The Impact of the Renewable Fuel Standard on US Oil Refineries

Jesse Burkhardt*
Colorado State University

March 26, 2019

Abstract

This paper uses a confidential refinery-level dataset to estimate how unexpected changes in the costs of the Renewable Fuel Standard (RFS) affected US oil refinery prices and production decisions for regulated and non-regulated products between 2012 and 2014. The RFS mandates blending of biofuels with conventional gasoline and diesel. Each gallon of biofuel blended with conventional fuel generates a renewable fuel credit (RIN). Refineries comply with the RFS by purchasing RINs from blenders and retiring them with the EPA. I find that RIN costs were fully passed through to wholesale gasoline and diesel prices on average, consistent with previous literature and a necessary condition to ensure the effectiveness of the RFS. Furthermore, I estimate full pass-through in all regions of the US, with the exception of the Eastern Seaboard. I also find that RIN cost increases are associated with higher jet fuel production, a non-regulated product, and with decreased jet fuel prices. Finally, I corroborate previous findings by showing that refinery specific input cost shocks are not fully passed-through to wholesale output prices. These results, combined with other estimates in the literature, suggest that on average the RFS is functioning efficiently and that the wholesale petroleum market is highly competitive.

Keywords: petroleum refining; pass-through; emissions leakage.

*Department of Agricultural and Resource Economics, Colorado State University, 1200 Center Ave. Mall, Fort Collins, CO 80523, phone: 503-312-8943, email: jesse.burkhardt@colostate.edu.

1 Introduction

The Renewable Fuel Standard (RFS) is one of the most important policies currently impacting the oil refining industry. Under the RFS, oil refineries are mandated to blend a certain percentage of biofuels into each gallon of gasoline and diesel sold. In 2017 for example, the RFS mandated 25 billion gallons of biofuels be blended with conventional gasoline and diesel, representing approximately 13.6% of the total gasoline and diesel consumption for that year.[1] Refineries comply with the RFS by purchasing renewable fuel credits, called Renewable Identification Numbers or RINs, and retiring them with the Environmental Protection Agency (EPA). In doing so, the RFS taxes gasoline and diesel fuels while leaving other petroleum products untaxed.

One of the long-run goals of the RFS is to encourage innovation in biofuel production and a transition from a non-renewable to a renewable fuel vehicle fleet. This transition, and therefore the effectiveness of the policy, will depend on the degree to which the costs of the RINs are passed through to conventional and biofuel prices. Several recent papers have estimated the pass-through of RIN prices (taxes and subsidies) to wholesale and station level retail fuel prices (Li and Stock 2019; Lade and Bushnell 2019; Knittel, Meiselman, and Stock 2017; Pouliot, Smith, and Stock 2017). Yet, there is no empirical evidence on the effect of the RFS on US refineries, an important omission in light of policy debate regarding the exemption of small refineries. In this paper, I use highly detailed data from the Energy Information Administration on US refinery outputs and prices to evaluate the effect of the RFS on refinery prices and production decisions.

This paper makes several important contributions. First, I estimate the pass-through rate of RINs in regulated and non-regulated petroleum product markets. Consistent with previous estimates at the wholesale level (Knittel, Meiselman, and Stock 2017; Pouliot, Smith, and Stock 2017), I find that oil refineries fully passed-through changes in RIN costs to wholesale gasoline and diesel prices between 2012-2014 on average. This result provides an important robustness check for studies that evaluate downstream pass-through.

Second, I estimate pass-through heterogeneity across several dimensions. The EPA

[1] The 25 billion gallons refers to the Clean Air Act mandated volumes for 2017. The Environmental Protection Agency has the authority to reduce the mandated volumes, which it has done each year. Thus, the actual amount of biofuel blended with conventional fuels, the Renewable Volume Obligation, has been consistently lower than the mandated volumes.

often grants small refineries exemptions from RFS compliance. If RIN costs are fully passed-through to gasoline and diesel prices nationwide, then small refineries that are exempt from RFS compliance may receive substantial benefits from the policy. Indeed, I find the pass-through rates of the smallest and largest firms are not statistical different from one another in the gasoline market. Moreover, similar to Muehlegger and Sweeney (2017), I find that aggregate crude oil price trends, such as the Brent spot price, are fully passed-through to refinery specific output prices but refinery-specific crude oil costs are not fully passed-through. Both of these pieces of evidence suggest that the market is fully integrated, consistent with economic theory.

