Spatial Incidence of National Policies with Fixed Infrastructure: An Application to the Ethanol Mandate

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Abstract

Using a quantile difference-in-differences econometric approach to analyze weekly gasoline price data for 200 cities from 2007 to 2014, we find evidence that the Renewable Fuel Standard (RFS) ethanol mandate differentially impacted gasoline prices across the U.S. Driven by the east coast- which receive roughly half of all ethanol shipments- cities farther from ethanol production centers paid significantly higher gasoline prices than cities close to ethanol production centers. We argue that the observed price differences are driven by transportation costs for ethanol which, unlike petroleum, cannot be shipped via pipeline. Our research design attributes our findings to positive ethanol RIN (renewable identification numbers) prices from the ethanol mandate binding after 2013.

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1 Introduction

Whenever policymakers pass a new regulation which either directly or indirectly creates a market, there are often both intended and unintended consequences. The unintended consequences of laws have received significant attention in the economics literature recently (Goulder et al. 2012, Bento et al. 2014). One class of unintended consequences due to new regulation that has received less attention occurs when new regulation creates new market frictions.

Most generally, market frictions are transaction costs. If a new regulation creates asymmetric transaction costs then new regulation can differentially affect newly regulated agents. Differential transaction costs can lead to a reallocation of welfare in which agents facing higher costs pay disproportionately more than agents with lower costs. In this paper we provide evidence that due to lack of a zero marginal cost of ethanol shipping and fixed infrastructure, the passage of the Renewable Fuel Standard (RFS) in 2007 in the United States is one example.

The RFS created a mandate that makes blenders of gasoline mix ethanol with gasoline blendstock such that total ethanol consumed in the U.S. in a given year exceeds some minimum level. Ethanol is an imperfect substitute for gasoline: by law it can be blended with gasoline until gasoline contains up to 10% ethanol. Thousands of blenders have long existed and are distributed widely throughout the U.S. serving to blend various additives to gasoline according to regional laws. The mandate acts as a tax for obligated parties that do not comply. This together with the concentration of ethanol production in the Midwest created a market for transportation of ethanol to demand centers across the U.S. (Hughes 2011). Pipelines provide the most cost-effective way to transport refined petroleum to and from landlocked parts of the U.S.; transportation of refined petroleum by more expensive rail and truck is generally used only for short distances (Borenstein and Kellogg 2014). Due to a lack of ethanol pipelines, though, ethanol must be shipped via rail and truck throughout the U.S. Relative to pipelines used for petroleum, shipping ethanol via these channels is more costly than shipping petroleum products due to higher transportation costs.[1]

[1]Though we do not study them here there is evidence that railroads exercise market power in the

To meet the RFS mandate, an obligated party can either purchase minimum required volume of ethanol for blending into gasoline or buy Renewable Identification Numbers (RINs) in the RIN marketplace.[2] The RFS was likely not binding for most of the initial period of the mandate; more ethanol was produced than mandated. Before 2013, for example, the price of corn ethanol RINs had been close to zero. In 2013 corn ethanol based RIN prices started to increase, reaching about \$1.00 per gallon in March 2013. Among the reasons cited for the run-up in RIN prices for corn ethanol are rising RFS-mandated volumes.[3]

In this paper, we estimate the impact of how a binding ethanol mandate differentially impacted gasoline prices across the United States focusing on distance from the Midwestern U.S., where much of the ethanol in the U.S. is produced.[4] To do so, we constructed a comprehensive weekly panel dataset of rack gasoline prices in 200 U.S. cities. These rack prices are recorded post-ethanol blending and reflect the price paid by retailers. We combine that data with weekly oil, diesel, and ethanol price data. Importantly, we observe significant heterogeneity in distance between ethanol refineries in the Midwest and the cities in our dataset.

We sketch a simple theoretical framework which describes the decision blenders face on whether to blend ethanol or purchase RINs to meet a binding ethanol mandate. There are three intuitive results of that model which give empirical predictions and motivate our empirical approach. First, blending is more likely when ethanol is relatively cheaper than gasoline blendstock. Second, increased ethanol shipping distance should increase

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transportation of ethanol by price discriminating based on environmental regulations at the route destinations (Hughes 2011). While we focus on the direct shipping aspect of transportation cost, we note that transportation costs can come in many forms. As a result, our study is complementary to this earlier work.

[2]Once ethanol is produced, a serial number is assigned to a batch of ethanol to identify the type of fuel and gallons of ethanol. Known as RINs, these unique numbers allow Environmental Protection Agency to monitor compliance with the RFS. RINs are separated after they are initially sold and can be traded in the open market. Obligated parties (refiners, blenders, and importers) fulfill the mandate requirement by mixing at least the minimum required volume of biofuel, or, alternatively, by purchasing enough RINs from the third parties. For a blender that purchases RINs to meet a mandate, RIN prices directly increase the cost of producing gasoline.

[3]Related to increasing RFS-mandated volumes were the E10 (10% ethanol and 90% gasoline) ethanol blend wall which created the need to blend ethanol with gasoline throughout the U.S. See http://www.eia.gov/todayinenergy/detail.cfm?id=11671. Last accessed: May 10, 2015.

[4]In addition, there is a debate whether positive ethanol RIN prices since 2013 contributed to rising gasoline prices. See http://ethanolrfa.org/page/-/rfa-association-site/studies/informa_gasoline_price_analysis.pdf?nocdn=1. Last accessed: May 10, 2015. We do not address the overall level effect of the ethanol mandate in this paper.

gasoline prices when blending is profitable. Third, the effect of ethanol shipping distance on gasoline prices should increase if diesel prices increase since truck, rail and barge all use diesel for fuel.

Our research design uses a quantile difference-in-differences estimator. The first difference is before and after the mandate binds in 2013. The second difference is a continuous measure of ethanol shipping distance as measured by a distance proxy we generate. We take January 2013 to be the start date of the binding mandate since RIN prices begin to rise significantly above zero at that date. The date is plausibly exogenous to the blenders since the mandated nationwide ethanol blending levels for 2013 and 2014 were set by the RFS law passed in 2007. We compare the effect of distance on gasoline pre- and post-January 2013 using our continuous distance proxies, similar in spirit to Kiel and McClain (1995). Within this difference-in-differences design and consistent with the theoretical model, we then allow the marginal impact of ethanol shipping distance on gasoline prices to vary with the diesel fuel price. We include city fixed effects and month-by-year fixed effects. City fixed effects are important since there could be correlations between our distance measure and pre-existing region and city level laws which mandate different additives be added to a city's gasoline. Month-by-year fixed effects narrow our identification window to differences across cities within a month. Because we use gasoline, ethanol and diesel prices, all of which vary with market conditions, it is important to have a research design which parses out changing market conditions from a changing spatial composition of prices attributable to the mandate. We argue in the empirical section the difference-in-differences design does just that.

There are two reasons for using a quantile regression rather than OLS technique. First, refiner profits (often proxied by the crack spread) vary with demand for gasoline. Ethanol can have a differential effect on gasoline prices as demand rises and falls through the refiner profits channel as ethanol reduces the market power of refiners during high demand periods (Knittel and Smith 2015). Second, recent work has shown that pass through rates of taxes in the gasoline market can vary systematically with gasoline prices (Marion and Muehlegger 2011). Given that we are studying a form of pass through, albeit at a different point in the supply chain, it is important to allow for a flexible relationship. Quantile techniques account for asymmetric effects throughout the distribution of gasoline prices explicitly, while OLS can only identify the mean effect.

We find that after the RFS became binding in 2013 and RIN prices started to increase, cities farther from ethanol production centers paid significantly higher gasoline prices relative to cities nearer to ethanol production centers. Consistent with this being attributable to ethanol shipping, the impact of distance on gasoline prices was largest when diesel prices were highest. For example, when gasoline prices were in the 50th percentile and the diesel fuel price was \$4.00/gallon, the point estimate for the price difference between a location that is 1,000 miles away from the ethanol production center in the Midwest was roughly 3 cents. The yearly cost of this market friction for a Florida household relative to an Iowa household is on the order of \$14.24 given observed ethanol, oil, diesel, and gasoline prices from January 2013 to July 2014. This amounts to a yearly wealth transfer on the order of \$197.97 million from Florida households far from the Midwest to, in all likelihood, trucking and railway companies who shipped ethanol. These qualitative results are robust to level and percent specifications and controlling for relative ethanol and oil/gasoline blendstock prices and other blending incentives.

Sample trimming shows that the results are largely driven by cities on the east coast of the U.S. When we exclude east coast cities the distance effect stay positive but costs are not increasing in the price of diesel as we would expect. This could be due simply to lack of variation in shipping distances from the Midwest to the Gulf PADD region and a paucity of data for west coast cities (roughly 6% of our data). This is consistent with where much ethanol is shipped: the top six east coast states received for 40% of all shipped ethanol in 2013. Subject to our identifying assumptions and driven primarily by east coast cities, we take our results as causal evidence that the binding RFS exacerbated the effect of market friction after 2013 which asymmetrically affected gasoline prices in the U.S.

Our results contribute to two different areas in the economics literature. First, there is a healthy debate in the literature about the effect of the ethanol mandate on gasoline prices.[5] These studies tend to use PADD (Petroleum Administration of Defense Districts) level data (Du and Hayes 2009, 2011, Knittel and Smith 2015). Knittel and Smith (2015)

[5]There is an additional question as to how substitutable ethanol and gasoline are for consumers (Anderson 2012). We are not able to address this question whatsoever. Although there is evidence that ethanol and gasoline are imperfect substitutes, as long as consumer preferences within a city are fixed over time our results are robust to this issue since we use city fixed effects in our econometric model.

makes the convincing claim that, overall, the ethanol mandate has had little to no effect on average gasoline prices ($\sim$ -10 cents). We do not claim to identify the total effect of the ethanol mandate on gasoline prices. Nor do we attempt to study the price behavior and pass through of RINs like other recent work (Knittel et al. 2015, Lade et al. 2015, Mason and Wilmot 2015). Rather our quantile difference-in-differences design allows us to address the incidence of the mandate across the U.S. at different levels of gasoline prices.[6] In that sense our findings are consistent with Knittel et al. (2015) in that we find evidence of pass through in this market.

Second, we contribute to the literature on how new regulations affect economic activity in unintended ways (Dinardo and Lemieux 2001, Goulder et al. 2012, Bento et al. 2015). We show that even in cases like RFS where there is a relatively well-functioning market for satisfying the regulation, there can still be unforeseen impacts created by a regulation which affect the incidence of the regulation.[7] In this case, the evidence suggests that the lack of transportation infrastructure in the ethanol industry affects the incidence of the policy. Policy makers should consider mitigating those effects when new regulations create new markets.[8] Generally, this falls into a framework of accounting for the incidence associated with creating a new market or regulatory framework (Bovenberg et al. 2008).

The rest of the paper is organized as follows. Section 2 discusses the economics of ethanol blending, and gives a background on ethanol mandate and transportation. We develop a theoretical model in section 3 which motivates our econometric specification. Section 4 describes data and the variables used in the paper. We present the econometric specification in section 5. In section 6 we discuss the estimation results. Then, we conduct robustness analysis of our empirical results in section 7. Section 8 summarizes and concludes.

[6]There is an additional question as to the non-market CO_2 effects of the ethanol mandate due to the interaction between land and fuel markets created by policy toward ethanol (Bento et al. 2015). We do not address this important policy question in this paper.

[7]This is distinct from regulatory rents more generally Rose (1985).

[8]There is a literature which discusses this in the context of spatial variation in the damages from pollution by source, for example (Fowlie and Muller 2013, Carson and LaRiviere 2014).

2 Ethanol Blending Economics and Background

This section provides a background for the ethanol industry in order to motivate the theoretical framework, research design and econometric model. We describe the industry and the law first generally. We then introduce how distance between ethanol refineries and demand centers can act as a market friction due to relatively large transportation costs of shipping ethanol.

Renewable Fuel Standard

Initially, used as an octane booster and to meet air quality requirements, ethanol is now an important input in transportation fuel.[9] The Energy Policy Act of 2005 required increased use of ethanol by introducing Renewable Fuel Standard. It mandated use of 4 billion gallons of ethanol in 2006 and further increasing by 0.7 billion gallons each year until 2012.

Energy Independence and Security Act (EISA) of 2007 supplanted the 2005 RFS and set mandated volumes through 2022 for total renewable fuels and various biofuel subcategories from non-corn sources, including advanced biofuels, cellulosic biofuels, and biomass-based diesel. While the updated RFS does not specify corn ethanol mandate explicitly, ethanol derived from corn starch counts toward the non-advanced biofuel portion of the total renewable fuel mandate. It mandates consumption of 9 billion gallons of renewable fuels in 2008, 20.5 billion gallons in 2015, and 36 billion gallons by 2022. The implied volume of corn ethanol mandate is set at 9 billion gallons in 2008 and is capped at 15 billion gallons in 2015 and thereafter. In this paper we focus on corn ethanol because it makes up the vast majority of the RFS mandate and the actual use of total renewable fuels in 2007-2014 sample period.

To encourage the use of renewable fuels, federal and state governments provide biofuel tax incentives in addition to the mandate which penalizes lack of compliance. Ethanol is added to gasoline blendstock by blenders. Thousands of blenders are widely distributed

[9] The Clean Air Act Amendments of 1990 lead local regulators to require use of oxygenated fuels in all areas with the worst vehicle emissions that exceed the federal carbon monoxide air quality standard. Blenders initially used MTBE (methyl-tertiary butyl ether) as an oxygen additive for gasoline so that fuel would burn cleaner. Due to concerns over groundwater contamination from MTBE, its use was banned by states, eventually being phased out by 2006 nationwide with ethanol primarily being used as a substitute.

throughout the U.S. They mix fuel additives with gasoline before it is sold at retail gasoline stations. Federal blenders tax credit, also known as volumetric ethanol excise tax credit (VEETC), provided a \$0.51 credit (\$0.45 since 2009) for every gallon of pure ethanol mixed with gasoline to blenders of ethanol until 2012 when VEETC was allowed to expire.

Figure 1 plots the production, consumption, and mandated levels of fuel ethanol in the U.S. The 2005 RFS was not binding as the actual production and consumption of ethanol was greater than the mandated quantity. This corresponds to a period when the use of MTBE (methyl-tertiary butyl ether), an oxygen additive, was banned nationwide, effectively leading to an increased demand for ethanol to be used as an oxygenate. Even when more stringent RFS of 2007 replaced the 2005 RFS, the fuel ethanol production and consumption levels have generally been above the new RFS-target levels until 2012-2013. Coupled with a RIN price of zero, we take this as evidence that RFS did not bind until 2013. Rather, ethanol blending behavior was the result of profit maximizing decisions of blenders given the VEETC and the relative prices of gasoline blendstock and ethanol.

The price of a RIN is a better indicator of a binding mandate and its value is determined by the difference between the supply and demand prices for ethanol. The RIN prices will be zero if the market equilibrium quantity exceeds the mandate and positive if the equilibrium quantity falls below the mandate. Before 2013 corn ethanol RIN prices did not significantly deviate from zero. The situation was much different starting in 2013 when RIN prices increased sharply and have since stayed positive (see Figure 2). The higher the RIN prices, the more costly it is to meet the RFS mandate because national quantity demanded for ethanol at market prices does not satisfy the mandate. Positive D4 (biodiesel) and D5 (advanced biofuel) RIN prices before 2013 reflect the rise in biodiesel blending margins and the fact that they can be used to fulfill advanced biofuel as well as total renewable fuel mandates while D6 corn ethanol RINs can be used to meet only the implied non-advanced category of the mandate.[10]

There are at least three reasons why RIN prices increased in 2013. First, gasoline consumption in the U.S. decreased relative to 2007 levels. When the RFS was enacted into law, the mandated volumes of renewable fuels were based on projected gasoline con-

[10]See http://farmdocdaily.illinois.edu/2013/07/rins-gone-wild.html.

sumption in the U.S. Actual gasoline consumption was 135.5 billion gallons in 2013, while in 2007 it was equal to 142.4 billion gallons.[11] Therefore ethanol blending did not satisfy the volume specific ethanol mandate. Second, as the RFS target levels increased each year while gasoline consumption declined, certain PADD (Petroleum Administration for Defense Districts) regions have reached ethanol saturation point. By law, retail E10 gasoline cannot contain more than 10% ethanol because it is corrosive to engine parts.[12] Because of E10 blend wall, increasing the use of ethanol may require purchasing RINs in the open market. Third, continued increase in ethanol consumption under the RFS coupled with lower gasoline consumption and E10 blend wall will eventually require investment in infrastructure that can handle higher ethanol blends. As a result, blending ethanol has become more expensive in the sense that blenders must still need to meet their renewable obligations under the RFS. In the past obligated parties had generally used more ethanol and banked the excess RINs when blending ethanol was profitable.[13] The RFS regulations allow the obligated parties to use banked RINs toward up to 20% of the their current year obligations. However, as the mandated volumes of fuel ethanol increased and more and more blenders reached E10 blend wall, they started drawing down their stocks of RINs (Johansson and Meyer 2014). This in turn and the anticipation of continued future decline in RIN inventories contributed to rising RIN prices in 2013.

