type to over 17 types as a result of the regulation [23].

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 [19,22]. Economists and policy makers hypothesize that, in addition to potentially increasing marginal costs, gasoline content regulations may increase prices for two 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 the market power of incumbent suppliers in periods of relatively tight supply [21]. Second, producing reformulated fuel often involved large fixed cost investments [18]. Hence, many producers may have opted to exit the regulated markets, leading to a decrease in the number of competitors supplying those 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]

We use weekly wholesale prices for unbranded gasoline for selected distribution racks in the United States to estimate a reduced-form relationship between prices and gasoline content regulation. We examine how this price effect varies with changes in the number of competitors versus geographic market segmentation induced by regulation. Our reduced-form analysis compares regulated metropolitan areas with unregulated metropolitan areas in close geographic proximity in order to estimate the price effect of gasoline content regulation within the regional gasoline supply chain. 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 cents/gal, the point estimate for the price effect of content regulation varies across regulated cities by approximately 8 cents/gal. 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 1.24 cents/gal. 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 expected direction.

[1] EPA classifies counties as ‘‘non-attainment’’ if air pollution levels exceed criteria limits. The three main types of regulation are Federal Reformulated Gasoline, which was required for metropolitan areas with highest levels of ozone non-attainment, Reid vapor pressure, and oxygenate requirements, for non-attainment areas for ozone and CO, respectively.

[2] A related literature examines how environmental regulations deter entry. For example, a study of the Portland cement industry finds that Title V of the CAAA increased the sunk costs of entry [16]. This exacerbated industry concentration and firms’ ability to exercise market power.

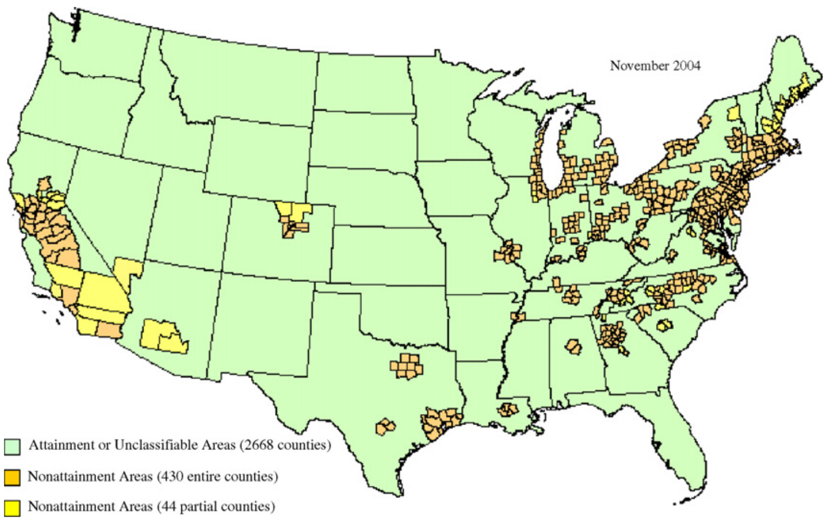

Fig. 1. Attainment and nonattainment areas in the US 8-h ozone standard. *Source*: http://www.epa.gov/oar/oaqps/greenbk/naa8hrgreen.html

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.

2. Background on environmental gasoline content regulation

2.1. Overview of federal regulations

The CAAA is a federal law, administered through EPA, which 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 (RVP), mandate minimum oxygen content and prescribe specific requirements for reformulated gasoline (RFG). 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 Fig. 1). States and regions not required to participate may opt-in to the programs. There are three programs aimed at reducing fuel-related air pollution: the Oxygenated Gasoline Program, the RVP Program, and the Federal RFG Program.[3] Minimum standards are mandated by the EPA, and the program allows regional regulators to impose more stringent requirements through State Implementation Plans (SIPs). 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.

2.2.1. Oxygenate Program

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 of gasoline, which enables the fuel to burn more completely. To produce oxygenated gasoline, either ethanol or methyl tertiary-butyl ether (MBTE) is added to the product after refining.[4] Generally, refiners and distributors sell oxygenated gasoline during winter months,

[3]See, for example [12] for a thorough survey of gasoline content regulations and adoption timing across US counties and metropolitan areas.

[4]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. Since 2000, at least 16 US states have banned MBTE. Because MTBE has the

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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.

2.2.2. RVP program

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.

2.3. Reformulated Fuels Program (RFG)

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, RFG requirements combat CO emissions. RFG regulations stipulate both content criteria (such as benzene content limits) and emissions-based performance standards for refiners.[5] 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 RFG Program is a major gasoline regulation; RFG gasoline constitutes one third of all gasoline sold in the US, and the EPA attributes a 17 percent reduction in emissions of VOC and other toxics to this program [20].

We will focus on RFG and RVP regulations in our analysis. Both RFG and RVP require changes in production at the refinery. They are more costly to refine than conventional gasoline, and gasoline that does not meet the RFG or RVP requirements cannot be substituted in case of a supply shortage or a sudden local increase in demand. In contrast, oxygenates are splash blended, meaning that they are added to gasoline at the terminal. Therefore, gasoline blend stock in oxygenated and non-oxygenated markets is fungible, and does not required different refining processes for production. Hence, unlike oxygenate regulations, RFG and RVP requirements act to prevent arbitrage between geographic markets and require production decisions on the part of firms—both of these features may change the competitive environment.

RFG and RVP regulations have been phased in over time, with increasingly stringent standards required in each successive phase. 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 US: Baltimore, Chicago, Hartford, Houston, Los Angeles, Milwaukee, New York City (including CT and NJ "suburbs"), Philadelphia, and San Diego. Two types of RFG programs are in place: RFG North and RFG South, where the geographic definition is given by the Mason-Dixon Line.[6]

2.4. SIPs and the opt-in program

In order to preserve state autonomy and flexibility, the EPA allowed states to submit plans for compliance with the CAAA. Several multi-state regions also chose to implement specific standards and formulations that

(*footnote continued*)
same RVP as gasoline, the gasoline into which MBTE is blended requires no change in formulation. Ethanol, on the other hand, has a much higher RVP than gasoline. This implies that the gasoline to which it is added must have a lower initial RVP level in order to meet the overall RVP requirement for conventional gasoline.

[5] Between 1995 and 2000, both ethanol and MTBE were used in the RFG Program.