I also estimate RIN cost pass-through by PADD to explore regional heterogeneity. I find complete pass-through for the Midwest, the Gulf States, the Rocky Mountain Region, and the West Coast, but incomplete pass-through along the Eastern Seaboard. These findings are consistent with Pouliot, Smith, and Stock (2017) who estimate RIN pass-through at gasoline terminals in 57 large cities across the US. Pouliot, Smith, and Stock (2017) find RIN costs are fully passed-through to rack prices in the Midwest (where most of the ethanol is produced) and Gulf states. In contrast, they find less than complete pass-through to rack prices along the Eastern Seaboard. Thus, these results present an important robustness check for the estimates presented in Pouliot, Smith, and Stock (2017) and show that the incomplete pass-through along the East Coast is driven by the refineries in that region.

Third, incomplete regulations such as the RFS, which apply to only a subset of products produced by a particular industry, allow firms to substitute non-regulated production for regulated production (Fowlie 2009; Auffhammer and Kellogg 2011). Such incomplete regulations can therefore impact non-regulated product prices and marginal costs and can potentially lead to emissions leakage. An important feature of refineries is that they are multi-product firms by nature. All of the products refineries produce come from a common input and utilize common production technology. Thus, taxes that apply to the output of only certain regulated products, e.g., gasoline and diesel, will also affect the marginal cost of capital of non-regulated products such as jet fuel. Indeed, I find that changes in RIN costs are associated with changes in non-regulated fuel prices and production. Specifically, increased RIN costs are associated with lower ultra-low sulfur diesel production and higher jet fuel production. Correspondingly, I also find RIN cost increases are associated with lower jet fuel prices, consistent with an outward shift in the jet fuel supply curve.

The remainder of the paper is organized as follows. In the following section, I discuss my paper in the context of several strands of related literature. Section 3 provides some background on the refining process and the Renewable Fuel Standard. In Section 4, I outline the data set I construct and provide summary statistics. In Section 5 I present results and discussion, and Section 6 concludes.

2 Related Literature

This paper contributes to a growing literature on the environmental regulation of the petroleum industry and pass-through of input costs to fuel prices. There is ample evidence that fuel content regulations under the Clean Air Act (CAA) resulted in increased prices for regulated fuels (Muehlegger 2006; Brown et al. 2008). Recent structural work by Sweeney (2015) shows that content regulations under the CAA increased refinery costs by 7 cents per gallon and 3 cents per gallon for reformulated and low sulfur diesel production, respectively.

With respect to the RFS, several recent papers estimate the pass-through rate of RIN subsidies and costs to retail E85 and E10 prices. Li and Stock (2019) find that RIN prices are fully passed through to retail E10 prices within one month but pass-through to E85 retail prices exhibites more heterogeneity. For instance, they estimate pass-through of RIN subsidies to retail E85 prices of 0.53 with higher pass-through rates for gas stations with more nearby competitors. Similarly, Lade and Bushnell (2019) estimate the pass-through of RIN subsidies to retail E85 prices and find pass-through rates and speed depend on local market structure.

Two other papers have evaluated the pass-through rate of RIN costs to wholesale petroleum product prices. Knittel, Meiselman, and Stock (2017) estimate an average long run pass-through rate of 1 across diesel and gasoline between 2013 and 2015, with considerable variation at the daily and weekly level. In a related paper, Pouliot, Smith, and Stock (2017) estimate RIN pass-through to aggregate rack prices across 57 major cities in the US. Their results also point generally towards complete pass-through. However, they find some differences between branded and unbranded fuels and they estimate less than complete pass-through along the East Coast. There are two main differences between the results presented in this paper and those presented by Knittel, Meiselman, and Stock (2017) and Pouliot, Smith, and Stock (2017). First, I estimate refiner specific pass-through at the rack or bulk distribution terminals, the level at which wholesale transactions occur, while Knittel, Meiselman, and Stock (2017) estimate pass-through in the wholesale spot market. Second, I evaluate the impact of changes in RIN costs on production decisions and non-regulated product prices.