Transportation of Ethanol

Petroleum Administration for Defense Districts (PADDs) divide 50 states into five districts that correspond roughly to areas within which transportation is relatively unconstrained (Borenstein and Kellogg 2014). PADD 1 correspond roughly to the locations on the East Coast, PADD 2 - Midwest, PADD 3 - Gulf Coast, PADD 4 - Rocky Mountain, and PADD

[11] U.S. Short Term Energy Outlook, November 12, 2014.

[12] Introduction of gasoline with greater than 10% ethanol content in the market has generally been slow due to lack of infrastructure. Even though in 2011 EPA allowed E15 (gasoline with up to 15% ethanol content) for use in light-duty motor vehicle models of 2001 and later, it is not widely available and is mainly sold in some of the Midwestern states. Similarly, the penetration of flex-fuel vehicles capable of using E85 (gasoline with up to 85% ethanol content) has been lower than expected. According to the Energy Information Agency (EIA) latest estimates, the consumption of E85 fuels was equivalent to 137.2 million gasoline gallon equivalent for 2011, which is only 1% of total ethanol consumed in the U.S. in 2011. See http://www.eia.gov/renewable/afv/index.cfm. Last accessed: May 10, 2015.

[13] Positive RIN prices might also be influenced by speculation although we are not aware of strong evidence speculation led to positive RIN prices.

5 - West Coast (see Figure 3). The bulk of crude oil and petroleum products movements within and between PADDs, especially among PADD 1, 2, and 3, occur through pipelines.

A distinguishing feature of corn ethanol relative to gasoline is that ethanol must be shipped via barge, rail or truck whereas gasoline can be shipped via pipeline. With respect to the ethanol mandate, distance between ethanol refineries and blending terminals could therefore act as a market friction due to lack of pipeline infrastructure in the ethanol industry. Spatial variation in infrastructure development and ethanol plant location could have a significant effect on ethanol shipping costs, therefore leading to price differentials across locations (Engel and Rogers 1996, Das et al. 2010).

Ethanol production is concentrated mainly in the Midwest, closer to corn growing counties in the Corn Belt. This is not surprising given that corn is the main feedstock in corn ethanol and hauling corn is more expensive. Nevertheless, ethanol is shipped throughout the U.S. Figure 4 shows the distribution of corn production by county, ethanol plants and gasoline blending terminals in the United States in 2011.[14] Blending terminals are distributed across the U.S. closer to demand centers. Consequently, despite the uniform federal RFS mandates, there is a geographical variation in how quickly ethanol penetrated different markets. Figure 5 shows the state-by-state variation in ethanol penetration for 2000-2010. Before the RFS was made into law, ethanol was the main oxygenate additive in finished gasoline in the Midwest (panel i). However, when the use of MTBE was phased out nationwide by 2006, ethanol emerged as a primary fuel oxygenate component in other states as well (panel ii). With the more stringent 2007 RFS, ethanol usage increased throughout the U.S., although for the first few years most of the additional ethanol had been absorbed in the Midwest (panel iii). This is expected since most ethanol refineries are located in the Corn Belt. However, as the RFS mandate requires greater ethanol consumption over time, additional ethanol has to be absorbed elsewhere, specifically East and West Coasts where the gasoline consumption is much higher than the other regions in the U.S. (panel iv). For example, ethanol blend share in PADD 1 and PADD 2 regions have been around 10% since 2009 (see Figure 6), which likely meant that additional ethanol

[14]Ethanol refinery plant locations are taken from the Renewable Fuels Association website, corn data - from the U.S. Department of Agriculture 2009 yields data, and active fuel terminal locations - from the Internal Revenue Service.

had to be shipped to other PADD regions.

Ethanol transportation costs per gallon are larger than that for refined petroleum (Morrow et al. 2006). Ethanol produced in the Midwest is transported via barges (5%), trucks (29%), and rail (66%) to wholesale terminals near population centers (USDOE 2010). Refined petroleum is shipped at close to zero costs due to pipeline infrastructure. While barges are the cost effective way to transport ethanol, ethanol is shipped by more expensive means, mainly by rail for longer distances and by trucks for shorter distances. Shipping ethanol by pipelines is virtually nonexistent. A 2010 study by the U.S. Department of Energy found construction of separate ethanol pipelines from the Midwest to the East Coast to be economically not viable at current ethanol consumption projections.[15] Furthermore, existing petroleum pipelines used to transport petroleum products cannot be used in shipping ethanol because the water found in low level pipelines causes ethanol to separate from gasoline and mix with water. Therefore, unlike some other petroleum additives, ethanol cannot be mixed into gasoline at refineries to be shipped via existing pipelines.

When transported by rail, ethanol is mainly transported by each of the seven Class I railroads (BNSF, Canadian National, Canadian Pacific, CSX, Kansas City Southern, Norfolk Southern, and Union Pacific) and only 15 to 20% of ethanol rail movements originate in non Class I railroads (AAR 2015). In 2013 railroads carried a little more than 300,000 carloads of ethanol, up from about 40,000 carloads in 2000 (Table 1). Most rail ethanol originations occurred in Iowa, Nebraska, South Dakota, Illinois, and Minnesota, while top rail ethanol terminations were led by Texas, California, and New Jersey.

Because of these factors, shipping ethanol can be relatively more expensive. Physically transporting ethanol to the East and West Coasts costs at least \$0.13 per gallon and to regional markets it costs about \$0.07 per gallon (Coltrain 2001). It is also possible that this \$0.13/gallon number varies with diesel fuel prices since trains, trucks and barges all use diesel fuel. These numbers are likely a lower bound. Hughes (2011) found that railroads have market power in the ethanol shipment and price discriminate based

[15]There are a few places where ethanol is shipped by pipelines (for example, in Florida). These are typically short pipelines and the volumes of ethanol shipments are small. See `http://www.afdc.energy.gov/pdfs/km_cfpl_ethanol_pipeline_fact_sheet.pdf`. Last accessed: May 10, 2015.

on environmental regulations at destination points (e.g. carbon monoxide non-attainment areas). In addition, shipping via rail sometimes proved problematic due to rail transportation constraints: cold weather and increased crude oil shipments were blamed for causing rail traffic to back up in the Midwest, leading to an increase in premium for ethanol in New York relative to the price in Chicago from $0.25 (January, 2014) to $1.0 a gallon (February, 2014).[16]

While at blending terminals, ethanol is kept in separate tanks underground and then splash blended with motor gasoline to the desired level before being delivered to retail gasoline stations. The minimum quantity of ethanol required to be blended is a yearly volume regulated by RFS.[17] The maximum amount of ethanol to be blended is 10% in volume. Blenders make decisions to blend ethanol that must meet or exceed the mandated amount. The exact amount of ethanol content depends on several factors, such as the mandate, local and state regulations, relative prices of ethanol and gasoline blendstock, seasonal oxygenation regulations, and reid-vapor pressure (RVP).[18] Some studies found blending at 10% ethanol and 90% gasoline blendstock, known as E10, to be more prevalent in the corn-growing locations than places far from such feedstocks (Walls et al. 2011). Underdeveloped ethanol infrastructure and the cost of transporting ethanol from geographically remote ethanol refineries in the Midwest to blending terminals across the U.S. limit the ability of blenders at far away places to take advantage of low cost ethanol during high oil price periods.

Diesel fuel

Diesel fuel is widely used fuel in freight transportation. In 2010 medium-and heavy-duty trucks consumed about 90% of all the diesel fuel consumed on U.S. highways, while Class

[16] See, for example, The Wall Street Journal articles available here `http://online.wsj.com/articles/SB10001424052702303546204579439740561525518` and here `http://online.wsj.com/articles/SB10001424052702303847804579479643372241358`. Last accessed: May 10, 2015.

[17] This is a unique feature of the regulatory structure for ethanol: the mandated level of ethanol to be blended is an absolute yearly volume rather than a percent of total gasoline consumed. This is a useful aspect of the policy for our study: a volumetric mandate permits blenders to have more flexibility to choosing their blending strategy within a year as opposed to a percentage requirement. A percentage requirement implies that as the quantity demanded of gasoline fluctuates within a year, blenders would have to respond more quickly.

[18] For example, because ethanol increases RVP, gasoline blendstock may be optimized so that after mixing with ethanol RVP does not exceed the established standards.

I railroads used 3.5 billion gallons (Baumel 2013). Shares of diesel fuel substitutes, such as compressed natural gas (CNG) and biodiesel, in transportation fuel are small. However, relative to petroleum diesel, the prices for CNG tend to be lower, while the prices for biodiesel are higher. Figure 7 shows the national average prices of CNG, diesel fuel, and biodiesel in diesel gallon equivalent (DGE) basis. Although sharply declining natural gas prices make it potential alternative to petroleum diesel for freight transportation, it has some obstacles, including the need for major costly changes in engines, fuel distribution system, and limited fueling stations (Baumel 2013).

As for biodiesel, the RFS mandate, $1 per gallon blenders' tax credit, and other state and local biodiesel incentives ensure that there is a market for biodiesel.[19] However, given the relatively higher cost of biodiesel and its low energy content, trucking firms and railroad companies are less likely to use biodiesel beyond the mandated amounts by federal, state, and local governments (Baumel 2013). Consequently, petroleum diesel fuel remains as the preferred fuel in the transportation system.

Our primary goal in this study is to estimate how the ethanol mandate affects gasoline prices across space due to asymmetric market frictions (e.g., transportation costs of ethanol). The wholesale price of gasoline blendstock is in large part driven by oil prices and refiners' ability to exercise market power. The price of ethanol is largely driven by the price of corn and how mandated levels of ethanol interact with capacity constraints of refiners. However, as noted below we are concerned with blenders' decisions. The next section develops a theoretical framework which sharpens our hypotheses and motivates our econometric specification.

[19] Biodiesel is made from animal fats, vegetable oils, soybean oils, or waste restaurant greases that is used in light-, medium-, and heavy-duty diesel vehicles. Biodiesel is blended into petroleum diesel in blends ranging from B1 (1% biodiesel and 99% prtroleum diesel) to B99 (99% biodiesel and 1% petroleum diesel), but blends B5, B10, and B20 are more commonly used in diesel vehicles.

3 Theoretical Framework

Currently, most gasoline sold in the U.S. is blended with ethanol.[20] The amount of ethanol blended into finished gasoline depends on gasoline blenders' decisions to mix gasoline with ethanol and whether or not the ethanol mandate binds. The RFS mandate binds at the year level giving blenders flexibility over when to blend, how much to blend and when to buy RINs. In this section we sketch a very simple model in the spirit of Pouliot and Babcock (2014) meant to sharpen intuition regarding three critical parameters of the blender's problem: the incentive to blend as a function of relative refined oil and ethanol prices, distance from a blender to ethanol production center and the unit cost of shipping ethanol. This framework is not a stand alone contribution, but simply a framework for understanding our hypotheses and motivate the empirical approach.

We assume throughout that blenders are price takers for both gasoline blendstock, ethanol and Renewable Energy Credits (RECs) because there are thousands of blenders throughout the U.S. and multiple blenders within MSAs. We also assume that blenders purchase two potential intermediate materials, gasoline blendstock and ethanol, to produce finished gasoline. Blenders can either blend ethanol into gasoline blendstock or not, but their goal is to minimize price offered to a competitive retail market. We assume for simplicity that gasoline with and without ethanol are perfect substitutes for the retail market. While Anderson (2012) shows this is not precisely true, we consider the blender's decision for all gasoline which contains "up to 10% ethanol" at the pump. Conditional on a consumer coming to a station with gasoline containing up to 10% ethanol, it is reasonable to assume that any extant percentage of ethanol is indistinguishable to the consumer.

Under these assumptions, the cost of a gallon of gasoline will be a function of different parameters at a location if the blender chooses to blend or purchase RECs to satisfy their obligation. The model's implications extend directly to blenders without a mandate obligation.

At any point in time a blender could either sell gasoline with or without ethanol

[20] Ethanol is a substitute, though imperfectly, to gasoline blendstock. When blended at 10% or less, fuel efficiency loss is small and, therefore, it is less likely finished gasoline blended with ethanol will be priced at a discount. According to EIA study, average fuel efficiency per gallon has declined by about 3% over the last 20 years due to increased ethanol blending. See http://www.eia.gov/todayinenergy/detail.cfm?id=18551 for details. Last accessed: May 10, 2015.

blended into it to the retail market. The blender seeks to minimize the price charged to the downstream retailer given blenders within a city are price takers and selling a homogenous good, by assumption. Conditional on blending or not blending, there are two possible functional forms the price of a gallon of retail gasoline can take conditional on the mandate binding:

$$\text{BLENDED: } P_g^B = .9P_p + .1[P_e - \rho + d \cdot t(P_d)] \quad (1)$$

$$\text{NOT BLENDED: } P_g^{NB} = .9P_p + .1[P_p + \rho] \quad (2)$$

where P_p is price of a gallon of gasoline blendstock, P_e is price of a gallon of ethanol, and P_d is the diesel fuel price. To account for transportation cost of ethanol, we assume d is distance from an ethanol refinery to a blender, $t(P_d)$ is per-unit transportation cost of shipping ethanol with $t'(P_d) > 0$. ρ represents the cost of a REC (e.g., a gallon's worth of blended ethanol). When ethanol is blended, the blender can sell the REC to refiners and earn $.1\rho$. When ethanol is not blended, the blender must purchase a REC. In this model, we assume that the effect of transportation costs of ethanol on gasoline prices depends both on distance and per-unit transportation costs. Note that per-unit transport cost is a function of diesel fuel price since rail and truck transportation use diesel fuel.

Given this framework a blender's problem is to choose whether or not to blend in order to minimize the cost of producing finished gasoline. Conditional on the mandate binding, a blender will choose to blend if the price of blended fuel is lower than the price of unblended fuel:

$$.9P_p + .1[P_e - \rho + d \cdot t(P_d)] \leq .9P_p + .1[P_p + \rho] \quad (3)$$

$$\rightarrow \quad d \cdot t(P_d) \leq [P_p - P_e] + 2\rho \quad (4)$$

In other words, when the ethanol mandate binds blenders have increased incentive to blend ethanol when: (i) P_p is relatively high, (ii) P_e is relatively low, (iii) ρ increases, (iv) d is lower, and (v) P_d is lower. Note that when $\rho > 0$ the mandate is binding. Hence, a binding mandating leads to more blending.