[6] According to the EIA, based on higher average ambient temperatures in southern climates, RFG South has slightly different requirements.

met or exceeded the federal standards. We describe two of the largest SIPs here. First, the state of California implemented its own gasoline content regulation in March of 1996. The California Air and Resources Board (CARB) administers the state's gasoline content program, and requires the production and sale of CARB gasoline throughout the state of California. CARB gasoline is similar to RFG, but has more stringent standards than the federal version. This regulation *replaced* the federally mandated RFG requirements in Los Angeles and San Diego, and was required in all California counties—attainment or non-attainment—from March 1996 onwards.[7]

Wisconsin and Illinois implemented tax incentive programs to encourage the use of ethanol to meet oxygenate requirements and ozone emissions standards in non-attainment areas. While this did not explicitly require a different formulation of gasoline like CARB, it effectively differentiated the market. Blending with ethanol requires a lower-RVP level in the underlying gasoline than does blending with MTBE. Hence, in order to use ethanol and gain the tax subsidy, firms would have to produce a lower-RVP gasoline for sale in non-attainment areas in this region. The tax incentives made it beneficial for firms to adopt ethanol with lower-RVP blendstock; over 95 percent of RFG sold in the region used ethanol as the additive, according to EPA surveys of gasoline content from 1996 to 1998, while from 1999 to 2001, all of the gasoline sold in Chicago and Milwaukee was ethanol-blended RFG [12].

Although RFG and RVP requirements are federally mandated in non-attainment areas, many state and local governments opted-in to the regulation in order to reduce emissions. Indeed, the geographic scope of the RFG program may be attributed to the large number of opt-in areas. Table 1 lists regions in the US that were either regulated by the EPA or opted-in to the RVP or RFG programs.[8] The table specifies the start and end dates of the program, the type of program, and whether the regulation falls under a SIP or under the EPA's fuel content specifications. Note that the opt-in areas are defined by county, municipality or state boundaries rather than by supply system boundaries. Hence, the ability for localities to opt-in separately from supply regions has led to the increased market segmentation. For example, in Arizona, the Phoenix metropolitan area opted-in to the RFG program while Tucson did not, even though these two urban centers are only 2 h apart and are connected by a pipeline for wholesale gasoline supply. Parts of New York opted-in to the RFG program, but others did not, even though New York supply is interconnected by the Buckeye system of pipelines, and a large network of gasoline distributors that can arbitrage price differences between distribution racks.

Fig. 2 illustrates the geographic isolation and proliferation of fuel requirements by 2002. 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.

3. Related literature

Despite the importance of understanding the impact of gasoline content regulation on wholesale gasoline prices, there are relatively few empirical studies on the topic. In examining the impacts of merger activity during the late 1990s on wholesale gasoline prices, several papers control for gasoline content regulation (e.g. [3,7]). However, these studies do not focus on the price effects of gasoline content regulation and the degree to which these price effects are driven 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 wholesale price. Using state-level panel data with monthly average wholesale prices from 1995 to 2001, Muehlegger [13] develops a structural model of refinery behavior to determine the causes of recent wholesale gasoline price

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

[8]Some areas that joined the RFG program opted-out either before the program took effect or shortly thereafter (Table 1). According to media articles and a Testimony of Robert Perciasepe, from the EPA before US Senate Committee on Agriculture, Nutrition and Forestry, in April 11, 2000, many areas opted-in as a "cost effective measure to combat their air pollution problems".

Table 1
Reformulated and RVP program details for selected US cities[a]

	City[a]	Start date	End date	RFG region
Reformulated gasoline program				
Mandated	Baltimore, MD	January 1, 1995		South
	Chicago, IL	January 1, 1995		North[b]
	Hammond, IN	January 2, 1995		North
	Hartford, CT	January 1, 1995		North
	Houston, TX	January 1, 1995		South
	Los Angeles, CA	January 1, 1995	May 31, 1996	CARB[c]
	Milwaukee, WI	January 1, 1995		North[b]
	New York City, NY	January 1, 1995		North
	Philadelphia, PA	January 1, 1995		North
	Sacramento, CA	June 1, 1995	May 31, 1996	CARB[c]
	San Diego, CA	January 1, 1995	May 31, 1996	CARB[c]
Opt-in	Phoenix, AZ	July 3, 1997	June 10, 1998	
	New Haven, CT	January 1, 1995		North
	Cincinnati, OH	January 1, 1995		North
	Covington, OH	January 1, 1995		North
	Louisville, KY	January 1, 1995		North
	Boston, MA	January 1, 1995		North
	Springfield, MA	January 1, 1995		North
	Bangor, ME	January 1, 1995	March 10, 1999	North
	Portland, ME	January 1, 1995	March 10, 1999	North
	St. Louis, MO	June 1, 1999		South
	Newington, NH	January 1, 1995		North
	Paulsboro, NJ	January 1, 1995		North
	Newark, NJ	January 1, 1995		North
	Newburgh, NY	January 1, 1995		North
	Long Island, NY	January 1, 1995		North
	Albany, NY	January 1, 1995	July 8, 1996[d]	North
	Buffalo, NY	January 1, 1995	July 8, 1996[d,e]	North
	Providence, RI	January 1, 1995		North
	Dallas-Fort Worth, TX	January 1, 1995		South
	Norfolk, VA	January 1, 1995		South
	Richmond, VA	January 1, 1995		South
	Fairfax, VA	January 1, 1995		South
State	Phoenix, AZ	June 10, 1998		
	State of California	June 1, 1996		CARB

	City	Start date	End date	RVP level
RVP program				
Federal[f]	New Orleans, LA	1992		7.8 from June to September 15
	Chalmette, LA	1992		7.8 from June to September 15
	Convent, LA	1992		7.8 from June to September 15
	Greensboro, NC	1992		7.8 from June to September 15
	Raleigh, NC	1992		7.8 from June to September 15
	Sparks/Reno, NV	1992		7.8 from June to September 15
	Portland, OR	1992		7.8 from June to September 15
	Nashville, TN	1992		7.8 from June to September 15
	Memphis TN	1992		7.8 from June to September 15
	Beaumont, TX	1992		7.8 from June to September 15
	Salt Lake City, UT	1992		7.8 from June to September 15
	Denver, CO	1992		7.8 from June to September 15
SIP	Wood River, IL	August 11, 1997		7.0 from June to September 30
	Olathe, IN	April 9, 1996		7.8 from June to September 15
	Kansas City, KS	March 15, 2002		7.0 from June to September 15

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Table 1 (*continued*)

City	Start date	End date	RVP level
Kansas City, KS	May 2, 1997	March 15, 2002	7.2 from June to September 15
Portland, ME	April 5, 2002		7.8 from May to September 15
Detroit, MI	May 5, 1997[g]		7.8 from June to September 15
Pittsburg, PA	July 23, 1998		7.8 from June to September 15
Midland, PA	July 23, 1998		7.8 from June to September 15
El Paso, TX	May 1, 1996		7.0 from June to September 15

[a]Regulations were enacted on either a state, multi-county, county or city level. For convenience, we list only city names.
[b]Oxygenate used is 100% ethanol (10%).
[c]California Air Resources Board began to regulate gasoline at a state level on June 1, 1996. Selected California cities had RFG requirements since December 1, 1994. San Francisco, CA, and San Jose, CA were not regulated prior to the state-wide regulation and will therefore be used as control cities in this study, as described in the next table.
[d]On January 1, 1995 and July 8, 1996, the EPA granted temporary exemptions to the RFG requirements. On July 8, 1996, New York was removed formally from the list of RFG areas.
[e]Opted out before ever carrying RFG.
[f]1 psi waiver in federal requirement for 10% ethanol.
[g]Interim program started July 1, 1996.