Evaluating pass-through at the rack is important for three reasons. First, it allows me to estimate pass-through heterogeneity. For instance, I estimate pass-through by refiner capacity and by region of the US. Second, estimating refiner specific pass-through speaks to a broader question about the geographic scope of petroleum product markets. This paper, in conjunction with Muehlegger and Sweeney (2017), shows that refinery output prices move in tandem with prices that are homogeneous across the US, for instance Brent spot prices and RIN prices. However, because refinery output prices are more or less pegged to national transportation fuel price trends, refineries do not fully pass-through local input cost shocks such as regional crude price changes. This suggests that the national petroleum market is integrated and refineries make short term losses and gains based on local input market conditions. Third, the estimates in this paper serve as a robustness check on previous estimates that use spot market prices.

There is also a large literature describing heterogeneity in the pass-through rates of input costs to fuel prices. For instance, Marion and Muehlegger (2011) and Stolper (2016) find tax pass-through rates to retail fuel prices are heterogeneous and depend on market conditions and local regulatory structure. Muehlegger and Sweeney (2017) show that refinery specific input cost shocks exhibit lower pass-through rates than do national-level input cost shocks. Likewise, Borenstein and Shepard (2002) show that refineries pass-through input price increases at a faster rate than input price decreases.

3 Policy Background

The Energy Policy Act of 2005 established the RFS under the umbrella of the Clean Air Act. The RFS was subsequently revised under the Energy Independence and Security Act of 2007. The latest policy seeks to increase domestic biofuel consumption to 36 billion gallons (bgals) per year by 2022 by mandating that the total volume of gasoline and diesel sold in the US is blended with a minimum volume of renewable fuel.[2] The blending proportion is set annually by the EPA and is referred to as the blend mandate. Additional goals of the RFS are to significantly reduce greenhouse gas emissions from the consumption of transportation fuels, to increase energy security by reducing petroleum imports, and to improve rural economies (EPA 2015a). This section outlines how the RIN tax obligation is calculated and why variation in the RIN tax obligation can be considered exogenous to refineries.

The EPA keeps track of the quantity of renewable fuel blended with conventional fuel via a system of tradable credits called RINs. Each gallon of renewable fuel that is produced in the US or imported to the US generates a RIN. Obligated parties under the RFS (petroleum refineries and petroleum importers) purchase RINs from renewable fuel producers. The RIN is detached from the renewable fuel when the renewable fuel is blended with conventional fuel. The obligated parties must retire RINs to the EPA in proportion to the quantity of conventional gasoline and diesel that they produce. If the obligated party has a surplus of RINs, they can sell excess RINs to other obligated parties that are in need of additional RINs, creating a market for RINs. Thus, RIN trading is a transfer payment between refineries and biofuel producers and effectively taxes gasoline and diesel production while subsidizing biofuel production.[3] In other words, the rack price of obligated fuels, the primary price used in this paper, should be a function of the refiner's production costs and the RIN tax obligation associated with gasoline production. It is important to note that only gasoline and diesel are regulated under the RFS, while other products such as jet and aviation fuel are unregulated.

The RFS specifies four nested categories for renewable fuels: total or conventional

[2]The EPA has the authority to reduce the blending mandates and it has consistently done so each year. Therefore, the legislated volumes have not been on track to meet the 36 billion gallon target.

[3]Other parties including fuel retailers and speculators can also purchase RINs.

renewable fuels (such as ethanol), advanced biofuel, biomass-based diesel (BBD), and cellulosic.[4] Each of the four categories is associated with a category specific RIN and a category specific blending requirement, or blending percentage. Given the nested structure, it is well understood that the price of the four RINs can be aggregated to an overall RIN tax obligation (See Knittel, Meiselman, and Stock (2017) or Lade, Lin Lawell, and Smith (2018) for details).[5]