Now consider the comparative statics of gasoline price conditional on blending as summarized by equation (4). Conditional on blending, this framework shows that ethanol shipping distance can affect gasoline prices in two different ways. If blending is occurring, then an increase in distance increases the gasoline price at the following rate:

$$\frac{\partial P_g}{\partial d} = .1t(P_d). \tag{5}$$

Thus, conditional on blending occurring throughout the U.S., this framework suggests that cities far away from ethanol production centers should pay higher gasoline prices. Further, the marginal impact of distance on gasoline price varies with diesel fuel prices:

$$\frac{\partial^2 P_g}{\partial d \partial P_d} = .1t'(P_d). \tag{6}$$

Recall that we assumed $t'(P_d) > 0$. Therefore, our framework suggests that marginal effect of distance on gasoline price should be increasing as the level of diesel fuel price increases. This is consistent with empirical findings: as the Midwestern states became saturated with ethanol, volume and distance of interstate ethanol shipments have been increasing over the last decade (Strogen et al. 2012). In addition, ethanol transport costs tend to be higher than other liquid fuels. A 2013 study conducted by International Energy Agency compares the transport costs of various transportation fuels and finds higher costs for ethanol transport than other liquid fuels due to remote location of biorefineries from large demand centers (Cazzola et al. 2013).

4 Data

Our objective in this paper is to present evidence that the RFS asymmetrically affected the price of gasoline throughout the U.S. as a function of shipping distances. We use a panel dataset of weekly prices from January 2007 to July 2014 that spans pre- and post-U.S. binding ethanol mandate. All price data are converted to July 2014 U.S. dollars using the U.S. Bureau of Labor Statistics consumer price index (CPI) for urban consumers. We focus on contiguous U.S. by excluding observations for states Alaska and Hawaii. The dataset is unbalanced panel of 200 cities from 35 states that are widely distributed throughout the U.S.

This paper analyzes data collected from a variety of sources. Wholesale gasoline prices are given by cities across the U.S. and are taken from Bloomberg databases. We use wholesale rack prices of unbranded gasoline with up to 10% ethanol for gasoline prices. Importantly, this city specific gasoline price could contain anywhere from zero to 10% ethanol. We were unable to find any dataset containing the ethanol content of gasoline at a weekly or even monthly level. Corn ethanol prices are weekly average prices at Iowa ethanol plants and are obtained from Agricultural Marketing Resource Center at Iowa State University. By using ethanol prices at Iowa plants we assume that the production price of ethanol is set in the Midwest ethanol market. PADD-level diesel fuel price data are obtained from Bloomberg databases.

We use the price of crude oil as a proxy for gasoline blendstock. Ideally, we would have preferred to use the city specific gasoline blendstock price paid by blenders to refiners. However, we were not able to identify any reliable dataset with that data at a weekly or monthly level. As a result, we use PADD-level crude oil spot prices with delivery points within those PADD regions.[21] We use PADD-level prices because of substantial divergence between Brent and WTI (West Texas Intermediate) crude oil prices beginning in 2011. For PADD 2 region, we use WTI crude oil spot price for Cushing, Oklahoma, for PADD 3 - Light Louisiana sweet crude oil price with delivery point in St.James, Louisiana. However, we lack PADD-level prices for PADD 1 and PADD 5 regions. Instead, for PADD 1 region we use weekly Brent oil prices because PADD 1 region refines oil imported mainly from abroad as well as domestically produced oil. Though, in recent years, East Coast refiners have been reducing imported crude oil and increasing domestic crude oil thanks to increased domestic crude oil production and its lower cost.[22] As for PADD 5 region, we use Alaska North Slope crude oil spot price because the region also imports oil from Alaska North Slope, in addition to oil produced in California. To proxy for gasoline blendstock, we match the PADD-level oil prices with states and cities located within that PADD region. A barrel of oil is equivalent to 42 gallons of refined petroleum. Therefore, we divide the oil

[21] By using the oil price directly we assume that there is no variation in refinery profits. However, as long as variations in oil refinery profits are uniformly distributed across the United States to all blenders this problem amounts to measurement error in the price of oil variable.

[22] See EIA article at http://www.eia.gov/todayinenergy/detail.cfm?id=21092. Last accessed: May 10, 2015.

price by 42 to get per gallon price, increasing comparability to the ethanol price. Crude oil price data are taken from Bloomberg databases.

Since ethanol prices vary across regional markets due to transportation costs, we use distance from ethanol plants to destination points to proxy for ethanol shipping costs. Ethanol is first delivered to blending terminals, there blended with gasoline blendstock, and then delivered to gasoline stations. Since blending terminals are located in and around cities, we use distance from ethanol production center in the Midwest to cities, instead of from ethanol plants to blending terminals to cities. This allows us to to explicitly control for transportation costs associated with shipping ethanol via rail and truck to blending terminals in and around cities where retail gasoline is sold. We define ethanol production center as the geometric center of six Midwestern states where the vast majority of ethanol is produced. The six largest ethanol producing states (Iowa, Nebraska, Illinois, Minnesota, Indiana, and South Dakota) accounted for about 75 percent of the domestic ethanol production over the sample period (RFA 2007-2014). The next largest ethanol producing states, Ohio and Wisconsin, each expected to produce one-half the amount of the smallest of the six largest ethanol producing states in 2014. The centroid of these six states, which we define as the ethanol production center in the Midwest, falls within the boundaries of the state of Iowa, the largest ethanol producing state in the U.S. We find the shortest distance (in thousands of miles) from each city to the ethanol production center in the Midwest using great-circle distance.

Table 2 presents the summary statistics for the sample period that is the basis of this study. The distances from cities to ethanol production center in the Midwest ranges from 26 miles up to around 1,450 miles. For the sample period, PADD-level oil prices ranged from low \$30 to a high of \$162 per barrel. In per gallon terms, PADD-level oil prices ranged from \$0.72 to \$3.85 with a standard deviation of \$0.46. Per gallon cost of corn ethanol at Iowa plants ranged from \$1.56 to \$3.15 with a standard deviation of \$0.38. The blender's decision to mix ethanol into finished gasoline depends on the relative prices of ethanol and gasoline blendstock. Figure 8 shows the weekly variation in the costs of ethanol and WTI oil prices. The existence of market friction in ethanol transportation may change the competitiveness of ethanol to blenders, especially for those that are farther away from the Midwest. The price spike in the delivery price of ethanol in early 2014 due to back up in rail traffic is one example of the existence of market friction in the ethanol market.

In addition to federal RFS, several states have their own renewable fuel programs. Some of these programs predates federal ethanol mandates. Table 3 presents a list of six states that have statewide oxygenate mandates. For example, in Minnesota all gasoline must contain at least 10% ethanol, but blends with at least 9.2% of pure ethanol (e.g. excluding denaturants and other permitted components) by volume are considered to be in compliance.[23] Hawaii, Minnesota, Missouri, and Oregon require that gasoline contain at least 10% ethanol in volume.

5 Econometric Model

Using a difference-in-differences design, our econometric model attempts to estimate the causal impact of a marginal increase in ethanol shipping distance on gasoline prices in the U.S. attributable to the RFS becoming binding in 2013. Using a quantile estimator rather than an OLS allows us to estimate the impact of a marginal increase in shipping distance on gasoline prices for different levels of the gasoline price. This section describes our econometric model in detail.

Our research design uses a quantile difference-in-differences estimator in which one difference is before and after the mandate binds and the other is a measure of ethanol shipping distance as measured by our distance proxy. We begin our sample in 2007 and assume that the mandate becomes binding in January 2013. The evidence of the binding mandate comes from RIN prices increasing above zero in 2013. Before that corn ethanol RINs were trading close to a zero value, but they sharply increased starting in 2013. As the Figure 2 shows, the value of ethanol RINs increased from about 5 cents at the end of 2012 to approximately $1.50 by July of 2013. While the price of RINs since decreased to hover around $0.50, it is clearly still much larger than zero through 2014. As discussed above, when the RIN price increases, it encourages blending ethanol because purchasing RINs increase the cost of gasoline production.[24] This explains why we are using January

[23]See https://www.revisor.mn.gov/statutes/?id=239.791. Last accessed: May 10, 2015.

[24]The article published in Reuters suggests that higher RIN prices cost refiners at least $1.35 billion in 2013. See http://www.reuters.com/article/2014/03/31/

2013 as the time period when the mandate binds.

The difference-in-differences design is important to attribute the estimated effects on the mandate rather than changing market conditions which are correlated with distance from the Midwest. On the coasts, demand increases lead to price increases which are potentially larger than price increases in the interior U.S. due to refining constraints. The difference-in-differences design isolates differences in the marginal impact of distance on gasoline prices which occur in 2013 and 2014. Figure 8 shows that the support of oil and ethanol fuel prices in 2013 and 2014 is fully contained within pre-2013 prices. Further, Figure 5 shows that even coastal states were blending at above mandated level as early as 2010. As a result, the difference-in-differences design mitigates the concern that the estimated effects are an artifact of market conditions rather than shipping distance.

We are mainly interested in the causal impact of the mandate becoming binding on the marginal impact of ethanol shipping distance on gasoline price. We compare the effect of distance on gasoline pre- and post-January 2013 using our continuous distance proxies, similar in spirit to Kiel and McClain (1995). There is a great deal of variability in distance measure as our dataset includes cities distributed throughout the U.S. while ethanol production is concentrated in the Midwest (see Table 2). Within this difference-in-differences design, we then allow the marginal impact of ethanol shipping distance on gasoline prices to vary by the level of diesel fuel prices.

Using the quantile rather than OLS estimator lets us estimate a different marginal effect of distance on different levels of gasoline prices. We use quantile regression in order to test if the impact of ethanol shipping distance on gasoline prices depends on the level of gasoline prices themselves. The literature on quantile regression shows that it has been applied in different settings. For instance, the techniques has been used in studying the impact of welfare reform on earnings (Bitler and Hoynes 2006), returns to education (Arias et al. 2001), and birthweight determinants (Abrevaya and Dahl 2008). Using the quantile approach also allows refiner profits (often proxied by the crack spread) vary with demand for gasoline. Ethanol can have a differential effect on gasoline prices as demand rises and falls through the refiner profits channel as ethanol reduces the market power of refiners

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`us-rins-spike-costs-analysis-idUSBREA2U0PT20140331`. Last accessed: May 10, 2015.

during high demand periods (Knittel and Smith 2015). Quantile techniques account for this asymmetric effect throughout the distribution of gasoline prices explicitly, while OLS can only identify the mean effect which is important in our context because previous work shows differential pass through as a function of market conditions in this sector (Marion and Muehlegger 2011).

Our identification relies on the assumption that weekly fluctuations in gasoline prices are driven by demand shifts and, therefore, supply capacity is assumed to be constant during the study period. This is likely a reasonable assumption for gasoline refineries. It is more questionable with respect to ethanol. Over our time period, the total supply and the number of suppliers of ethanol were increasing (see Figure 1). However, the spatial distribution of the supply of ethanol (e.g., Midwest ethanol) was roughly constant, especially in 2013 and 2014. More importantly, from the perspective of price taking blenders, the prices of ethanol and gasoline blendstock are exogenous: there is no single blender large enough to influence the price of either ethanol or gasoline blendstock. As a result, we interpret our estimates are causal.

The main empirical specification regresses the gasoline price on diesel fuel price, distance variable, and indicator variable for relative prices of ethanol to gasoline blendstock, and an indicator variable for 2013-2014 period when the mandate became binding:

$$\begin{aligned}
P_{g_{it}} = {} & \beta_0 + \beta_1 \mathbb{1}\{P_{e_t} \le P_{o_t}\} \times P_{d_{it}} + \beta_2 \mathbb{1}\{Year > 2012\} + \beta_3 \mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_{e_t} \le P_{o_t}\} \times P_{d_{it}} \\
& + \beta_4 \mathbb{1}\{P_{e_t} \le P_{o_t}\} \times P_{d_{it}} \times Dist_i + \beta_5 \mathbb{1}\{Year > 2012\} \times Dist_i \\
& + \beta_6 \mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_{e_t} \le P_{o_t}\} \times P_{d_{it}} \times Dist_i + \lambda_i + f_{my} + \epsilon_{it} \qquad (7)
\end{aligned}$$

$$P_{g_{it}} = x'_{it}\beta + \lambda_i + f_{my} + \epsilon_{it} \qquad (8)$$

$$Q_\tau\left(\epsilon_{it} | x_{it}, \lambda_i, f_{my}\right) = 0 \qquad (9)$$

$$Q_\tau\left(P_{g_{it}} | x_{it}, \lambda_i, f_{my}\right) = x'_{it}\beta_\tau + \lambda_{i,\tau} + f_{my,\tau} \qquad (10)$$

where the dependent variable $P_{g_{it}}$ is the wholesale gasoline price for city i in week t, x is our vector of regressors, β_τ is the vector of parameters to be estimated. P_{e_t} is the weekly corn ethanol price, P_{o_t} is the weekly price of a gallon of oil. $Dist_i$ is the shortest distance from city i to ethanol production center in the Midwest, and ϵ_{it} is the error term with unknown distribution function and potential heteroskedasticity.[25]

$\lambda_{i,\tau}$ control for city fixed effects. At the local level, blender's decision to operate depends on the costs of its inputs, such as gasoline blendstock, ethanol, labor costs, etc. City fixed effects control for local unobserved production costs, variations in local environmental policies, and differences in local regulations. For example, Brown et al. (2008) find that there are significant spatial differences in regulation and that those differences significantly affect gasoline prices.[26] In addition, some states regulate how the information about the ethanol content be labeled in retail outlets.

$f_{my,\tau}$ are month-by-year effects, where m is month and y is year. Month-by-year effects, $f_{my,\tau}$, are monthly dummies for each year of the data sample. In other words, every month in a certain year is allowed to have a different impact from the same month in a different year.[27] They control for everything that was fixed within that time period and remove all of the fluctuations common across states and PADDs over time. For example, month-by-year effects control for variations driven by national level events as well as variations due to seasonality.

Estimation of quantile regression with large number of fixed effects is subject to incidental parameters problem (Neyman and Scott 1948, Lancaster 2000). The incidental parameters problem leads to inconsistent coefficient estimates when the number of individuals fixed effects goes to infinity while the time period is fixed. Eliminating fixed effects by demeaning the variable using the within transformation is not available for quantile regression models. As demonstrated in Koenker (2004), a penalization method could be used in controlling the variability due to the large number of fixed effects. Consequently, we employ l_1-norm regularization method to shrink the individual and time fixed effects.[28]

The justification for the inclusion of the indicator variable for relative prices of ethanol and gasoline blendstock in the regression is straightforward. We assume that ethanol is a

[25] Quantile regression is a semiparametric method because one does not need to specify the distribution function of the error term. The presence of heteroskedasticity is captured by the quantile regression coefficients. See Koenker (2005) for further details.

[26] To the extent that there is seasonal variation in these regulations, we assume that seasonal variation in regulations are orthogonal to distance from ethanol refineries.

[27] Given the weekly observations, we determine the corresponding calendar month the weeks belong to generate month-by-year effects.

[28] The value of shrinkage parameter is a subject of active research. When the shrinkage parameter is sufficiently large, $l1-$norm penalty shrinks the fixed effects toward zero. Following Koenker (2004), we set the shrinkage parameter to 1.

substitute, though imperfectly, for gasoline blendstock. The incentive to blend ethanol is greater when the ethanol price is lower than cost of gasoline blendstock. Then a blender would have to face the transportation cost which depends on diesel fuel price. This is shown by the indicator variable $\mathbb{1}\{P_e \leq P_o\} \times P_d$.

We estimate the relationship of each independent variable with $P_{g_{it}}$ for different values of τ which indexes the quantiles of the dependent variable. Thus, $Q_\tau \left(P_{g_{it}} | x_{it}, \lambda_i, f_{my}\right)$ denotes the τth conditional quantile of $P_{g_{it}}$ with $0 < \tau < 1$. Estimation and inference of β_τ is discussed in Galvao (2011). It is clear that the advantage of using a panel data (rather than cross sectional) quantile regression is that we can control for unobserved heterogeneity in the gasoline prices.