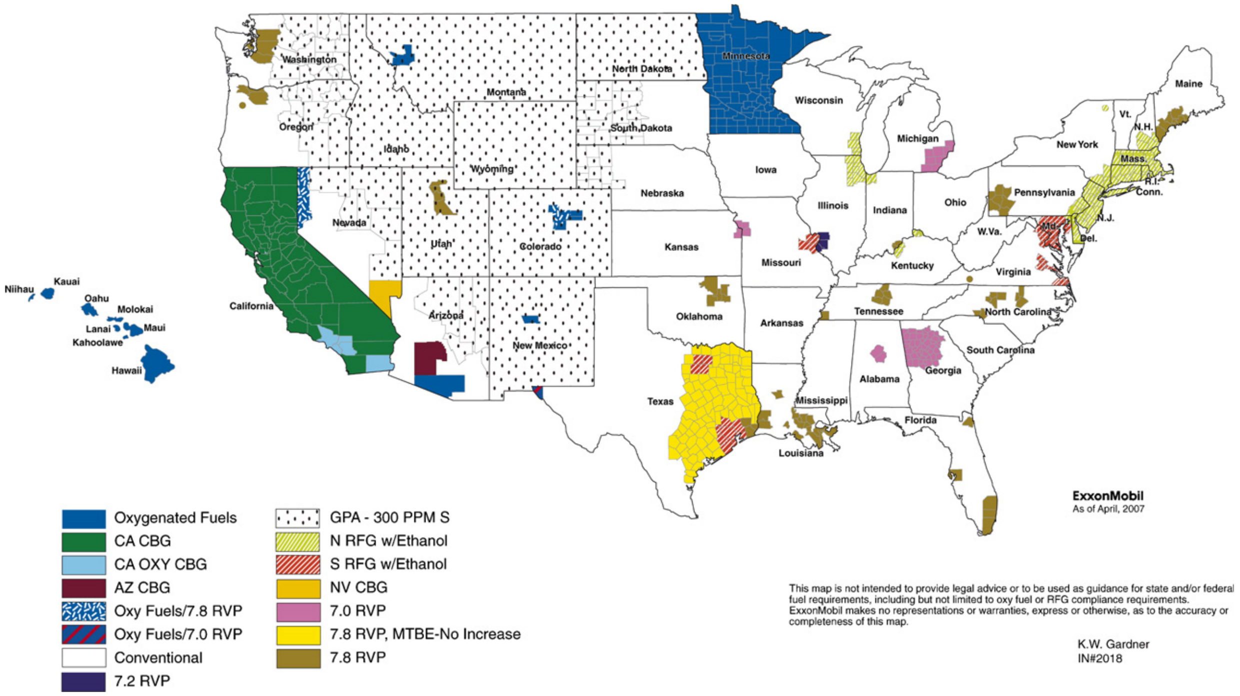

Fig. 2. US gasoline requirements. *Source*: [6].

spikes in California, Illinois, and Wisconsin. He models the production optimization problem of refineries for jet fuel, diesel, and four types of gasoline, as in [4]. He concludes that both production costs and regulatory incompatibility contribute to observed price volatility, and that most of the observed regional price spikes would have been mitigated under uniform content regulation. Chakravorty and Nauges [2] also examine the effects of gasoline content regulation on wholesale prices. They use a panel of state level, annual average wholesale gasoline prices from 1995 to 2002 to examine the effect of regulatory incompatibility on average wholesale prices by comparing a state's regulations with the regulations in neighboring states. Chakravorty

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and Nauges [2] conclude that gasoline content regulation resulted in higher wholesale prices, in part because of greater refining costs, but primarily because of market segmentation.

Our paper differs from the existing literature in several important ways. First, we use detailed, proprietary wholesale gasoline price data that vary by supplier, wholesale market, and week. Both last papers described above use publicly available data that have been aggregated by state and month (Chakravorty and Nauges [2] further aggregate the data by state and year). These data do not allow the authors to control for differential changes in, or shocks to, wholesale prices across markets within a state. By matching treatment and control cities, we account for unobservable weekly shocks specific to a region. Second, in contrast to other studies, we use data *before* (as well as after) the regulatory changes in order to control for unobservable market-specific characteristics. Despite these methodological differences, all three papers reach qualitatively similar conclusions: regulation-induced geographic isolation is an important determinate of relatively high wholesale gasoline prices.

4. Data and empirical analysis

4.1. Description of data and empirical approach

Our goal is to estimate the potential impact of regulation-induced changes in market structure on wholesale gasoline prices by exploiting the geographical incidence of such regulations. Ideally, we would like to estimate how regulation and geographic segmentation affect the entry decisions of refining firms, their production decisions, as well as their local supply and arbitrage decisions. Estimating a fully specified model of entry, production, supply and arbitrage, given regulatory requirements and demand, would allow for predictions of equilibrium market outcomes under alternative regulatory regimes. However, such estimation would require information on plant-level production, quantity supplied, and arbitrage decisions—data that are not available to any researcher. Since prices are available, we use market equilibrium prices to glean information on the effect of regulation on prices and the extent to which any identified effects can be attributed to changes in market structure induced by regulation. We therefore focus on the marginal impact of environmental regulation: the observed price impact of dividing once-contiguous markets, and the observed price effect of changing in the number of suppliers in each market. These ‘‘partial derivatives’’ may help us to understand the potential effect of alternative regulation on gasoline prices in the absence of estimates from an equilibrium model of gasoline supply.

Arbitrage between two geographically neighboring markets can occur primarily in two ways: via pipeline or via tanker truck. If a pipeline connects two metropolitan areas, refiners and wholesalers can ship more or less gasoline to each area when arbitrage opportunities exist.[9] Similarly, for geographically proximate markets, intermediate firms called ‘‘jobbers’’—who purchase gasoline at the rack and transport it to gasoline stations via truck—can purchase gasoline from the rack posting the lowest rack price and arbitrage differences in gasoline prices between the two metropolitan areas (including differences in transportation costs). For example, jobbers who supply stations in Austin, TX may purchase wholesale gasoline from local racks in Dallas or Austin, depending on the relative prices. Thus, before regulation, if two neighboring racks were carrying the same type of gasoline, we would expect the price at one rack to follow prices at the other rack very closely. However, if a regulation impacts one metropolitan area and not the other, preventing arbitrage by dividing the contiguous market, we may see a significant price difference between the cities. In addition, if regulation induces suppliers to exit the local market, we may see an impact on price both through the reduction in the number of competitors within a market and through a reduction in arbitrage opportunities across contiguous markets. This is the marginal impact of regulation that we wish to estimate.

[9] Refiners can ship gasoline via pipeline for wholesale sale. In addition, in many markets there are wholesale suppliers who are not refiners. Instead, these agents act as arbitragers, purchasing gasoline from one market and shipping it to another. These firms may own terminals or pipelines, may be of varying sizes, and operate locally, regionally, or nationally. Williams Energy and Trans Montagna are two examples of gasoline arbitrage firms.