A key identifying assumption in this paper, and one that has been employed by Knittel, Meiselman, and Stock (2017), Lade and Bushnell (2019), and Li and Stock (2019) is that shocks to the RIN tax obligation were exogenous to refinery decisions and more broadly, gasoline and diesel prices.[6] Figure 1 shows the aggregate RIN tax obligation for 2012 through 2014. Prior to 2013, the RIN tax obligation was low and fairly stable. However in 2013 there was a substantial spike in the RIN tax obligation, with some volatility carried through to 2014. To understand the shock in the RIN tax obligation in 2013, it is important to understand the nature of ethanol blending. Ethanol is blended with gasoline at three main levels: E0 containing 0% ethanol; E10 containing 10% ethanol; and E85 containing roughly 70-85% ethanol. The vast majority of vehicles on the road can burn fuel that contains up to 15% ethanol. However, E10 is granted a Reid vapor pressure or RVP waiver in the summer while E15 is not. This means that E15 cannot be sold year round (Irwin 2018). This limitation to E10 is commonly referred to as the blend wall and is one of the primary reasons for the shock in the RIN tax obligation in 2013.

The RINs are also a subsidy payment to the ethanol producers and are equal to the difference between the supply price of ethanol and the demand price for ethanol. As

[4]Cellulosic fuels are biofuels produced from non-edible portions of plants, biodiesel is commonly produced from soybean or canola oil, advanced biodiesel is biofuel with life-cycle emissions at least 50% below baseline values, and the overall renewable biofuel is all approved biofuel including biofuel produced from cornstarch such as ethanol. As is common in the literature, I ignore the cellulosic mandate when calculating the aggregate RIN obligation (Knittel, Meiselman, and Stock 2017; Lade, Lin Lawell, and Smith 2018). The blending requirement for cellulosic fuels is much lower than the other requirements meaning a minor amount of the renewable fuels blended into the market have been cellulosic fuels.

[5]For example, in 2013, the blending standards required that for each gallon of gasoline or diesel sold, 0.0005 cellulosic RINs, 0.0113 biomass-based diesel (BBD) RINs, 0.0162 advanced RINs, and 0.0974 conventional renewable fuel RINs were to be retired (C.F.R. 2015). The nested structure of the RIN obligations implies that for every gallon of fuel sold, refineries must sell at least 0.0113 gallons of biodiesel. After that is satisfied, refineries need an additional 0.0162-0.0113=0.0049 gallons of advanced biofuel. After that, they need an additional 0.0974-0.0162=0.0812 gallons of conventional renewable fuels. Therefore, in practice the aggregate RIN tax obligation is 0.0113 times the biodiesl RIN price, plus 0.0049 times the advanced RIN price, plus 0.0812 times the overall RIN price. In practice, the formula is adjusted for the blending mandates of different years. In 2011, the mandates were 0.0069, 0.0078, and 0.081 and in 2012, the mandates were 0.0091, 0.0121, and 0.0923 for BBD, advanced, and conventional renewable fuels respectively (C.F.R. 2015).

[6]As a robustness check, Lade and Bushnell (2019) instrument RIN prices with indicators for key policy decisions and find that pass-through estimates are robust to IV specifications.

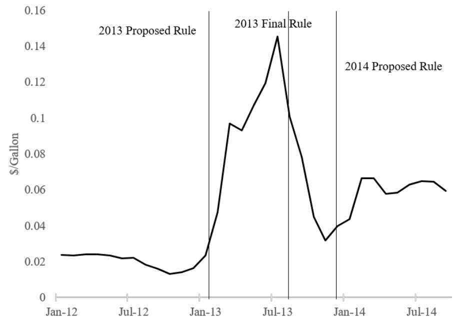

Figure 1: RIN tax obligation per gallon of gasoline and diesel produced

such, RIN prices, and therefore the subsidy payments, largely depend on the marginal gallon of ethanol sales (Burkholder 2015). When the RFS mandate is below the blend wall, the marginal gallon of ethanol is sold as E10. E10 contains 3% less energy per volume than E0 so refineries and blenders can sell E10 at virtually the same price as E0. However, if the blend wall is breached, as was initially proposed by the EPA in early 2013 (1st vertical line in Figure 1), the marginal gallon of ethanol must be sold as E85. E85 contains 33% less energy per volume than E0 meaning a car burning E85 will travel a noticeably shorter distance than a car burning E0. Consumers are therefore willing to pay less for a gallon of E85 than a gallon of E0 or E10. Thus, the demand price for ethanol is relatively high when the marginal gallon of ethanol sales is E10 and relatively low when the marginal gallon of ethanol sales is E85.[7] This implies the subsidy payment, and therefore RIN prices, increase when the blend wall is breached and E85 is the marginal fuel. Additionally, ethanol and biodiesel RIN prices converged in 2013, which suggests that refineries responded by over complying with the biodiesel mandate as some biodiesel RINs can be substituted for ethanol RINs (Lade, Lin Lawell, and Smith 2018; Irwin 2014).