6 Results

Table 4 presents the regression results for different quantiles of gasoline price distribution. We are interested in estimating the marginal effect of distance from ethanol production centers to cities on gasoline price and how this effect changes with binding ethanol mandate after 2013. To find the marginal distance effect pre- and post-2013, we take the derivative of gasoline price with respect to distance from equation 7. The complete derivation of marginal effects of distance are provided in the Appendix. Thus, we get

1) 2007-2012:

$$\frac{\partial P_g}{\partial Dist} = \beta_4 \mathbb{1}\{P_e \leq P_o\} \times P_d \tag{11}$$

2) 2013-2014:

$$\left.\frac{\partial P_g}{\partial Dist}\right|_{Yr>2012} = \beta_5 + \beta_6 \mathbb{1}\{P_e \leq P_o\} \times P_d \tag{12}$$

It follows that the marginal impact of distance on gasoline price depends on diesel fuel price used in transportation of ethanol. In addition, ethanol is more appealing to blenders when the relative price of gasoline blendstock is high. As can be seen from Figure 8, which shows the weekly variation of spot ethanol and crude oil prices used to proxy for gasoline blendstock, the price competitiveness of ethanol varied throughout the 2007-2014 period. However, when the RFS mandate was binding (2013-2014) and RIN prices started to increase in 2013, more ethanol was possibly shipped to places outside the Midwest. When the mandate is binding, far away places may be better off blending ethanol to fulfill their obligations, especially when the alternative compliance method (i.e. buying RIN credits) is more costly.

As can been seen from Table 4, the marginal distance effects for pre- and post-2012 periods are statistically different from zero at conventional significance levels. Next we plot these effects graphically. Figure 9 plots the marginal effect of distance (in 1,000 miles) on gasoline prices for different levels of diesel fuel price during 2007-2012. We can also see how these effects vary across different conditional quantiles of gasoline prices since different lines indicate different quantiles. Additionally, different distances can be represented by rescaling the y-axis. For example, the effect of distance on a city 500 miles from ethanol centers is represented by dividing the y-axis by 2, 100 miles by 10, and so on. There are two striking features of Figure 9. First, the marginal effect of distance varies with the cost of diesel fuel price. As expected, when diesel fuel is more expensive, marginal effect of distance is higher. Second, the positive effect of distance on gasoline prices becomes larger when gasoline prices increase (e.g., lines for higher quantiles are steeper than for lower quantiles). In other words, in locations where gasoline prices are in upper quantiles, the distance effect is more pronounced.

As the mandate became binding at the national level starting in 2013, more ethanol has to be shipped to far away places because E10 market in the Midwest has been saturated with ethanol. Therefore, additional ethanol consumption due to the binding mandate must have come from places that have not yet hit the blend wall. This is because, even though the RFS is a national mandate, the penetration of ethanol across the U.S. has not been uniform. Even if blenders choose not to blend ethanol to the required minimum level, a binding mandate means that blenders in far away places would have to pay significantly higher prices for RINs to meet their renewable volume obligations. As ethanol transport costs increase with distance, so too does the marginal impact of distance on gasoline prices. This means cities farther away from ethanol production centers faced higher gasoline prices than cities closer to ethanol sources.

Figure 10 plots the post-mandate marginal effect of distance on gasoline price. As expected, the distance effect is larger when diesel fuel price is high. The steeper lines for the upper quantiles of gasoline prices indicate that locations with higher gasoline prices are likely to experience larger distance effect when the cost of diesel fuel increases. Figure 10 shows that the implied point estimate for additional cost per gallon of gasoline when the distance is 1,000 miles and diesel fuel price is around \$4.0 (sample median), is about 3 cents for $\tau = 0.50$. This is in addition to the effect of shipping distance on gasoline price before 2013 when the mandate was essentially nonbinding. The magnitude of these estimates seem reasonable: the average price of a RIN for a gallon of ethanol post-2012 was on the order of \$0.75. One tenth of that, the amount of ethanol blended with a gallon of gasoline, was 7.5 cents. The distance created wedge persists as a market friction, though, since any arbitrage opportunity of shipping ethanol to eliminate a price wedge always embeds the transportation costs.

Although the impact of distance on price is increasing in the price of diesel across all quantiles, in Figure 10 the marginal effect of distance on gasoline price is negative when diesel prices are low and when gasoline prices are in upper quantiles. There are two explanations. First, there are not very many observations when the gasoline price is high and the diesel price is low. As a result, those point estimates are noisy. Second, the RFS tends to lower gasoline prices for ozone non-attainment areas relative to other cities. The reason is many of these ozone non-attainment areas, which are on the coasts and far from the ethanol production centers in the Midwest, were already paying the high transportation cost to blend ethanol due to the 1990 Clean Air Act amendments and subsequent MTBE bans in 2006. With the RFS binding, the relative effect of distance could be lower in those cities when the price of diesel is low and price of gasoline is high because blending is most likely to occur with those market conditions. Since we do not explicitly control for ozone non-attainment cities in our regression model, we are not able to claim that this negative distance effect is due to the presence of reformulated gasoline regulations in ozone non-attainment areas but offer it as one possible explanation for this result.

Given the point estimates of differences in gasoline prices due to the differential costs of shipping ethanol, we can construct the predicted relative increase in gasoline prices for a representative household across different locations in the U.S. Table 5 shows additional spending for a representative household in three sample locations: Miami, FL, Charlotte, NC, and Portland, ME, since they provide obvious instances in which ethanol must be shipped long distances. The distance from Miami to the center of the ethanol industry by our measure is roughly 1,450 miles. Assuming EPA estimates for yearly average gasoline consumption for passenger vehicles of 497 gallons, back of the envelope calculations show that an average Florida household spends an additional $14.24 on gasoline per year due to the shipping costs attributable to a binding ethanol mandate.[29] Assuming there are roughly 13.9 million licensed drivers in Florida (total population is 19.89 million according to the 2014 census), it means the total yearly wealth transfer from Florida due to the binding mandate is $197.97 million up and above what Midwesterners from ethanol producing regions had to pay for gasoline.[30] Similarly, representative households in Charlotte, NC, and Portland, ME, spend an additional $10.61 and $12.11, respectively, on gasoline per year. Assuming there are about 7.0 and 1.01 million licensed drivers in North Carolina and Maine, respectively, these additional spendings translate into yearly wealth transfer of $74.56 and $12.34 million, respectively, up and above what Midwesterners from ethanol producing regions had to pay for gasoline. Note that these additional spendings on gasoline would increase with higher diesel prices and decrease with lower diesel prices. We do not claim to model the dynamics of oil and ethanol prices in this paper and, instead, assume that blenders are price takers. We claim instead that our calculated effects are the causal impact of the binding mandate in gasoline prices through the shipping channel.

A related question to explore is whether or not these results are driven by the existence of spatially dependent market power in the ethanol market. Our results are consistent with the existence of market power in the ethanol shipping market and/or RIN markets. According to the Federal Trade Commission's report to Congress, the U.S. ethanol production industry seems unconcentrated (FTC 2013). We are not aware if there exists similar analysis about the RIN market. The sharp increase in RIN prices in 2013 fueled discussions about speculative activity in the RIN market. High RIN prices post-2012 could be the result of transaction costs or speculative activity by market participants. Because of lack

[29]Average gasoline consumption for passenger cars is given on page 4 at http://www.epa.gov/otaq/consumer/420f08024.pdf.

[30]Number of licensed drivers is from http://www.fhwa.dot.gov/policyinformation/statistics/2014/dl22.cfm.

of information about the RIN market, we are unable to study the factors behind a sharp spike in RIN prices in 2013. Further, we are unable to separate the effects of market power in shipping from the distance effects. Both types of market power, though, manifest as a form of market friction created by the RFS ethanol mandate. We therefore take our results as causal evidence that the binding ethanol regulation and positive RIN prices led to market friction that asymmetrically affected gasoline prices in the U.S. over space.

7 Robustness Checks

The main regression results presented in Table 4 and discussed in the previous section use the distances from cities to the centroid of major ethanol producing states. Note that ethanol production is mainly located in the middle of the country, while blenders with long shipping distances are on the coasts. Although we include city fixed-effects to account for level differences across locations, it may not be enough if price changes are systematically different across the U.S.[31] To address these concerns, we conduct several robustness checks.

First, we use log gasoline price as the dependent variable which assumes similar percentage effects across locations. In this specification, diesel fuel price is also given in logs, while distance is in thousands of miles as before. The results are presented in Table 6. Looking at the signs and statistical significance of estimated coefficients, we note that the results are largely consistent with those from the main regression. The marginal distance effects are calculated as in Appendix and graphically presented in Figures 11-12. Figure 11 plots the marginal distance effect on gasoline prices (in percent) for different values of diesel fuel price (in logs) for 2007-2012 period. The percentage change in gasoline prices is positive across all quantiles and is increasing with diesel fuel price. The marginal distance effect for 2013-2014 when the mandate was binding is presented in Figure 12. Similarly, the marginal distance effects for post-2013 period are consistent with the results from the main regression. For example, we see that the marginal effect of distance on gasoline price (in percent) is positive for higher values of diesel prices. The steeper lines for upper

[31] We are grateful to an anonymous referee for bringing this to our attention and suggesting some possible solutions.

quantiles of gasoline prices mean that the effect will be more pronounced as diesel fuel prices increase.

Second, since locations on the East and West Coasts tend to have higher gasoline prices and, therefore more likely to appear in the upper quantiles, we run additional robustness checks by dropping different sets of PADDs from the estimation sample. We first drop PADD 1 (East Coast) and re-estimate the main specification. We present the estimation results in Table 7 and plot the marginal distance effects in Figures 13-14. We note that during 2007-2012 period, the distance effects in both the full sample and without PADD 1 are of similar magnitude. They are increasing with the cost of diesel fuel and stronger at upper quantiles of gasoline prices. However, for 2013-2014 when the RFS was binding, we see that the marginal distance effects are negative once we drop PADD 1 from the sample, which seems counterintuitive. We explain this behavior further below.

Similarly, in Table 8 we drop the locations in PADD 5 (West Coast) and re-estimate the main specification. However, the results did not change in a significant way and are similar to the main regression results. This is also evident if we look at the marginal effect of distance for 2007-2012 (Figure 15); the marginal distance effects are similar whether or not PADD 5 region is dropped from the estimation sample. As for 2013-2014 period (Figure 16), the marginal effect is positive for different levels of diesel fuel price, but it is also larger and the lines are steeper for upper quantiles.

It seems that inclusion of PADD 1 in the sample is important and could be the driving force behind these results. Unlike PADD 1, dropping PADD 5 did not lead to negative marginal distance effects for 2013-2014 period. There are two possible explanations for this behavior. First, unlike PADD 1-3, PADD 5 transportation fuel market is relatively isolated; there are no petroleum pipelines between the Midwest and PADD 5 and there are only limited pipelines going from PADD 3 to PADD 5 (USEIA 2015). In addition, because gasoline specifications within PADD 5 region differs from most of the other states, about 90% of in-region gasoline demand is met by refinery production in PADD 5 (USEIA 2015). As such, inclusion of PADD 5 in the estimation sample may not very well justified in our case. Second, we have only a small sample of observations for PADD 5 ($\sim$ 3,500 or 5%). Dropping them did not have a significant impact on the sample mean (0.64) and standard deviation of distance (0.31). On the other hand, dropping PADD 1 has resulted in sample mean of distance to drop from 0.68 for the full sample to 0.57 for the sample without PADD 1, while its standard deviation has not changed significantly (declined from 0.34 to 0.32).

Further, as additional robustness checks we also re-estimate the model by including only PADD 2 (Midwest) and PADD 1 (East Coast) and dropping both PADD 3 and 5 regions. Note our sample does not have data on PADD 4 (Rocky Mountain). The associated results are shown in Table 9 and Figure 17 in the Appendix. Focusing on period after mandate becoming binding, overall marginal distance effects are positive for all quantiles of gasoline price. However, when we re-estimate the model with only PADD 2 and PADD 3 regions by dropping PADD 1 and 5 (see Table 10 and Figure 18), the marginal distance effects are downward sloping or decreasing with the cost of diesel fuel used in ethanol transportation.

Sample trimming shows that the results are largely driven by cities on the east coast of the U.S. When we exclude east coast cities the distance effect stay positive but costs are not increasing in the price of diesel as we would expect. This could be due simply to lack of variation in shipping distances from the Midwest to the Gulf PADD (Texas receives 14% of ethanol shipments) region combined with a paucity of data for west coast cities (roughly 6% of our data). This is consistent with the data from Table 1 on where ethanol is shipped: the top six east coast states received for 40% of all shipped ethanol in 2013.

8 Conclusion

We find evidence that the RFS created a market friction in the ethanol industry due to transportation costs of moving refined ethanol throughout the U.S. Using weekly gasoline price data from 200 cities in the U.S. and a quantile difference-in-differences estimator, we find that distance from cities to ethanol production centers resulted in differential impacts on gasoline prices over space. Driven by east coast cities, locations farther from the ethanol sources paid significantly higher gasoline prices relative to the cities in upper Midwest. The impact of distance from ethanol production centers was greatest when gasoline prices were highest. The yearly cost of this market friction for a Florida household relative to an Iowa household is on the order of $14.24 given observed ethanol, oil, gasoline, and diesel fuel prices between January 2013 and July 2014. This amounts to a yearly wealth transfer on the order of \$197.97 million from Florida households far from the Midwest to, in all likelihood, trucking and railway companies who shipped ethanol. In this case, then, we find that regulation led to a market friction affecting the distribution of welfare in the U.S.

There are five caveats in interpreting these results. First, our ethanol distance measure is a proxy. Since we do not observe individual ethanol purchase contracts of blenders, it is difficult to know how accurate our distance measures are. Second, we do not observe the contracted gasoline blendstock price paid by blenders. Rather we use regional oil prices to proxy for gasoline blendstock prices. Third, we do not observe RIN purchases nor purchase prices of blenders. This motivates our focus on looking at the marginal impact of distance on gasoline prices only after average RIN prices were positive. Fourth, our constructed wealth transfer estimates are constructed using observed past ethanol, oil, gasoline, and diesel fuel prices. A change in those fundamentals, which we do not model here, could lead to a larger, smaller or even a reversal of the wealth transfer. Fifth, our results are driven by cities on the east coast. We do not observe contradictory evidence from west coast cities but our data is very Eastern US and Midwest centric.

There are other interesting economic questions associated with this line of inquiry. First is developing second best policy subject to spatial equity concerns. Second, the economics of the endogenous blending decision of market participants in the pre-2013 period would likely provide sharp predictions of how blended volumes vary with relative ethanol and gasoline blendstock prices as a function of diesel prices. Third, bringing more west coast data- and other more granular data in general- to this question would bring some additional clarity to the east coast driven nature of our results.