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Table 2
Treatment and control cities

PADD	Treatment city[a]	Control cities	Type	Regulation date
5	Albany, NY	Utica, NY	RFG	From January 1, 1995
1	Baltimore, MD	Harrisburg, PA, Philadelphia, PA	RFG	From January 1, 1995
1	Buffalo, NY	Rochester, NY	RVP	December 1994–January 1995
2	Chicago, IL	Rockford, IL	RFG	From January 1, 1995
2	Covington, KY	Cincinnati, OH, Dayton, OH, Lebanon, OH	RFG	From January 1, 1995
3	Dallas, TX	Austin, TX, Oklahoma City, OK, Waco, TX	RFG	From January 1, 1995
2	Detroit, MI	Flint, MI, Lansing, MI, Toledo, OH	RVP	June–September 1996/1997
3	El Paso, TX	Odessa, TX, Tucson, AZ	RVP	May–September 1995/1996
1	Fairfax, VA	Harrisburg, PA, Roanoke, VA	RFG	From March 1, 1995
3	Fort Worth, TX	Austin, TX, Oklahoma City, OK, Waco, TX	RFG	From January 1, 1995
2	Hammond, IN	Indianapolis, IN	RFG	From January 1, 1995
3	Houston, TX	Austin, TX, San Antonio, TX, Waco, TX	RFG	From December 1, 1994
2	Kansas City, KS	Topeka, KS	RVP	June–September 1997/1998
5	Los Angeles, CA	Las Vegas, NV, San Francisco, CA, San Jose, CA	RFG	From December 1, 1994
2	Louisville, KY	Cincinnati, OH, Lexington, VA	RFG	From January 1, 1995
1/2[b]	Midland, PA	Youngstown, PA	RVP	May–September 1998/1999
2	Milwaukee, WI	Madison, WI	RFG	From January 1, 1995
1	Newark, NJ	Macungie, PA, Scranton, OH	RVP	From March 1, 1995
1	Newburgh, NY	Albany, NY	RFG	From January 1, 1995
1	Norfolk, VA	Raleigh, NC, Roanoke, VA	RFG	From January 1, 1995
2	Olathe, KS	Topeka, KS	RVP	June–September 97/98
1	Paulsboro, NJ	Sinking Springs, PA	RFG	From December 1, 1995
1	Philadelphia, PA	Harrisburg, PA, Macungie, PA	RFG	From March 1, 1995
5	Phoenix, AZ	Tucson, AZ	RVP	May–September 95/96
1/2[b]	Pittsburgh, PA	Youngstown, PA	RVP	May–September 98/99
1	Portland, ME	Bangor, ME	RFG	From January 1, 1995
1	Richmond, VA	Raleigh, NC, Roanoke, VA	RFG	From January 1, 1995
2	St. Louis, MO	Decatur, IL, Indianapolis, MO	RFG	From June 1, 1999
2	Wood River, IL	Decatur, IL, St. Louis, MO	RVP	June–September 1995/1996

[a]At least one supplier in the treatment city posted prices for conventional gasoline after the regulation date.
[b]Midland and Pittsburg are located in PADD 1 and Youngstown is located in PADD 2.

4.2. Analysis of wholesale price effects

For each regulated city near a regulatory border, we create control groups of local, unregulated markets (i.e. we selected regulated cities located near unregulated cities). Table 2 lists the treatment and control pairs. We use wholesale gasoline price data from Oil Price Information Service for each of these distribution racks. The data are weekly prices by supplier of unbranded gasoline by distribution rack from 1994 to 1998. Since RFG was implemented in January of 1995, the data contains a year of wholesale gasoline prices before RFG requirements were in place. Since RVP comes into effect only during summer months in the regulated areas in our data set (see Table 1), we have within-city variation in RVP requirements each year for the entire sample of RVP regulated regions. We use the weekly prices to construct the average price for unbranded gasoline in city i at time t. The average is a straight average. Unfortunately, information on the volume sold at each price by each supplier does not exist (in any data set), so we cannot create volume-weighted price indexes or concentration measures using volumes as market shares. We use the number of suppliers posting wholesale prices as a measure of the number of suppliers supplying the market at each rack in each week.[10] This measure does provide richer local-market-level variation in regulation, price, and number of suppliers. This allows us to

[10]There may be suppliers who are present in a market who do not post unbranded rack prices. They may be selling gasoline through private contracts, for example. OPIS only collects data for refiners posting rack prices. In most metropolitan areas, rack volume is relatively high and this data issue is likely inconsequential. In West Coast markets, in particular California, rack volume is very low and direct delivery and refiner exchange volumes are likely much higher. Therefore, the number of suppliers in some West Coast cities may not accurately reflect the number of firms supplying unbranded gasoline to the market.

Table 3
Number of gasoline suppliers in treatment cities before and after regulation[a]

Treatment city	Before regulation	After regulation[b]	
	Conventional	Conventional	Regulated
Albany, NY	6.96	7.69	1.14
Baltimore, MD	9.62	5.50	9.56
Buffalo, NY	1.19	–	1.00
Chicago, IL	8.79	3.78	6.49
Covington, KY	4.00	3.07	3.18
Dallas, TX	12.37	5.10	7.14
Detroit, MI	9.99	–	8.69
El Paso, TX	4.19	–	4.13
Fairfax, VA	7.15	3.43	11.37
Fort Worth, TX	5.00	–	3.13
Hammond, IN	6.34	6.43	5.73
Houston, TX	6.00	1.49	8.87
Kansas City, KS	10.99	11.14	6.66
Los Angeles, CA	5.88	–	3.78
Louisville, KY	9.96	7.28	5.33
Midland, PA	2.27	1.00	1.68
Milwaukee, WI	7.96	4.93	4.69
Newark, NJ	7.22	–	6.54
Newburgh, NY	2.98	2.83	3.05
Norfolk, VA	15.39	8.60	12.88
Olathe, KS	5.77	2.94	3.12
Paulsboro, NJ	2.71	–	3.06
Philadelphia, PA	2.28	–	3.93
Phoenix, AZ	4.98	–	4.73
Pittsburgh, PA	9.47	2.95	6.74
Portland, ME	5.98	3.89	5.33
Richmond, VA	15.37	13.02	12.88
St. Louis, MO	6.39	5.30	5.03
Wood River, IL	4.79	3.32	2.99

[a]Supplier counts were calculated as the average number of suppliers appearing consistently in the data set before and after regulation. Suppliers appearing fewer than 12 times in a calendar year were omitted from this count, but remain in the full data set used in further analyses.
[b]Some gasoline suppliers sold both conventional and regulated fuels after the regulatory change.

take treatment and control approach, which would be less tractable using state-level aggregated annual data since regulations vary within state and within year. However, because the number of suppliers selling gasoline at a given rack during a given week may be endogenous to weekly changes in the local market price, we create instruments for the number of suppliers and present instrumental variables results for some regression specifications. We discuss the instruments in more detail below.