The fact that the 2013 proposed rule was expected to breach the blend wall explains the initial increase in the RIN tax obligation in 2013 but does not fully explain the decrease in the RIN tax obligation in the latter half of 2013 or the subsequent variation in 2014. As discussed in Knittel, Meiselman, and Stock (2017) and Lade, Lin Lawell, and Smith (2018), the additional volatility in the RIN tax obligation was driven by policy

[7] While differences in energy content between E0, E10, and E85 can explain some of the variation in ethanol prices, other factors are also important. For instance, refineries use ethanol as an octane booster, which creates additional demand for ethanol.

uncertainty. In particular, Lade, Lin Lawell, and Smith (2018) show that the largest drivers of the variation in RIN tax obligation were three separate policy shocks: the release of the EPA's 2013 Final Rule (2nd vertical line in Figure 1), which caused the decrease in the RIN tax obligation in the latter half of 2013; a leaked version of the EPA's 2014 Proposed Rule, which caused a further decrease in the RIN tax obligation in late 2013; and the release of the 2014 Proposed Rule (3rd vertical line in Figure 1), which caused the RIN tax obligation to increase once again.

This evidence suggests that although variation in RIN prices is correlated with the demand for biofuel (Pouliot and Babcock 2015), the surge in the demand for RINs, was caused by policy uncertainty regarding whether or not the EPA's blending mandates would breach the blend wall (Lade, Lin Lawell, and Smith 2018). Variation in the aggregate RIN tax obligation is therefore exogenous to refineries because the refineries have no short term control over the composition of vehicles on the road, the RVP waivers for E15, or the number of gas stations offering E85.

4 Data

I construct a confidential refinery-firm level data set spanning 2012-2014 using surveys from the US Energy Information Administration.[8] Production data is collected at the refinery level while sales data, including output prices, are collected at the firm-region level. For example, firms such as Chevron, may own multiple refineries in different locations around the US.

Survey form EIA-810 provides very detailed data on each refinery's inputs, gross production, gains and losses, shipments, ending stocks, and capital. I observe the full distribution of products produced by each refinery in each month. Refineries report the output of approximately sixty end products, most of which fall into several broad categories including liquified petroleum gases, aviation fuel, gasoline and gasoline blending components, jet fuel and kerosene, distillates (diesel fuels), heavy residual fuel oils, asphalt and road oil. Gasoline and diesel are reported by various types including conventional and reformulated gasoline and high, low, and ultra-low-sulfur diesel. I subtract petroleum

[8]Surveys can be found at http://www.eia.gov/survey/.

product inputs such as unfinished gasoline, diesel, and kerosene from the gross production of finished gasoline to construct net production of finished fuels.[9]

Firms report sales prices of gasoline, diesel, jet fuel, aviation fuel, and a handful of other products by state, fuel type (regular, mid-grade, premium), and sales type (retail, rack, dealer-tank-wagon, bulk, commercial/industrial, and other end users) on form EIA-782A.[10] Petroleum products travel around the US via pipeline, tanker, and truck. The majority of petroleum products leave refineries via pipelines and make an intermediate stop at a terminal (bulk storage facility) where they are temporarily stored, blended with biofuels, and then trucked to retail gasoline and diesel stations, or commercial customers.[11] The sales prices reported on EIA-782A do not include taxes but do include shipping costs. I follow Sweeney (2015) to construct an estimate of shipping costs for each firm. Firms are assumed to minimize transportation costs by supplying each state with end product produced from the nearest refinery. I use a GIS mapping tool to find the distance between each refinery and each terminal in each state following pipelines. I assign a transportation cost of 2 cents per gallon per thousand miles traveled (Sweeney 2015; Muehlegger 2006). I can then use these estimates to subtract transport costs from the sales prices reported on EIA-782A.