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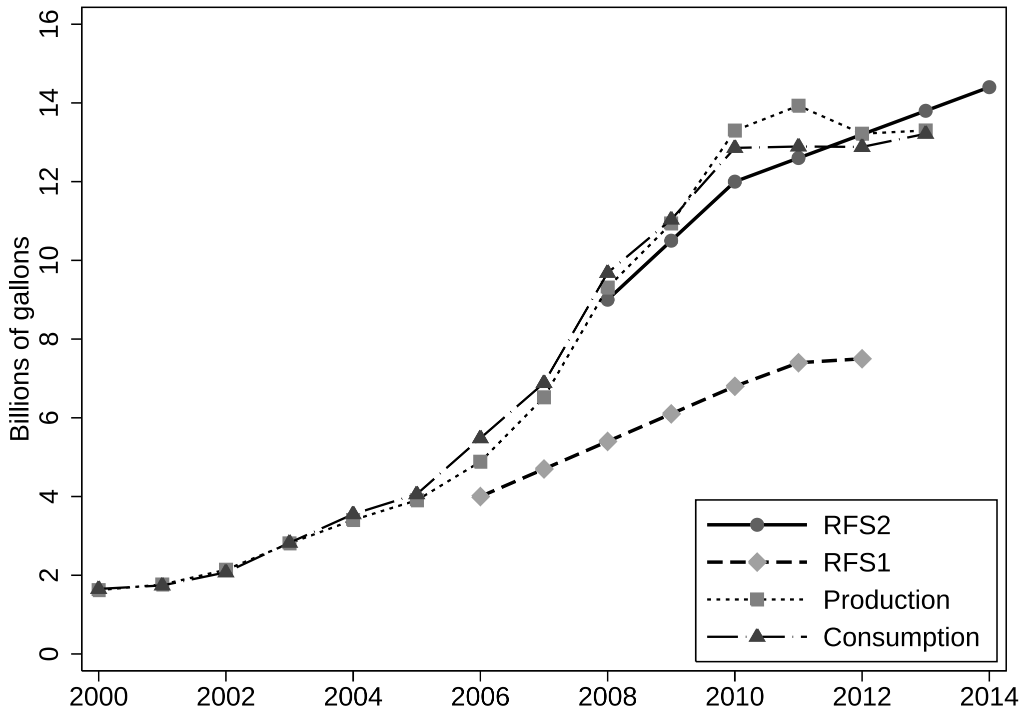
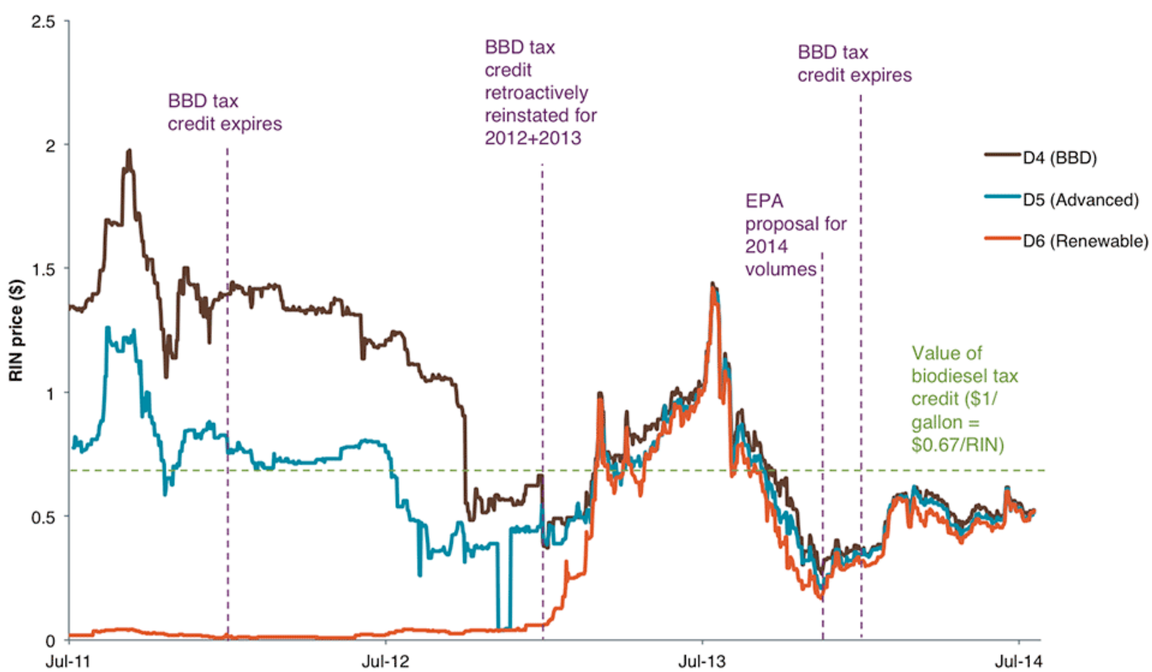
Figure 1: Fuel Ethanol Mandate, Production, and Consumption



Notes: Ethanol production and consumption fell below the RFS-mandated levels starting in 2013.

Source: U.S. Energy Information Administration, *Monthly Energy Review,* Table 10.3, October 2014; Energy Independence and Security Act of 2007 (Section 202); Energy Policy Act of 2005, (Section 1501).

Figure 2: Prices of Renewable Identification Numbers



Notes: D4, D5, and D6 represent historical RIN prices for biomass-based diesel (BBD or biodiesel), advanced biofuel, and corn ethanol, respectively.

Source: The International Council on Clean Transportation. See http://www.theicct.org/blogs/staff/does-biodiesel-really-need-tax-credit. Last accessed: May 10, 2015.

Figure 3: Map of Petroleum Administration for Defense Districts (PADDs)

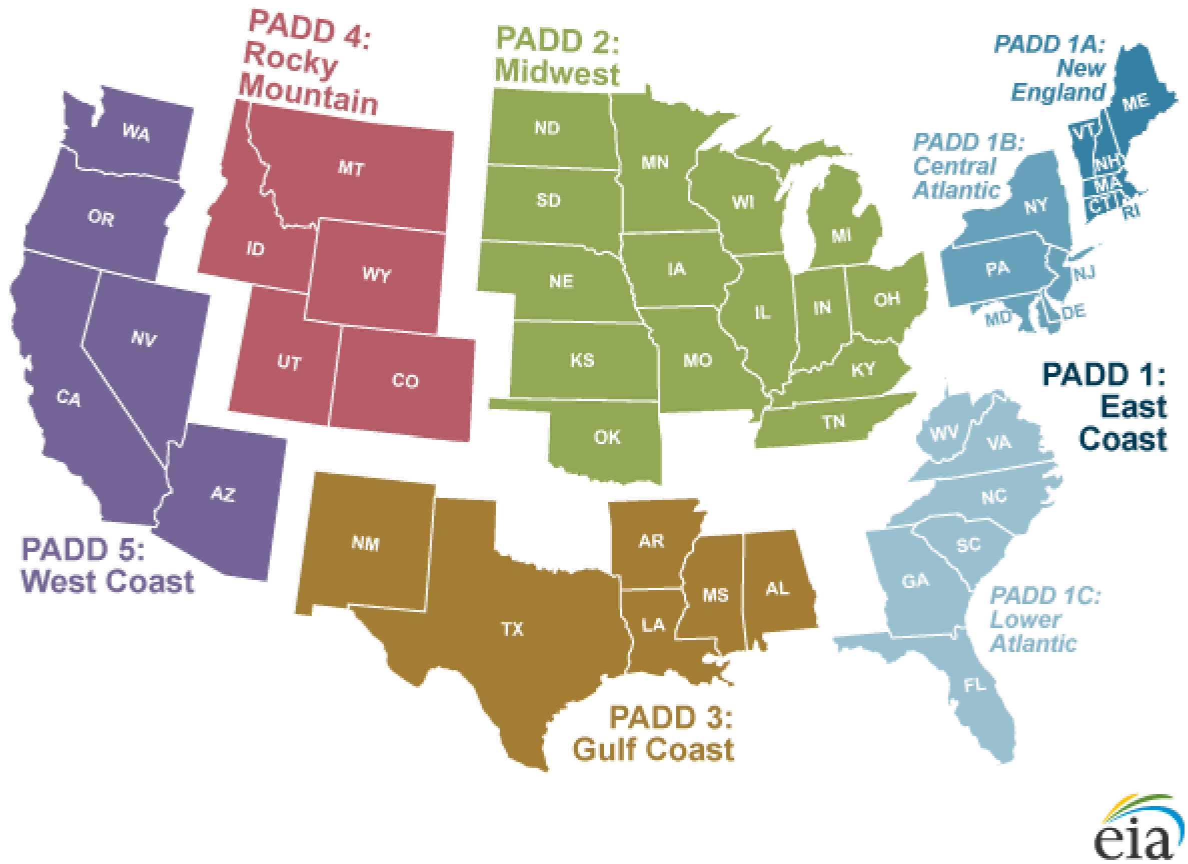


Figure 4: Location of Corn Growing Counties, Biorefineries, and Gasoline Terminals

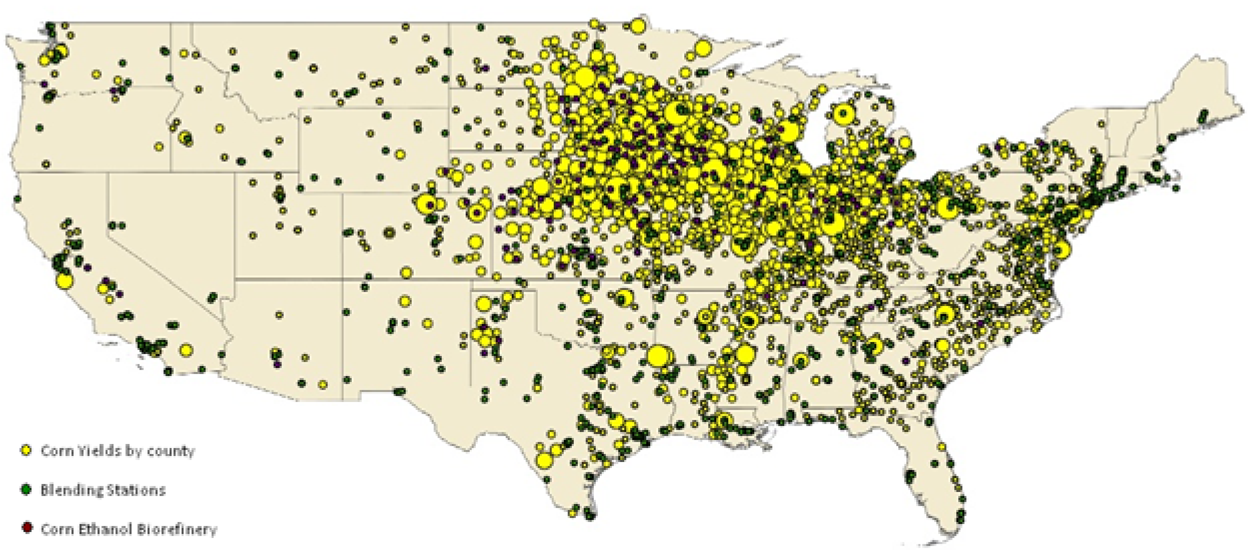
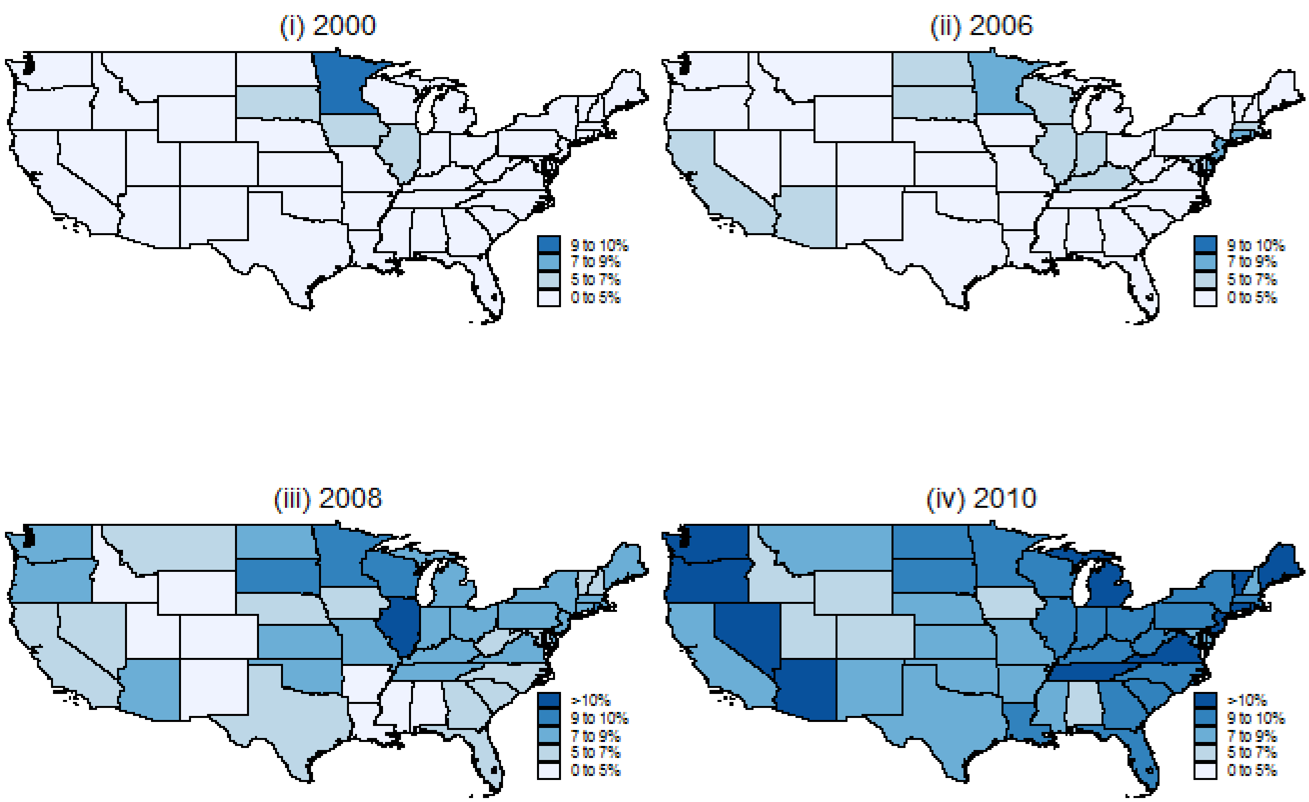


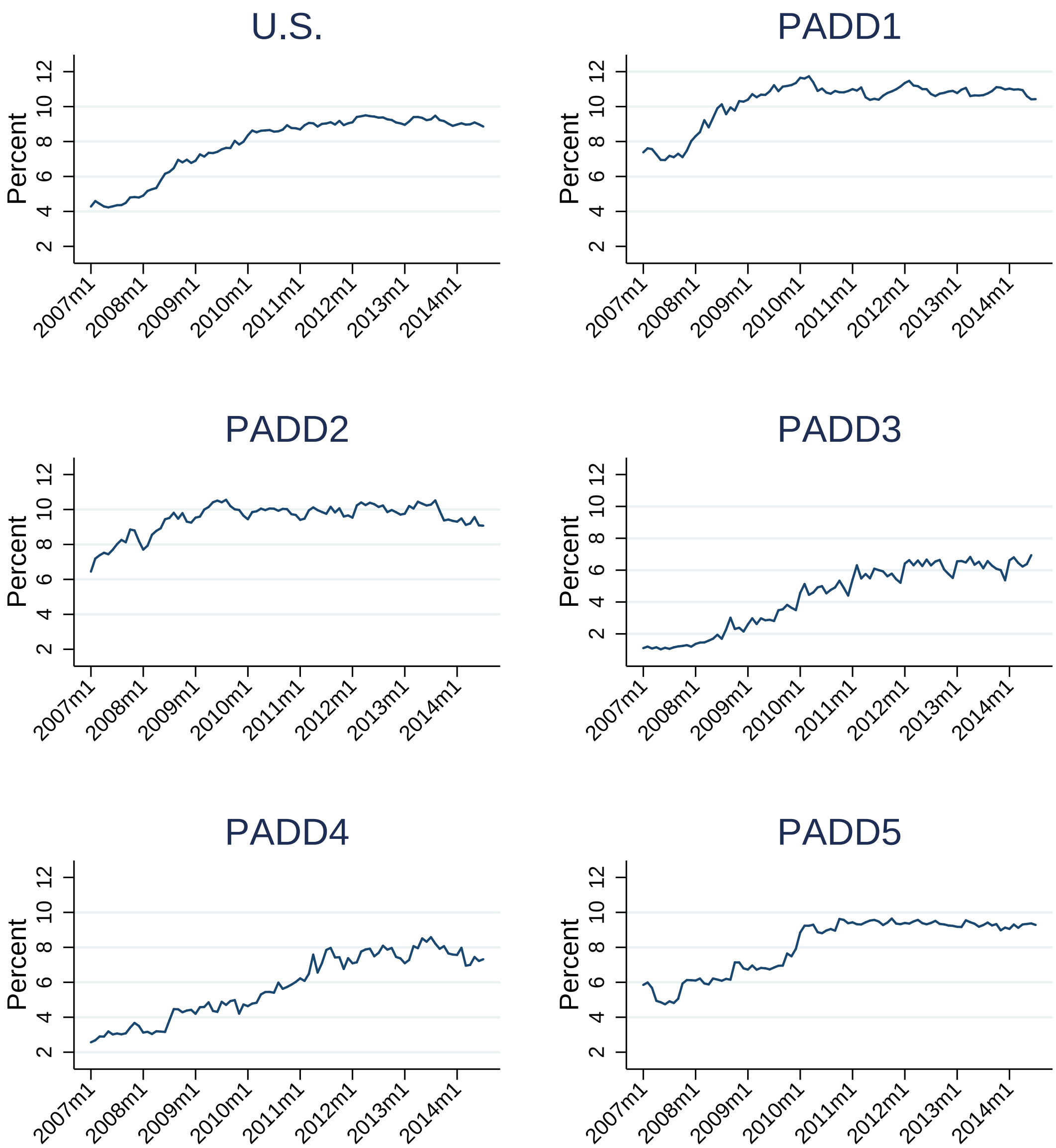
Figure 5: Ethanol Blend Share for Selected Years(%).