Table 3 reports the total number of "consistent" gasoline suppliers appearing in an average day in the treatment cities before and after regulation. Suppliers appearing less than 12 times in a calendar year were omitted from this count, but remain in the full data set used in further analyses. Since some gasoline suppliers sold both conventional and regulated gasoline simultaneously after the regulatory change, the total number of suppliers in a market may not be the sum of the number of conventional and regulated suppliers in Table 3.

We model the average unbranded price in each regulated city as a function of the average price in neighboring unregulated cities. If arbitrage can occur, these two prices should track each other closely and we should be able to control for all cost factors affecting local regional prices using the wholesale price of gasoline in neighboring cities.[11] Once regulation occurs, price in regulated city may deviate from this historic relationship since arbitrage is no longer possible (Table 4).

[11]In fact, by estimating Eq. (1) using only pre-regulation data, we fail to reject arbitrage: the law of one price appears to be holding.

Table 4
Variable definitions and summary statistics

Variable	Notes	1994–1996		1994–1998	
		Mean	Std. dev.	Mean	Std. dev.
Mean price in the "treatment" cities	Cents/gal	56.164	6.206	58.348	9.649
Mean price in the "control" cities	Cents/gal	55.588	5.905	57.485	9.407
RFG dummy	= 1 if using treatment city price for RFG gasoline, = 0 otherwise	0.238	0.426	0.329	0.470
RFG ethanol blended dummy	= 1 if ethanol required, = 0 otherwise	0.023	0.149	0.035	0.183
RVP dummy	= 1 if using treatment city price for RVP gasoline, = 0 otherwise	0.025	0.156	0.042	0.202
Number of suppliers for "Treatment" cities	Daily count of unique suppliers by distribution rack	6.942	3.652	6.409	3.514

Table 5
Regression results for the price effects of gasoline content regulation

	1	2	3	4	5	6
Dependent variable: average gasoline price in treatment city (in cents/gal)						
Average price in control city	**0.952** (0.009)	**0.953** (0.009)	**0.970** (0.004)	**0.970** (0.004)	**0.942** (0.007)	**0.977** (0.002)
RFG dummy	**3.544** (0.198)	**3.512** (0.209)	**2.305** (0.143)	**2.188** (0.151)	**2.950** (0.095)	**2.744** (0.069)
RFG ethanol blended dummy	**6.777** (0.590)	**7.523** (0.649)	**7.493** (0.482)	**8.689** (0.553)	**3.995** (0.281)	**4.104** (0.214)
RVP dummy	**1.079** (0.288)	**1.056** (0.291)	**1.230** (0.133)	**1.237** (0.133)	**1.550** (0.193)	**1.107** (0.095)
Number of suppliers treatment city (# Sup)	**−0.146** (0.073)	−0.116 (0.076)	0.033 (0.048)	0.051 (0.049)	**−0.480** (0.073)	**−0.436** (0.043)
# Sup squared	0.006 (0.005)	0.004 (0.005)	−0.004 (0.003)	−0.005 (0.003)	**0.022** (0.004)	**0.020** (0.003)
Constant	**2.910** (0.610)	**2.776** (0.086)	**1.654** (0.400)	**1.614** (0.048)	**5.074** (0.450)	**2.950** (0.203)
Auto-correlation (ρ)	0.858	0.858	0.858	0.858	0.338	0.374
p-Value of Hausman test for random effects	0.012		0.003			
Instruments used for # sup?	No	No	No	No	Yes	Yes
Random effects?	Yes	No	Yes	No	No	No
Fixed effects?	No	Yes	No	Yes	Yes	Yes
Number of observations	2866	2838	7215	7186	2866	7215
Years of data used	1994–1995	1994–1995	1994–1998	1994–1998	1994–1995	1994–1998

Note: Values in parentheses are standard errors. Bold represents statistical significance at the 5 percent level.

We estimate regressions of the following form:

$$\bar{P}_{it} = \alpha_i + \beta\bar{P}_{ct} + \gamma\,\mathrm{RFG}_{it} + \delta\,\mathrm{RVP}_{it} + \theta N_{it} + \varepsilon_{it}. \quad (1)$$

The dependent variable is the average price in treatment city i at time t for unbranded gasoline. This price series changes discretely from conventional fuel to regulated fuel for these cities when the regulation begins. The right-hand side variables include a city-specific component (fixed or random effect, depending on the specification), the average price for conventional fuels at the matched control cities, dummy variables for the type of fuel content regulation, and the number of suppliers posting prices in treatment city i at time t. The average price of conventional fuel in the neighboring unregulated markets controls for variable cost factors affecting gasoline at the local regional level. We allow for autocorrelation in each of our regression models and the results presented in Table 5 are robust to the specification of

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autocorrelation structure.[12] Moreover, for all regressions presented in Table 5, we reject the hypothesis of no autocorrelation at the one percent level using Durbin Watson statistics based on estimated autocorrelation coefficients.

Table 5 presents the reduced-form coefficients for various specifications. Columns 1 and 2 use data for 1 year before and 1 year after RFG is introduced into the market. This is the cleanest time period to examine as it captures the immediate change in prices around the introduction of the regulation. Columns 1 and 2 present the random- and fixed-effect specifications, respectively. The results are similar in both the fixed- and random-effect specifications; however, a Hausman test rejects the random-effect specifications in favor of city-level fixed effects.[13] The estimated coefficient on average price in the control city is near 1, as expected. All coefficients on the environmental regulation are positive and significant. We break RFG into two indicators: one for RFG and one for RFG in Midwestern cities with additional Ethanol (and hence RVP) requirements. Cities with RFG regulations experience average prices that are, on average, higher by 3.5 cents/gal than the control group. In addition, areas with ethanol-blended RFG gasoline requirements face another 6.8 cents/gal higher average price. RVP regulation requirements lead to a much smaller estimated average price increase of approximately 1 cents/gal.[14] Estimated coefficients on the number of suppliers and its square have the expected signs. However, they are only significant in the random-effect specifications and the estimated effect is small in magnitude. In the specification, a decrease in the number of suppliers from 4 to 3 results in a 0.2-cent increase in price. The fact that coefficients become insignificant in the fixed-effects specification is not surprising given such a short time period and the fact that the number of suppliers in a city is often relatively constant over short periods.

Columns 3 and 4 extend the time series to 1998. The longer time period allows us to examine if there are persistent effects of regulation on gasoline prices; however, the longer time period may introduce potentially confounding trends or changes to market structure for which we cannot control. Columns 3 and 4 present the random- and fixed-effect specifications, respectively. Once again, we can reject the random-effects specification. Focusing on the fixed effects results in Column 4, note that the coefficients on regulation are again positive and significant. Comparing the fixed-effect specifications of the shorter (Column 2) and longer (Column 4) data set, the coefficient on the RFG regulation dummy decreases significantly and the coefficient on ethanol RFG increases, though not significantly. Furthermore, the coefficient on the number of suppliers changes sign and becomes positive (although not significant) with the longer time series. This suggests that endogeneity in the number of suppliers in each market may be a significant concern. If more suppliers enter the market in response to high prices, we would find a (biased) positive relationship between prices and the number of suppliers. We address this in the Columns 5 and 6 of Table 5 by instrumenting for the number of suppliers, N, and analyzing the instrumental variables estimates of the coefficients of interest in the fixed-effects reduced-form regressions using both the shorter (Column 5) and longer data set (Column 6).

Suppliers are made up of 2 types: consistent suppliers such as refiners and wholesalers who produce gasoline in the region and/or own and operate shipping and terminalling facilities, and arbitrage firms who buy and sell gasoline, purchasing it in low priced markets and reselling it in high price markets. Both of these types of firms are present in our measure of N, even though we expect arbitrage firms to enter the markets sporadically in response to arbitrage opportunities (high prices). We therefore instrument for N with the number of refiners (consistent suppliers) supplying the city, the Petroleum Administration for Defense Districts (PADD) level Hirschman Herfindahl Index (HHI) of refiner concentration, and the state-level percent of fuel consumption that is reformulated versus conventional fuel. The PADD level HHI was constructed from EIA annual

[12]We ran alternative specifications to those in Table 5 including Newey–West robust standard errors instead of estimating the autocorrelation coefficient in a first-order autoregressive error structure. The estimated parameters and their statistical significance are qualitatively similar.

[13]We do not report the coefficients for the city-specific fixed effects to conserve space, and for both the long and short data series, all are positive and statistically significant at a 1 percent level. In the short time period, the fixed effects for Covington, Dallas, El Paso and Hammond are particularly large, at 6–7 cents/gal. Using the longer time-series, Covington and Hammond dummies are large relative to the other cities with coefficients of 6–7 cents/gal. The dummy variables for Albany, Phoenix, and Portland have the smallest coefficients in both regressions of 0.5–3.5 cents/gal.

[14]We do not find a significant difference between the average RFG effect in summer months, when demand is relatively high, and the effect in other months.

refinery production data and changes mostly due to the refineries' exits and mergers over time.[15] The monthly consumption information is also taken from the EIA's website. Both variables are significant determinants of the number of suppliers, with first stage coefficients in the expected directions. An increase in the HHI at the PADD level reduces the number of suppliers at a rack, while the fraction of gasoline sold as regulated fuel increases the number of suppliers at the rack. We instrument for N and N^2 using these instruments and their squares. Overall, the instruments perform well. The first stage R^2 value is large and the F-test on the instrumental variable joint significance is large with a p-value of zero. Hence, we reject the null hypothesis that the instrumental variables jointly have no significance in explaining the number of suppliers.

The instrumental variables estimates are reported in the Columns 5 and 6 of Table 5. Column 5 reports coefficients using the year before and after RFG regulation, while Column 6 reports estimates from the longer time series. Both specifications include city-level fixed effects. Note that in both specifications, instrumenting for N decreases the effect of both RFG and RFG with the ethanol requirement. It also increases the significance and magnitude of the effect of N on prices. The decrease in the estimated effect of RFG and RFG with ethanol on prices indicates that these two regulations were correlated with a decrease in N—the instrumental variables specification appears to separate the direct effect of regulation from the indirect effect of regulation through its impact on N. The coefficient on N now has the expected negative sign, even in the extended time series, and it is statistically significant in both specifications. In addition, the coefficient on N^2 is also statistically significant and positive. To get a sense of the marginal effect of a change in N on the average price in a regulated city, consider one example of a city that experienced a drop in N in Table 3. The number of suppliers in Milwaukee, WI decreased from 7.96 to 4.69 with regulation. The estimated price increase resulting from that decrease in N is 1.57 cents/gal $(-0.436*(5-8)+2*0.020*(8+5)/2)$.

4.3. Specification checks for wholesale price effects

The regressions in Table 5 used treatment and control groups defined by geographic proximity and differential changes in the gasoline content regulation requirements. Matching by geography allows us to capture the marginal impact of the regulation—the impact of dividing once-continuous neighboring markets on the price of gasoline in the regulated market. As a specification check, we present an alternative comparison for RFG-regulated markets. RFG regulation was implemented in the 9 dirtiest cities out of cities with a 1980 population of 250,000 or more, according to Section 212k of the CAAA. It may be the case that gasoline markets in other large metropolitan areas, contiguous or not, may better control for trends in demand that could affect equilibrium gasoline prices in regulated metropolitan areas. Therefore, we estimate a probit of RFG regulation for metropolitan areas with populations greater than 250,000. As explanatory variables, we include baseline factors that affect pollution trends (such as baseline air pollution measures from the EPA and summer and winter temperatures), and baseline factors that affect demand (such as income, population density, new vehicle purchases and average commute times obtained from the US census and Simmons Market Research, Applied Geographic Solutions), and regional supply dummies (defined by the PADDs). We then estimate the probability of being regulated for RFG (either required or through opt-in), as a function of these pollution and demand variables. We use the fitted values of the probability of regulation from the probit analysis (the propensity scores) to re-weight the regression sample, effectively creating a smooth version of a match on propensity score [10,1,11,9]. Let the propensity score, S, be the probability that a metropolitan area is regulated with RFG as a function of baseline characteristics. We re-weight observations in the non-regulated sample by $S/(1-S)$. This balances the distribution of baseline characteristics across the regulated and unregulated markets. Intuitively, this technique up-weights data from cities that were not regulated, but had a high probability of regulation based on baseline observable data.

[15] We use yearly measures of refinery concentration, aggregated across all fuel types, at the PADD level as instruments for the number of weekly suppliers posting prices at each distribution rack (consisting of both refineries and arbitragers). In so doing, we separate the variation in the local number of suppliers as explained by the concentration of refineries, by year and region, from weekly changes in local suppliers who may enter and exit local markets on a weekly basis in response to local demand or supply shocks. Annual state-level concentration measures, for a given fuel type, may be endogenous to changes in state averaged wholesale prices [2]. The concern is that local firms may lobby the federal government to influence the area covered by regulated fuels. In contrast, our instrument is defined across all fuel types and not likely faces the same endogeneity concerns.

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Table 6
Propensity score matched effect of RFG regulation on wholesale gasoline prices

	1	2
Dependent variable: average gasoline price in each city (in cents/gal)		
RFG dummy	**3.050**	**3.376**
	(0.257)	(0.224)
Number of suppliers treatment city (# Sup)	0.055	**−1.221**
	(0.214)	(0.193)
# Sup squared	−0.002	**0.057**
	(0.014)	(0.012)
Crude oil price	**1.139**	**1.195**
	(0.031)	(0.008)
Constant	**7.342**	**11.393**
	(1.693)	(0.936)
Instruments used for # Sup?	Yes	Yes
Random effects?	No	No
Fixed effects?	Yes	Yes
Number of observations	1727	5888
Years of data used	1994–1995	1994–1998

Note: Values in parentheses are standard errors. Bold represents statistical significance at the 5 percent level.