Notes: The share of fuel ethanol in finished gasoline have been greater in the Midwestern States even before the mandate (panel I). In 2008, the first year when 2007 RFS became a law, additional ethanol has been absorbed by the Midwestern states. However, as the mandate increased each year, additional ethanol had to be absorbed elsewhere, such as the East Coast and the West Coast. Due to blend wall, future additional ethanol is likely to be absorbed by the Gulf Coast states and states in the Rocky Mountain region.

Source: U.S. Energy Information Administration.

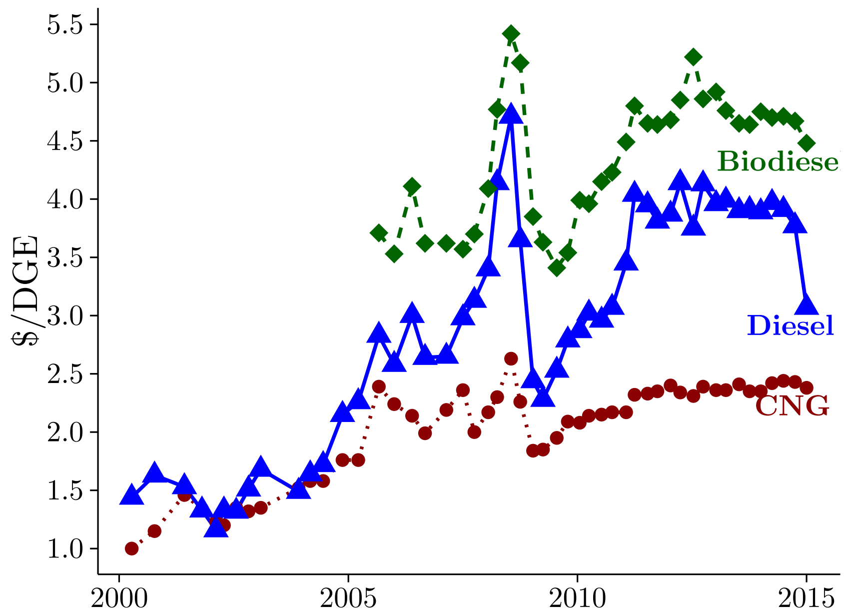
Figure 6: Ethanol Blend Share by PADD Regions



Notes: PADD 1 and PADD 2 regions have reached the blend wall, much earlier than the other PADD regions. PADD 5 is operating near the blend wall, while PADD 3 and PADD 4 are likely to see increased ethanol consumption soon as the RFS mandated volumes are expected to increase further.

Source: U.S. Energy Information Administration. Ethanol Blending Volumes: http://www.eia.gov/dnav/pet/pet_pnp_inpt_dc_nus_mbbl_m.htm, Finished Gasoline Production volumes: http://www.eia.gov/dnav/pet/pet_pnp_refp_dc_nus_mbbl_m.htm. Last accessed: May 10, 2015.

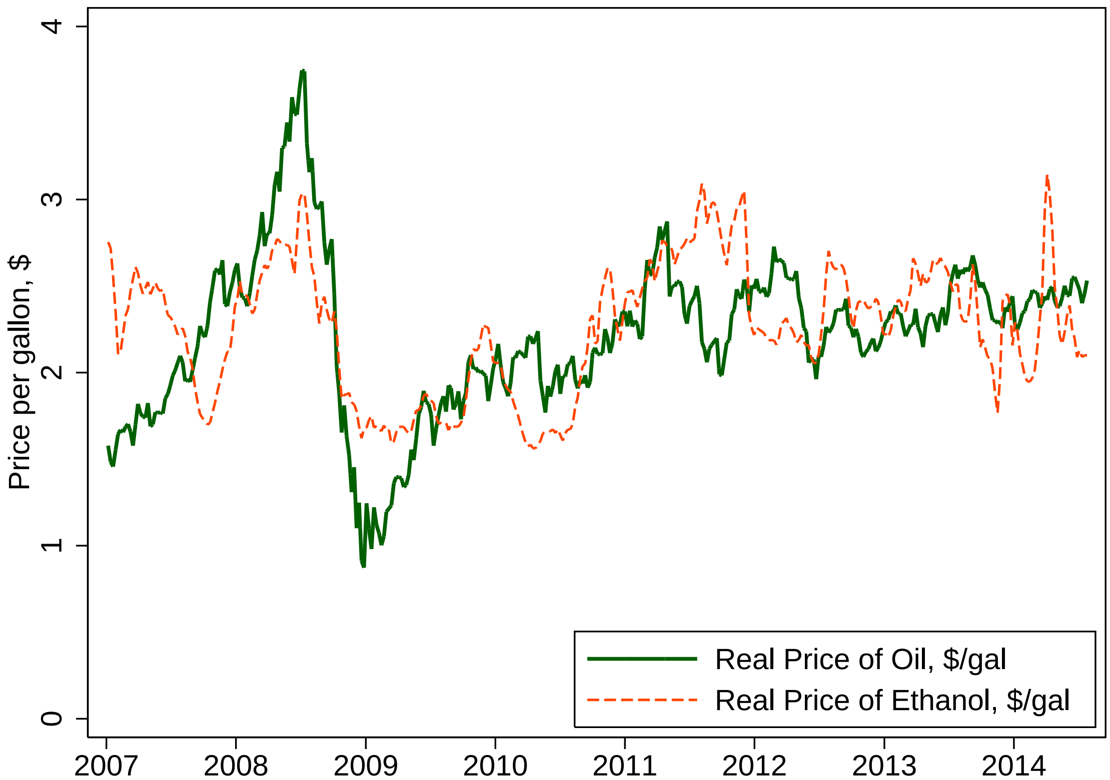
Figure 7: Compressed Natural Gas, Diesel, and Biodiesel Prices in Diesel Gallon Equivalent, 2000-2014



Notes: This Figure compares the national average prices of compressed natural gas (CNG), diesel, and biodiesel (B99/100) prices in per diesel gallon equivalent (DGE). DGE is the amount of CNG (biodiesel) needed to equal the energy content of one gallon of diesel fuel. The prices for CNG and biodiesel are converted from $/gallon to $/DGE using lower heating values for diesel fuel (128,700 BTU/gallon), CNG (114,300 BTU/gallon), and biodiesel (117,100 BTU/gallon), where BTU is British Theermal Units.

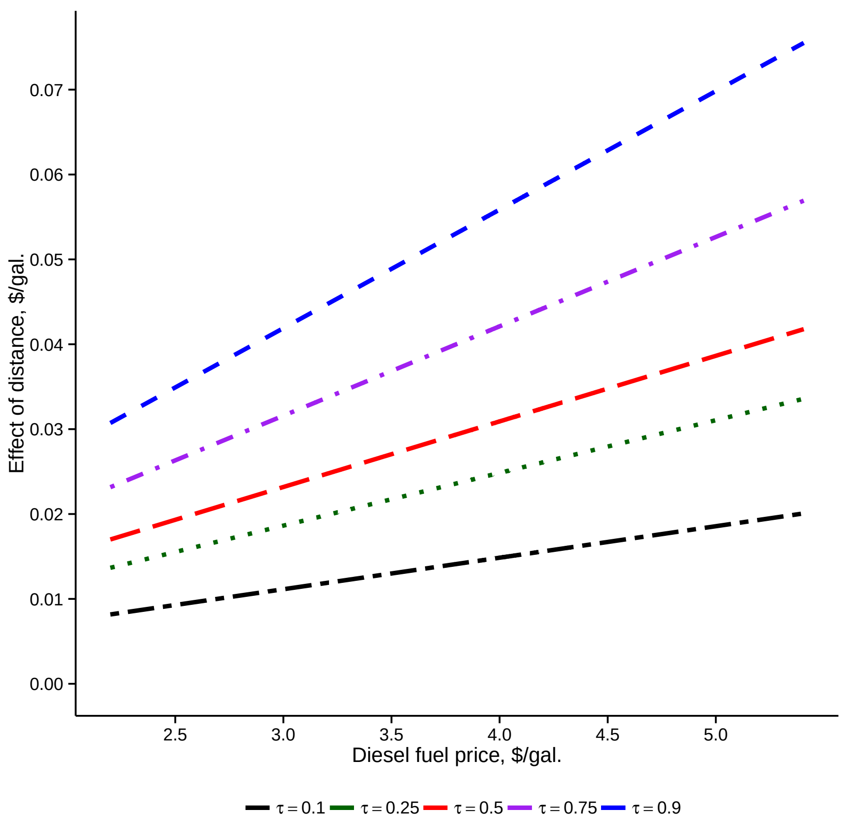
Source: U.S. Department of Energy: Clean Cities Alternative Fuel Price Reports. The reports and data are available at http://www.afdc.energy.gov/fuels/prices.html.

Figure 8: The Cost of Ethanol and Oil



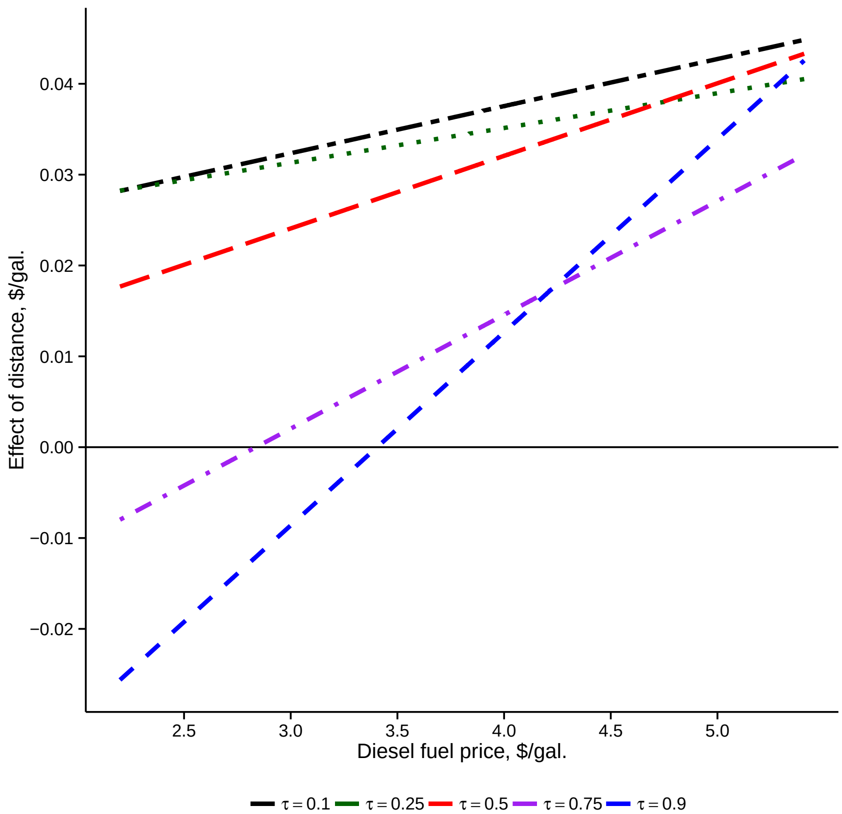
Notes: The figure shows the spot price of ethanol in Iowa ethanol plants and the spot price of WTI oil in Cushing, Oklahoma (converted to per gallon value by dividing oil prices by 42).

Figure 9: Marginal Effect of Distance on Gasoline Price, 2007-2012



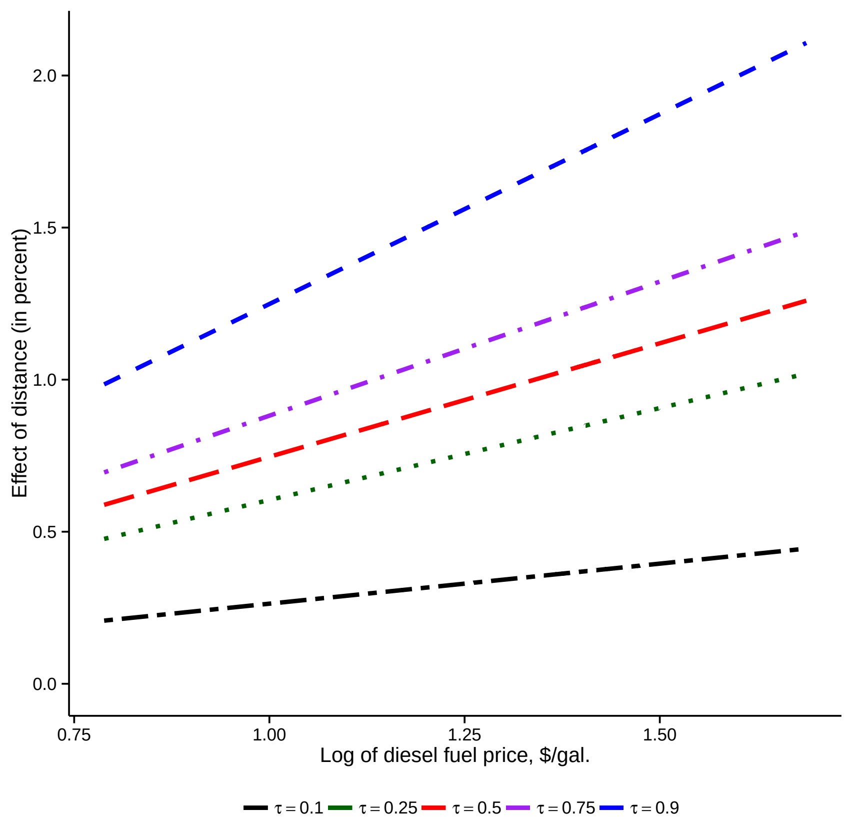
Notes: This Figure shows the marginal effect of distance from ethanol production centers in the Midwest to cities on gasoline prices.

Figure 10: Marginal Effect of Distance on Gasoline Price, 2013-2014



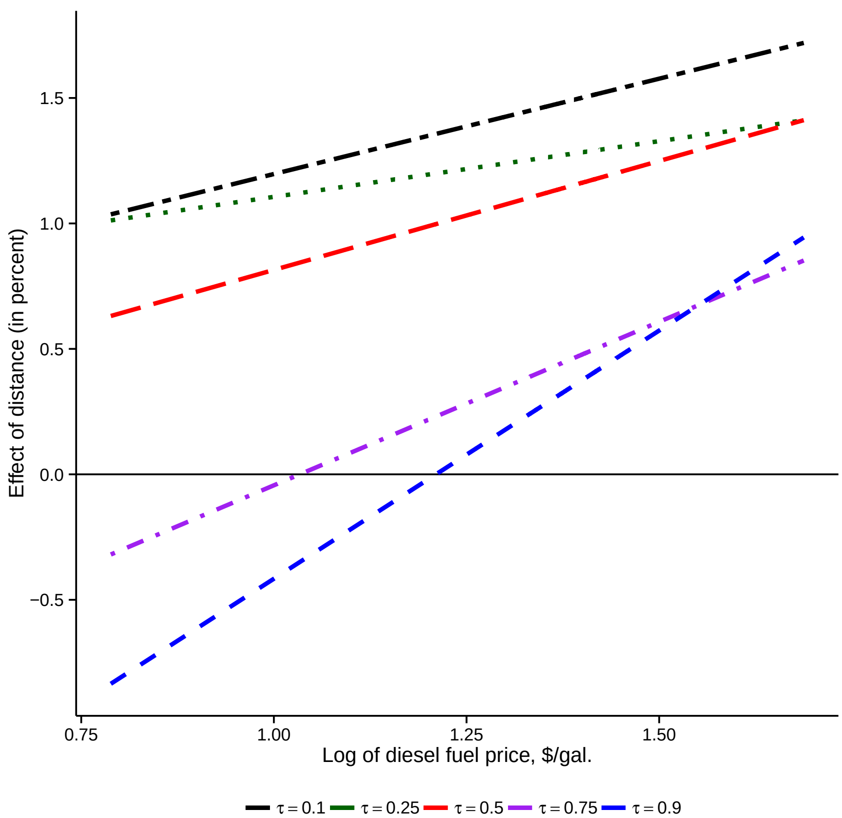
Notes: This Figure shows the marginal effect of distance from ethanol production centers in the Midwest to cities on gasoline prices.