Table 6 presents the results using this weighted specification. Here due to re-weighting, both the regulated and unregulated cities appear as observations in the data, and we control for cost factors using the price of crude oil (Cushings, OK) obtained from the EIA's website. As before, the regressions include city-fixed effects and instrument for N and N^2. The price of crude oil is a significant and positive determinant of gasoline prices as expected; however, the coefficient is slightly greater then one. The regulation coefficient for RFG is positive and significant—the average increase in wholesale price of gasoline due to RFG is approximately 3 cents/gal with shorter data set, and 3.4 cents when using the longer data set. The coefficients are similar in magnitude to those reported in Table 5. The coefficient on N differs somewhat in this specification from the coefficient in Table 5. In the shorter time period, the coefficients on N and N^2 are not significant, close to zero, and of opposite sign. In the longer time period (Column 2), where there is more within-city variation in N over time, the coefficient on N is significant with the expected signs. The overall effect of N is larger in this specification than in Table 5, Column 6. Using once again the example of Milwaukee, WI, the decrease in N from 7.96 to 4.69 would be associated with an expected increase in gasoline prices of 4.41 cents/gal $(-1.221*(5-8)+2*0.057*(8+5)/2)$. Overall, both matching specifications imply that RFG requirements lead to significant increases in average wholesale prices in the cities where they are implemented, controlling for changes in the number of suppliers, and that cities that experience decreases in the number of suppliers also experience increases in wholesale gasoline prices.

4.4. Empirical analysis of effects on wholesale price volatility

The results in Tables 5 and 6 provide empirical evidence that wholesale gasoline prices increased in markets requiring RFG, ethanol-blended RFG, and RVP. We can also use our data to examine if price volatility increased after regulation as well. Table 7 presents results from regressions using the quarterly standard deviation in wholesale gasoline prices as a dependent variable to measure price volatility in a market. The specification is similar to the specification in Table 5, except the dependent variable is the standard deviation of prices within a quarter, and we control for the standard deviation of prices in the control markets as well. We do not find evidence that price volatility increased with regulation in our treatment markets. The regression results show no statistically significant impact of any of the content regulation types on wholesale price volatility of the regulated cities for both the shorter (Column 1) and longer (Column 2) data set. For the shorter series, the coefficients on N and N^2 are jointly significant at the 4 percent level. The point estimates imply that volatility decreases at a decreasing rate as the number of suppliers in a metropolitan area increases. This is consistent with the idea that a decrease in the number of suppliers in a metropolitan area may increase

Table 7
Regression results for the effect of gasoline content regulation on price volatility

	1	2
Dependent variable: standard deviation of gasoline price in treatment city		
RFG dummy	−0.233	0.022
	(0.133)	(0.095)
RFG ethanol blended dummy	−0.235	−0.329
	(0.387)	(0.292)
RVP dummy	−0.225	−0.327
	(0.291)	(0.167)
Number of suppliers treatment city (# Sup)	−0.171	−0.103
	(0.103)	(0.060)
# Sup squared	**0.014**	**0.007**
	(0.006)	(0.004)
Standard deviation of gasoline price in control city	**0.868**	**0.900**
	(0.035)	(0.020)
Constant	0.721	0.473
	(0.431)	(0.242)
Auto-correlation (ρ)	0.389	0.451
Number of observations	222	555
Years of data used	1994–1995	1994–1998
Fixed effects	Yes	Yes
Instruments used for # Sup?	Yes	Yes

Note: Values in parentheses are standard errors. Bold represents statistical significance at the 5 percent level.

the ability of firms to raise prices in periods of relatively short supply. In regressions using the longer data series, the coefficients on N and N^2 are jointly significant only at the 14 percent level. However, the signs of the coefficients still imply that an increase in the number of suppliers would decrease volatility at a decreasing rate.

4.5. Investigating the effects of geographic isolation

The results in Table 5 indicate that regulation leads to a rise in relative wholesale prices. However, it is not clear exactly 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 geographic isolation. If the increase in prices were caused by an increase in marginal production costs, then we may expect the estimated price effect to be uniform across regulated markets given a regulation standard. If instead all or part of the price increase were due to geographic market segmentation, then we might expect heterogeneous price effects of regulation across markets and 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 simply due to a difference in marginal cost, we model a reduced-form specification that interacts regulation dummies and treatment city-fixed effects. Table 8 reports the effect of regulation in each metropolitan area. Column 1 presents results for the shorter time-series, and Column 2 presents results for the longer time-series. Both specifications instrument for N and include city-specific fixed effects. These specifications are similar to those presented in Table 5, Columns 5 and 6. However, instead of including a pooled estimate for RFG and RVP, Table 8 presents separate coefficients for regulation in each city (RFG and RVP interacted with city dummies). The point estimates for the price effect of RVP vary by 2–3 cents/gal. For example, in Column 2 the largest effect of RVP is in St. Louis, MO (2.106 cents/gal) and the smallest effect is in Pittsburgh, PA (−1.245 cents/gal). The price effect of RFG varies greatly across cities as well. The estimates are positive in most cases and statistically significant in many of the markets. In Column 2, the estimates for RFG range from a negative and significant 1.16 cents/gal in Newark to a positive and significant 6.87 cents/gal in Chicago. The results in the shorter time period data set (Column 1) are very similar. The large 8-cent range of price effects suggests that marginal production costs alone may not explain the average price effect of gasoline content regulation, even controlling for changes in N.

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Table 8
City specific price effects of gasoline content regulation

		1		2	
Dependent variable: average gasoline price in treatment city (in cents/gal)					
Average price in control city		**0.960**	(0.006)	**0.979**	(0.002)
Number of suppliers treatment city (# Sup)		**−1.001**	(0.083)	**−0.473**	(0.045)
# Sup squared		**0.059**	(0.006)	**0.023**	(0.003)
RVP interacted with	El Paso	**2.472**	(0.412)	**1.312**	(0.223)
	Kansas City	**1.759**	(0.439)	**1.223**	(0.240)
	Midland			**−0.993**	(0.412)
	Olathe	**1.046**	(0.421)	**0.878**	(0.230)
	Pittsburgh			**−1.245**	(0.393)
	St. Louis	**1.215**	(0.420)	**2.106**	(0.223)
	Wood River	0.321	(0.428)	**1.154**	(0.228)
RFG interacted with	Baltimore	**1.532**	(0.333)	**2.436**	(0.264)
	Buffalo	**3.380**	(0.586)	**3.032**	(0.554)
	Chicago	**7.115**	(0.338)	**6.873**	(0.266)
	Covington	**5.595**	(0.332)	**5.840**	(0.264)
	Dallas	**4.263**	(0.379)	**2.157**	(0.291)
	Fairfax	**1.687**	(0.357)	**1.901**	(0.256)
	Fort Worth	**2.313**	(0.521)	0.748	(0.433)
	Hammond	**6.899**	(0.336)	**7.337**	(0.263)
	Houston	**4.813**	(0.341)	**3.337**	(0.268)
	Los Angeles	**1.693**	(0.387)	**1.639**	(0.376)
	Louisville	**6.169**	(0.347)	**5.313**	(0.276)
	Milwaukee	**6.384**	(0.350)	**6.818**	(0.264)
	Newark	**−1.361**	(0.353)	**−1.158**	(0.204)
	Newburgh	**2.421**	(0.331)	**3.068**	(0.261)
	Norfolk	**4.519**	(0.364)	**3.393**	(0.288)
	Paulsboro	**1.091**	(0.335)	**1.461**	(0.262)
	Philadelphia	−0.019	(0.335)	**0.816**	(0.243)
	Phoenix			**5.275**	(0.273)
	Portland	**3.053**	(0.337)	**4.504**	(0.264)
	Richmond	**5.407**	(0.455)	**3.343**	(0.282)
Constant		**5.350**	(0.430)	**2.872**	(0.197)
AR (1) autocorrelation ρ		0.341		0.328	
Instruments used for # sup?		Yes		Yes	
Fixed effects?		Yes		Yes	
Number of observations		2866		7215	
Years of data used		1994–1995		1994–1998	