Figure 11: Marginal Effect of Distance on Gasoline Price (in percent), 2007-2012



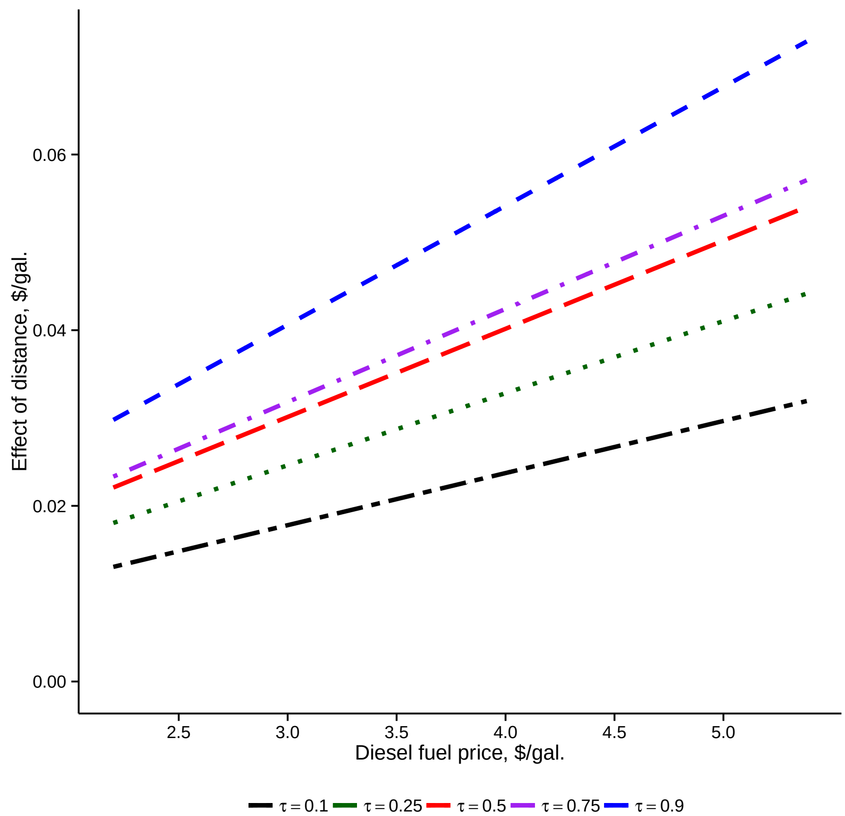
Notes: This Figure shows the marginal percentage effect of distance from ethanol production centers in the Midwest to cities on gasoline prices.

Figure 12: Marginal Effect of Distance on Gasoline Price (in percent), 2013-2014



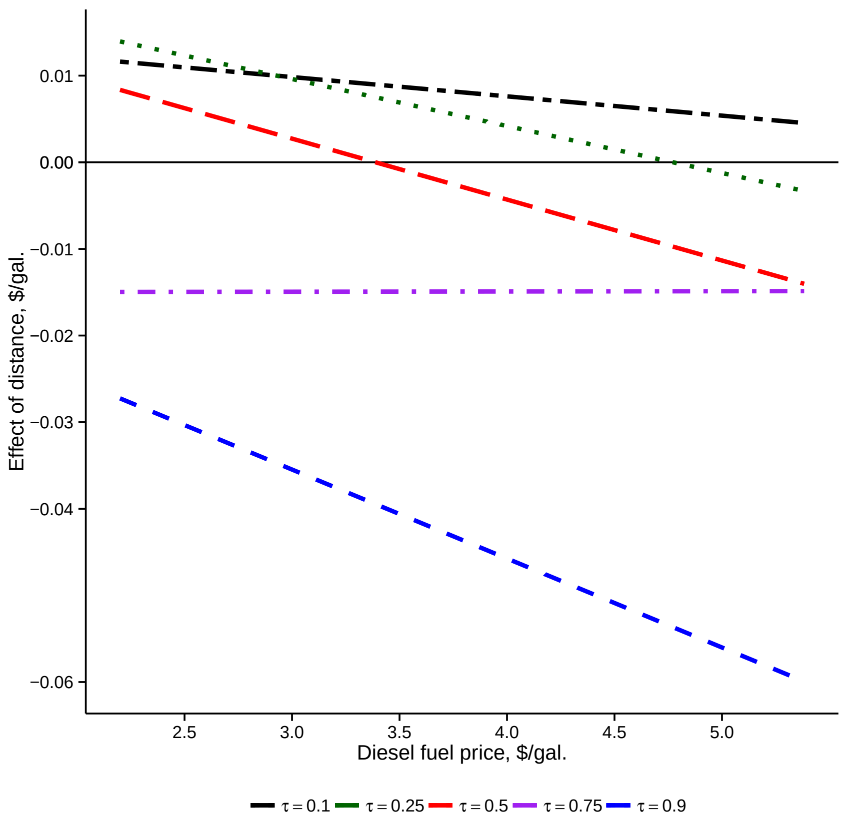
Notes: This Figure shows the marginal percentage effect of distance from ethanol production centers in the Midwest to cities on gasoline prices.

Figure 13: Marginal Effect of Distance on Gasoline Price Excluding Locations in PADD 1 (East Coast), 2007-2012



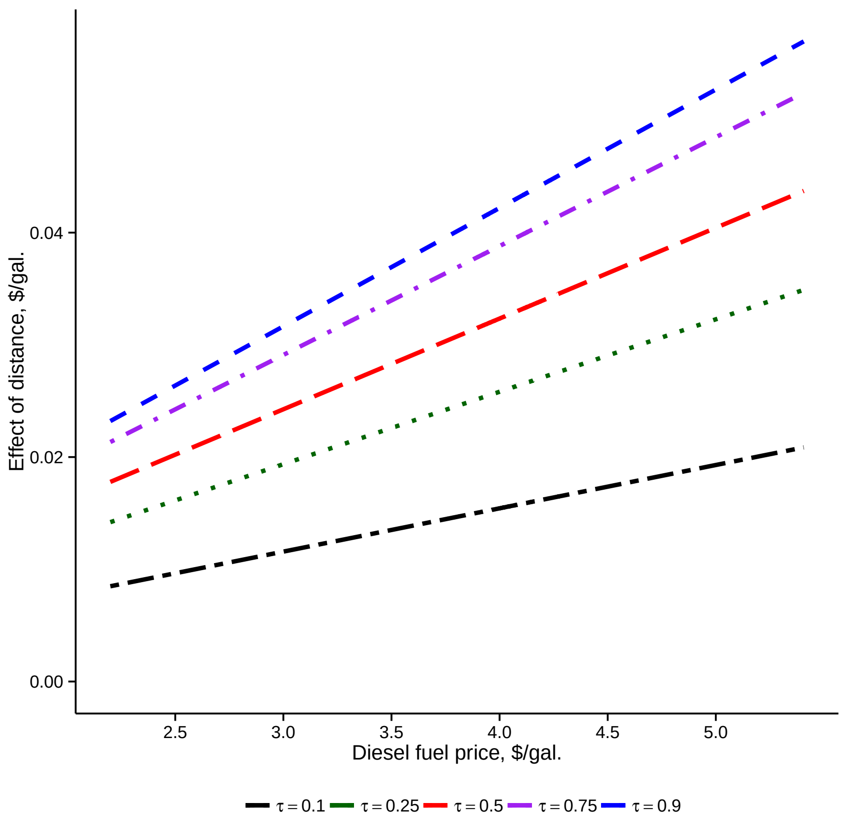
Notes: This Figure shows the marginal effect of distance from ethanol production centers in the Midwest to cities (excluding the cities in PADD 1 region (East Coast) on gasoline prices.

Figure 14: Marginal Effect of Distance on Gasoline Price Excluding Locations in PADD 1 (East Coast), 2013-2014



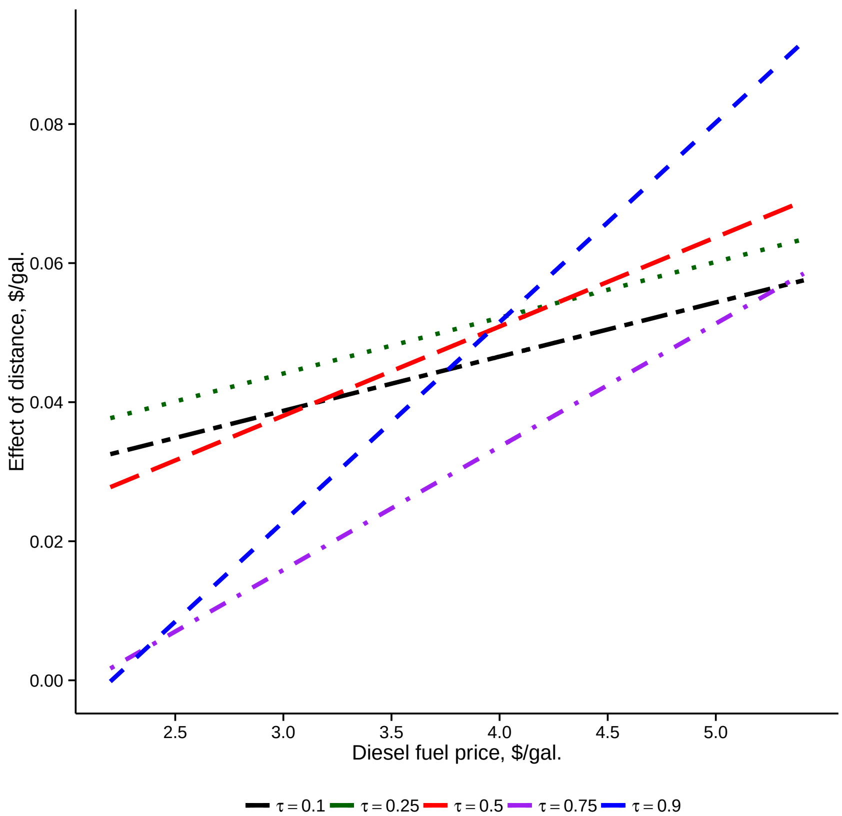
Notes: This Figure shows the marginal effect of distance from ethanol production centers in the Midwest to cities (excluding the cities in PADD 1 region (East Coast) on gasoline prices.

Figure 15: Marginal Effect of Distance on Gasoline Price Excluding Locations in PADD 5 (West Coast), 2007-2012



Notes: This Figure shows the marginal effect of distance from ethanol production centers in the Midwest to cities (excluding the cities in PADD 5 region (West Coast) on gasoline prices.

Figure 16: Marginal Effect of Distance on Gasoline Price Excluding Locations in PADD 5 (West Coast), 2013-2014



Notes: This Figure shows the marginal effect of distance from ethanol production centers in the Midwest to cities (excluding the cities in PADD 5 region (West Coast) on gasoline prices.

Table 1: Rail Ethanol Originations and Terminations by State, 2013

Originations			Terminations		
State	Carloads	Percent	State	Carloads	Percent
Iowa	89,273	33%	Texas	43,417	14%
Nebraska	59,602	22%	California	42,580	14%
South Dakota	34,229	13%	New Jersey	41,691	14%
Illinois	23,752	9%	North Carolina	18,311	6%
Minnesota	21,613	8%	Pennsylvania	16,893	6%
Indiana	11,933	4%	Iowa	16,820	5%
North Dakota	10,215	4%	Georgia	15,672	5%
Kansas	8,231	3%	Virginia	14,472	5%
Texas	5,688	2%	Florida	13,311	4%
Others	4,866	2%	Washington	10,692	3%
			Arizona	8,680	3%
			Alabama	8,308	3%
			New York	7,391	2%
			Maryland	6,192	2%
			Others	43,220	14%
Total	269,402	100%	Total	307,650	100%

Source: "Railroads and Ethanol." Association of American Railroads, July 2015, and STB *Waybill Sample.*

Notes: Most ethanol is moved in 30,000-gallon tank cars. Class I carload originations do not equal Class I carload terminations because some ethanol is originated on U.S. short line railroads.

Table 2: Summary Statistics

Variable	Unit	Mean	Std.Dev.	Min	Max
Distance	1,000 miles	0.68	0.34	0.03	1.45
Wholesale gasoline price	U.S.$ per gal.	2.70	0.50	0.95	5.31
PADD-level oil price	U.S.$ per gallon	2.35	0.46	0.72	3.85
WTI oil price	U.S.$ per gallon	2.25	0.41	0.87	3.75
Ethanol price	U.S.$ per gal.	2.27	0.38	1.56	3.15
Diesel price	U.S.$ per gal.	3.75	0.56	2.20	5.41

Notes: The data is for 200 U.S. cities covering January, 2007-July, 2014. *Distance* is the great circle distance from cities to ethanol production center in the Midwest. All price data are deflated into July, 2014 U.S. dollars.

Table 3: State Ethanol Mandates

State	Ethanol in Gasoline (%)	Effective Date
Florida	9 to 10	Dec 21, 2010
Hawaii	10	1994
Minnesota	9.2 to 10	2003
Missouri	10	Jan 1, 2008
Oregon	10	Nov 1, 2009
Washington	2 to 10	Dec 1, 2008

Source: Weaver et al. (2010); U.S. Department of Energy, Energy Efficiency and Renewable Energy, Alternative Fuels Data Center.

Table 4: Main Results

Dep. var.: Gasoline price	τ 0.10	0.25	0.50	0.75	0.90
Constant	2.013***	2.048***	2.146***	2.280***	2.675***
	(0.010)	(0.022)	(0.019)	(0.052)	(0.053)
$\mathbb{1}\{P_e \leq P_o\} \times P_d$	−0.004***	−0.002**	0.0004	0.001	−0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$\mathbb{1}\{Year > 2012\}$	0.708***	0.700***	0.676***	0.647***	0.341***
	(0.070)	(0.102)	(0.116)	(0.112)	(0.087)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d$	−0.001	−0.003*	−0.009***	−0.012***	−0.016***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
$\mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	0.004***	0.006***	0.008***	0.011***	0.014***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$\mathbb{1}\{Year > 2012\} \times Dist$	0.017**	0.020***	0.0001	−0.036***	−0.072***
	(0.008)	(0.007)	(0.008)	(0.007)	(0.015)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	0.005**	0.004*	0.008***	0.013***	0.021***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)
City fixed effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Month-by-year effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	57,948	57,948	57,948	57,948	57,948

Note: Standard errors are in parentheses. *p<0.1; **p<0.05; ***p<0.01

Table 5: Predicted Increase in Gasoline Prices
in a Few Different Sample Locations

Location	Distance (miles)	Annual Additional Spending ($/year)
Miami, Florida	1,450	14.24
Charlotte, North Carolina	926	10.61
Portland, Maine	1,240	12.11

Notes: Distance is from the ethanol production center in the Midwest. Additional dollars paid per year is assuming yearly average gasoline consumption of 497 gallons for passenger vehicles.

Table 6: Results Using Log-level Model Specification

	τ				
Dep. var.: Log of gasoline price	0.10	0.25	0.50	0.75	0.90
Constant	0.703***	0.719***	0.768***	0.826***	0.986***
	(0.005)	(0.010)	(0.008)	(0.034)	(0.052)
$\mathbb{1}\{P_e \leq P_o\} \times lnP_d$	−0.004***	−0.003**	0.001	0.003**	−0.0003
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$\mathbb{1}\{Year > 2012\}$	0.297***	0.293***	0.268**	0.248**	0.116
	(0.069)	(0.100)	(0.115)	(0.105)	(0.086)
$\mathbb{1}\{Yea > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times lnP_d$	−0.001	−0.003*	−0.010***	−0.013***	−0.014***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)
$\mathbb{1}\{P_e \leq P_o\} \times lnP_d \times Dist$	0.003**	0.006***	0.007***	0.009***	0.012***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
$\mathbb{1}\{Year > 2012\} \times Dist$	0.004	0.007***	−0.001	−0.013***	−0.024***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.006)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times lnP_d \times Dist$	0.008***	0.004**	0.09***	0.013***	0.020***
	(0.003)	(0.002)	(0.002)	(0.002)	(0.005)
City fixed effects	Yes	Yes	Yes	Yes	Yes
Month-by-year effects	Yes	Yes	Yes	Yes	Yes
Observations	57,948	57,948	57,948	57,948	57,948

Note: Standard errors are in parentheses. *p<0.1; **p<0.05; ***p<0.01

Table 7: Results Excluding the Locations in PADD 1 (East Coast)

	τ				
Dep. var.: Gasoline price	0.10	0.25	0.50	0.75	0.90
Constant	2.049***	2.076***	2.192***	2.362***	2.742***
	(0.014)	(0.020)	(0.032)	(0.054)	(0.050)
$\mathbb{1}\{P_e \leq P_o\} \times P_d$	−0.007***	−0.006***	−0.002	0.003***	−0.001
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
$\mathbb{1}\{Year > 2012\}$	0.681***	0.675***	0.639***	0.560***	0.280***
	(0.070)	(0.101)	(0.119)	(0.113)	(0.085)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d$	0.003	0.003	0.0002	−0.009***	0.001
	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)
$\mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	0.006***	0.008***	0.010***	0.011***	0.014***
	(0.001)	(0.001)	(0.001)	(0.002)	(0.002)
$\mathbb{1}\{Year > 2012\} \times Dist$	0.017	0.026***	0.024**	−0.015	−0.005
	(0.012)	(0.009)	(0.010)	(0.012)	(0.022)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	−0.002	−0.005**	−0.007**	0.000	−0.010*
	(0.003)	(0.003)	(0.003)	(0.003)	(0.006)
City fixed effects	Yes	Yes	Yes	Yes	Yes
Month-by-year effects	Yes	Yes	Yes	Yes	Yes
Observations	43,646	43,646	43,646	43,646	43,646

Note: Standard errors are in parentheses. *p<0.1; **p<0.05; ***p<0.01

Table 8: Results Excluding the Locations in PADD 5 (West Coast)

	τ				
Dep. var.: Gasoline price	0.10	0.25	0.50	0.75	0.90
Constant	2.014***	2.048***	2.149***	2.283***	2.725***
	(0.010)	(0.025)	(0.021)	(0.073)	(0.053)
$\mathbb{1}\{P_e \leq P_o\} \times P_d$	−0.003***	−0.002*	0.001	0.002*	0.002
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$\mathbb{1}\{Year > 2012\}$	0.699***	0.695***	0.661***	0.645***	0.287***
	(0.070)	(0.102)	(0.117)	(0.123)	(0.087)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d$	−0.002	−0.006***	−0.012***	−0.015***	−0.020***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.003)
$\mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	0.004***	0.006***	0.008***	0.010***	0.011***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
$\mathbb{1}\{Year > 2012\} \times Dist$	0.015*	0.020***	−0.0005	−0.037***	−0.063***
	(0.009)	(0.007)	(0.008)	(0.009)	(0.015)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	0.008***	0.008***	0.013***	0.018***	0.029***
	(0.003)	(0.002)	(0.002)	(0.003)	(0.004)
City fixed effects	Yes	Yes	Yes	Yes	Yes
Month-by-year effects	Yes	Yes	Yes	Yes	Yes
Observations	54,399	54,399	54,399	54,399	54,399

Note: Standard errors are in parentheses. *p<0.1; **p<0.05; ***p<0.01

Appendix: Marginal Effect of Distance on Gasoline Price

1. Table 4 is estimated using the main specification given in equation (7). For notational simplicity we drop the subscripts for time and city:

$$P_g = \beta_0 + \beta_1 \mathbb{1}\{P_e \leq P_o\} \times P_d + \beta_2 \mathbb{1}\{Year > 2012\} + \beta_3 \mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d$$
$$+ \beta_4 \mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist + \beta_5 \mathbb{1}\{Year > 2012\} \times Dist$$
$$+ \beta_6 \mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist + \lambda + f_{my} + \epsilon$$

By taking the derivative of gasoline price with respect to distance, we get the marginal effect of distance on gasoline price:

1) 2007-2012:

$$\frac{\partial P_g}{\partial Dist} = \beta_4 \mathbb{1}\{P_e \leq P_o\} \times P_d \tag{13}$$

2) 2013-2014:

$$\frac{\partial P_g}{\partial Dist} = \beta_5 \mathbb{1}\{Year > 2012\} + \beta_6 \mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d \tag{14}$$

Note that the marginal distance effect depends on the level of diesel fuel price. We plot these marginal distance effects against different values of diesel fuel price in Figures 9 and 10, respectively. Two things follow from the figures:

- The marginal effect of distance increases as the diesel fuel price increase.
- The marginal effect of distance depends on the level of gasoline prices as well shown by different quantile lines.

2. In Table 6 we estimate a log-level specification as following:

$$lnP_g = \beta_0 + \beta_1 \mathbb{1}\{P_e \leq P_o\} \times lnP_d + \beta_2 \mathbb{1}\{Year > 2012\} + \beta_3 \mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times lnP_d$$
$$+ \beta_4 \mathbb{1}\{P_e \leq P_o\} \times lnP_d \times Dist + \beta_5 \mathbb{1}\{Year > 2012\} \times Dist$$
$$+ \beta_6 \mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times lnP_d \times Dist + \lambda + f_{my} + \epsilon$$

This specification assumes similar percentage marginal effects of distance across different locations. By taking the derivative of gasoline price with respect to distance, we get the marginal effect of distance on gasoline price:

For 2007-2012 period:

$$d[lnP_g] = \beta_4 \mathbb{1}\{P_e \leq P_o\} \times lnP_d \times dDist \quad (15)$$

$$\frac{dP_g}{P_g} = \beta_4 \mathbb{1}\{P_e \leq P_o\} \times lnP_d \times dDist \quad (16)$$

$$\frac{100 \times \frac{dP_g}{P_g}}{dDist} = 100 \times \beta_4 \mathbb{1}\{P_e \leq P_o\} \times lnP_d \quad (17)$$

$$\frac{\%\Delta P_g}{\Delta Dist} = 100 \times \beta_4 \mathbb{1}\{P_e \leq P_o\} \times lnP_d \quad (18)$$

For 2013-2014 period:

$$d[lnP_g] = \beta_5 dDist + \beta_6 \mathbb{1}\{P_e \leq P_o\} \times lnP_d \times dDist \quad (19)$$

$$d[lnP_g] = [\beta_5 + \beta_6 \mathbb{1}\{P_e \leq P_o\} \times lnP_d] \times dDist \quad (20)$$

$$\frac{100 \times \frac{dP_g}{P_g}}{dDist} = 100 \times [\beta_5 + \beta_6 \mathbb{1}\{P_e \leq P_o\} \times lnP_d] \quad (21)$$

$$\frac{\%\Delta P_g}{\Delta Dist} = 100 \times [\beta_5 + \beta_6 \mathbb{1}\{P_e \leq P_o\} \times lnP_d] \quad (22)$$

Note that the marginal distance effect depends on the log of diesel fuel price. We plot these marginal distance effects against different values of diesel fuel price (in logs) in Figures 11 and 12, respectively.

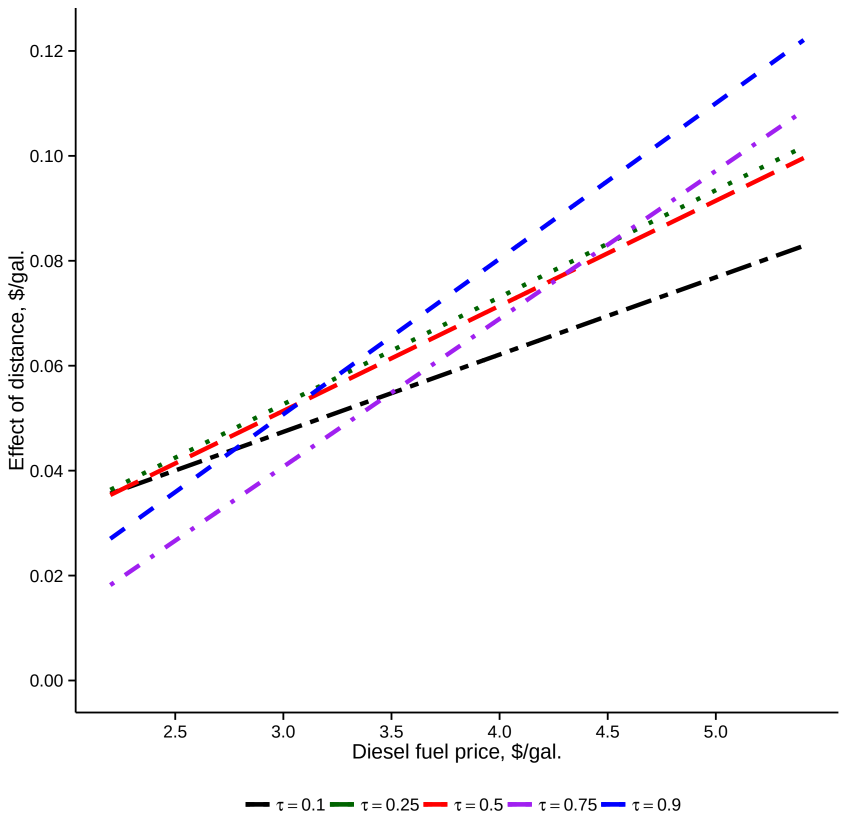
3. The marginal distance effects in the remaining Figures are constructed as in item 1 above.

Table 9: Results Excluding the Locations in PADD 3 (Gulf Coast) and PADD 5 (West Coast)

	τ				
Dep. var.: Gasoline price	0.10	0.25	0.50	0.75	0.90
Constant	2.048***	2.080***	2.182***	2.308***	2.758***
	(0.011)	(0.025)	(0.019)	(0.072)	(0.051)
$\mathbb{1}\{P_e \leq P_o\} \times P_d$	−0.001	0.002	0.005***	0.011***	0.011***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
$\mathbb{1}\{Year > 2012\}$	0.727***	0.722***	0.675***	0.636***	0.242***
	(0.070)	(0.102)	(0.116)	(0.123)	(0.086)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d$	−0.001	−0.007***	−0.009***	−0.021***	−0.025***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.005)
$\mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	0.002	0.004***	0.005***	0.006***	0.008***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)
$\mathbb{1}\{Year > 2012\} \times Dist$	0.003	−0.009	−0.009	−0.044***	−0.038*
	(0.009)	(0.008)	(0.009)	(0.009)	(0.021)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	0.015***	0.020***	0.020***	0.028***	0.030***
	(0.003)	(0.002)	(0.003)	(0.003)	(0.006)
City fixed effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Month-by-year effects	*Yes*	*Yes*	*Yes*	*Yes*	*Yes*
Observations	43,869	43,869	43,869	43,869	43,869

Note: Standard errors are in parentheses. *p<0.1; **p<0.05; ***p<0.01

Figure 17: Marginal Effect of Distance on Gasoline Price Excluding Locations in PADD 3 (Gulf Coast) and PADD 5 (West Coast), 2013-2014



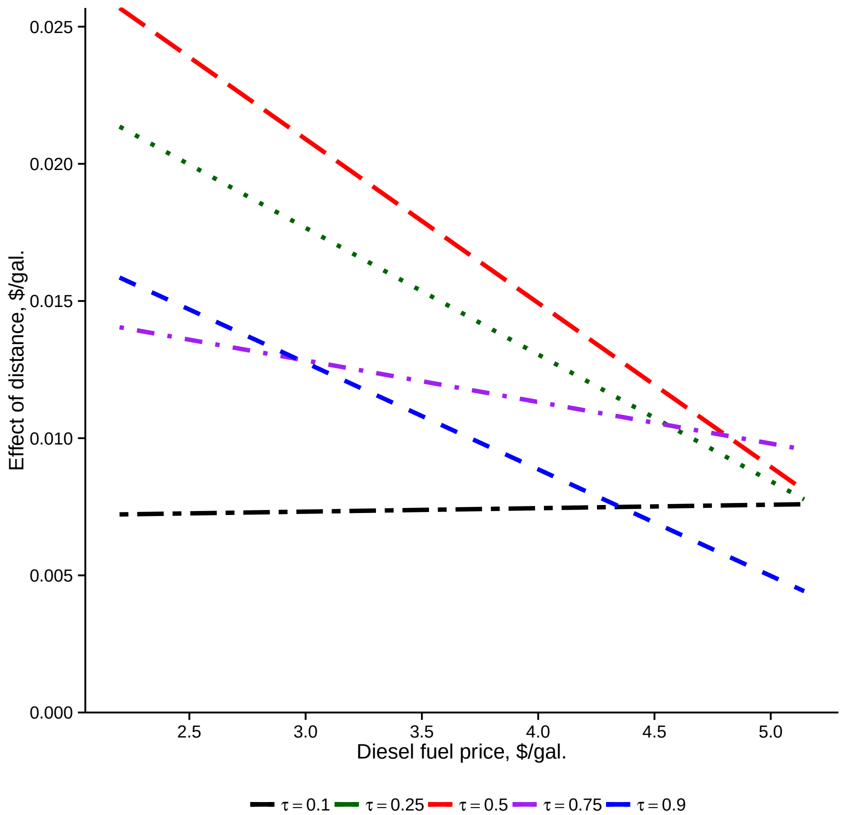
Notes: This Figure shows the marginal effect of distance from ethanol production centers in the Midwest to cities (excluding the cities in PADD 3 (Gulf Coast) and PADD 5 (West Coast) on gasoline prices.

Table 10: Results Excluding the Locations in PADD 1 (East Coast) and PADD 5 (West Coast)

	τ				
Dep. var.: Gasoline price	0.10	0.25	0.50	0.75	0.90
Constant	2.047***	2.079***	2.193***	2.377***	2.756***
	(0.013)	(0.032)	(0.030)	(0.049)	(0.053)
$\mathbb{1}\{P_e \leq P_o\} \times P_d$	−0.007***	−0.005***	−0.001	0.004***	0.001
	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)
$\mathbb{1}\{Year > 2012\}$	0.681***	0.654***	0.619***	0.529***	0.245***
	(0.070)	(0.104)	(0.118)	(0.111)	(0.087)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d$	0.003	0.0002	−0.001	−0.010***	−0.005
	(0.003)	(0.002)	(0.002)	(0.003)	(0.003)
$\mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	0.008***	0.012***	0.012***	0.011***	0.010***
	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)
$\mathbb{1}\{Year > 2012\} \times Dist$	0.007	0.032***	0.039***	0.017	0.024
	(0.014)	(0.012)	(0.010)	(0.015)	(0.015)
$\mathbb{1}\{Year > 2012\} \times \mathbb{1}\{P_e \leq P_o\} \times P_d \times Dist$	0.0001	−0.005	−0.006*	−0.002	−0.004
	(0.004)	(0.003)	(0.003)	(0.004)	(0.004)
City fixed effects	Yes	Yes	Yes	Yes	Yes
Month-by-year effects	Yes	Yes	Yes	Yes	Yes
Observations	40,097	40,097	40,097	40,097	40,097

Note: Standard errors are in parentheses. *p<0.1; **p<0.05; ***p<0.01

Figure 18: Marginal Effect of Distance on Gasoline Price Excluding Locations in PADD 1 (East Coast) and PADD5 (West Coast), 2013-2014



Notes: This Figure shows the marginal effect of distance from ethanol production centers in the Midwest to cities (excluding the cities in PADD 1 (East Coast) and PADD 5 (West Coast) on gasoline prices.