Note: Values in parentheses are standard errors. Bold represents statistical significance at the 5 percent level.

In Table 9, we present results 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 therefore sells conventional gasoline, then that city could potentially trade gasoline supply with any other city in the United States before the regulation. If a city is required to sell only RFG then it can only trade with other cities who sell RFG.[16] When gasoline content regulation is introduced, it may geographically segments markets in two ways. It first decreases the total number of supply markets for

[16]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.

Table 9
Reduced form relationship between geographic segmentation and wholesale prices

	1	2
Dependent variable: average wholesale gasoline price in treatment city		
Proximity measure	**−7.884** (0.991)	**−3.436** (0.667)
Potential partner count measure	**−0.060** (0.027)	0.004 (0.023)
RFG dummy	−17.403 (8.108)	2.867 (6.963)
RFG ethanol blended dummy	**3.266** (0.290)	**3.768** (0.221)
RVP dummy	−18.460 (7.823)	0.977 (6.716)
Number of suppliers treatment city (# sup)	**−0.470** (0.072)	**−0.421** (0.043)
# Sup squared	**0.023** (0.004)	**0.020** (0.003)
Average gasoline price in control city	**0.944** (0.006)	**0.977** (0.002)
Constant	**28.132** (9.059)	3.046 (7.772)
Auto-correlation (ρ)	0.513	0.429
Number of observations	2866	7215
Years of data used	1994–1995	1994–1998
Fixed effects	Yes	Yes
Instruments used for # Sup?	Yes	Yes

Note: Values in parentheses are standard errors. Bold represents statistical significance at the 5 percent level.
Proximity measure = sum of the inverses of the distances between treatment city and cities with similar content requirements. Potential partner count = total number of cities with content requirements similar to the treatment city.

each type of fuel, and then it may increase the geographic distance between markets supplying the same type of fuel. These two variables, Potential Partner Count and Proximity Measure, capture the 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 [8].

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, the proximity measure decreases and we expect price effects of regulation to increase. Similarly, we expect that if the number of trading partners decreases, then the price effect should increase.

For example, the weighted distance measure for Louisville KY is 0.446 before beginning the RFG program and 0.048 after the regulation was enacted, since potential trading partners now located farther away. In comparison, Newark NJ is located in a densely populated region of the US and had pre- and post-regulation proximity measures of 0.487 and 0.393, respectively.

Table 9 has two columns corresponding to the short time period (1994–1995) and the extended time-series (1994–1998), respectively. All regressions include fixed effects and instruments for the number of suppliers. In both specifications, the coefficient on the proximity variable is negative and significant. In Column 1, the coefficient on the potential partner variable is negative and significant; however, the coefficient is not significant in Column 2 using the longer time period. These coefficients suggest that proximity is an important source of variation in the impact of RFG on prices. For example, RFG regulation in Louisville changes the city's proximity variable by −0.39. Using the estimates in Column 2, this would result in a 3.14 cents increase in price—about half of the estimated RFG-related city-specific effect for Louisville reported in Table 8. Alternatively, because it is located in a region where many other markets also adopted RFG, Newark's proximity measure changes by only 0.09 with the regulation. This represents an estimated price effect of 0.7 cents/gal for Newark. The results in Table 9 lend support to the hypothesis that market segmentation—caused by the discontinuous design of gasoline content regulation—may have led to price increases that are not attributable to increased marginal costs of production.

Note that the estimates in Table 9 provide a basis for comparing the relative price effects of market segmentation versus the decreased number of suppliers. Consider an example using data from Dallas TX, where RFG regulation resulted in a proximity measure change of 0.41. Using the estimates from Table 9 (Column 2), the price effect of the proximity measure change is 1.41. Using the coefficients on number of suppliers and its square in Table 9 (Column 2), we see that if the number of suppliers in a city decreased from 9 to 2, the price change would also be 1.41 ($(1.41 = -0.42 + 2*0.02(9+2/2))*-7$). These reduced-form estimates give some suggestive evidence for the relative importance of market segmentation and increased seller concentration. If regulatory expansion leads to increased supplier entry into regulated fuel production, 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 regulatory expansion causes increased exit by marginal suppliers due to high fixed entry costs, then gasoline content regulation reform could lead to increased price distortions, depending on the trade off between gains from increased continuity and losses to competition through supplier exit.

5. Conclusions

This paper uses highly detailed supplier-specific weekly wholesale prices for unbranded gasoline at 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. Reduced-form evidence shows that prices in regulated metropolitan areas increased significantly relative to their unregulated counterparts. While the price effect of regulation is on average 3 cents/gal, the spot estimate for the price effect of content regulation varies across regulated cities by approximately 8 cents/gal.

Using the variation in the change in the number of competitors and the change in geographic isolation across the regulated 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 treatment and in nearby control cities do not absorb all the variation in the price effect of regulation across cities, but does have some effect in the expected direction. 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.

In terms of economic implications, these reduced-form estimates suggest that the secondary impact of the 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.

Similarly, the discussion of environmental federalism is complicated by the presence of firms exercising market power. The optimal scope and scale of environmental policy takes into consideration more than just the geographic differences in marginal damages and the "direct" marginal costs of abating pollution—environmental regulations may also impact firms' ability to exercise market power and their entry decisions. Our results suggest that spatially differentiated standards have the potential to segment markets that would be integrated under a uniform standard. Segmentation in turn may increase or enhance the ability of firms serving isolated markets to exercise market power. Thus, the devolution of decision-making authority under the CAAA to local regulators may not be socially desirable because it could lead to greater market segmentation and exercise of market power. However, measuring the overall welfare effects of gasoline content regulations would require information on the heterogeneity of marginal damages, as well as detailed models of consumer behavior in the retail gasoline markets and firm pricing (and entry) behavior in the refining, wholesale, and retail markets. For imperfectly competitive markets, answering the question of environmental federalism—what is the optimal scope of regulation?—requires extensive information. For this reason, our paper does not draw normative conclusions but offers instead one piece of evidence needed for such an analysis.

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