Finally, I observe firm-PADD level crude oil input prices for domestic and imported crude from survey form EIA-14. Firms report total expenditures on crude oil and the total number of barrels of crude processed per month. To generate refinery specific costs per barrel (or gallons), I divide total expenditures by the total number of barrels (or gallons). I drop observations that are more than $50/barrel from the average Brent spot price for that month. See Muehlegger and Sweeney (2017) for a detailed analysis of the refinery crude costs reported on EIA-14.

[9] This is how the EIA estimates net production of fuels. See the definition of refinery production here: http://www.eia.gov/dnav/pet/tbldefs/pet_pnp_refp2_tbldef2.asp

[10] Rack prices are the prices paid at the terminal for deliveries of end product in truckload sized quantities. Dealer-tank-wagon prices are essentially forward contract prices. The dealer-tank-wagon prices are consistently higher than other prices due to the guarantee of sale, regardless of supply disruptions. Bulk prices are assigned to bulk sales larger than a truckload. All sales on form EIA-782A are reported in the state where the transfer of title occurred. The transfer of title typically takes place at distribution terminals but the end product could ultimately be consumed in a neighboring state. I use rack, bulk, and sales for resale prices.

[11] There are over 192,000 miles of pipelines in the US In 2013, 96% of all products sold were shipped via pipeline (in total, 6.6 billion barrels of natural gas and petroleum products). Source: http://www.eia.gov/dnav/pet/pet_cons_psup_dc_nus_mbbl_a.htm and http://www.aopl.org/wp-content/uploads/2014/10/us-Liquids-Pipeline-usage-Mileage-Report-Oct-2014-s.png

4.1 Summary Statistics

Table 1 presents end product price and crude oil input price summary statistics by region and fuel type. The prices represent average wholesale prices (rack, bulk, or sales for resale prices).[12] Average prices are highest along the West Coast (PADD 5) and the Rocky Mountain regions (PADD 4) and lowest along the Gulf Coast (PADD 3) where a majority of refineries are located. See Appendix A for a discussion on data cleaning and the number of observations in each table in the paper. Crude oil input prices are lowest in the Rocky Mountain regions (PADD 2) where firms have access to low-cost domestic crudes.

Table 2 presents refinery-level production data summary statistics. I observe production data for 155 refineries owned by 65 firms between 2012 and 2014. The largest refinery in the US can process over 600,000 barrels of oil per day while the smallest refinery can only process 33. Hence, refineries are quite heterogeneous. The average refinery has a net production of 1,906,000 barrels of conventional and reformulated gasoline, 397,000 barrels of mid and low-sulfur diesel, 1,448,000 barrels of ultra-low sulfur diesel, and 643,000 barrels of jet fuel per month. A minimum production of 1 barrel per month indicates the refinery was shut down for that month.

5 The Renewable Fuel Standard and Refinery Prices and Production Decisions

5.1 Output prices and the RIN tax obligation

I begin by evaluating the relationship between wholesale petroleum product prices and the RIN tax obligation. I estimate pass-through of the RIN tax obligation to wholesale product prices in levels and first differences (Table 3).[13] The regressions take the following form,

$$P_{frjt} = \beta_0 + \beta_1 RIN_t + \beta_2 p^c_{frt} + \sigma_{fy} + G_r + M_m + J_j + \epsilon_{fjst}, \qquad (1)$$

[12] Gasoline prices include the prices of consumable fuel, which includes oxygenated and non-oxygenated gasoline and blended gasoline but excludes blendstocks, E85, and ethanol. More details on price averages are reported in Appendix Section A.2.

[13] Estimates on price spreads are presented in Table A.4 in the Appendix.

where P_{frjt} is the output price charged by firm f in region r for product j in month t (less transportation costs), RIN_t is the RIN tax obligation in month t, p^c_{frt} is the average Brent crude oil spot price in month t, and σ_{fy}, G_r, S_s, J_j are firm-year, region, month, and product fixed effects respectively.[14] I control for Brent spot prices as the majority of the movement in wholesale petroleum product prices can be attributed to movements in the price of crude oil. Standard errors are clustered by month-of-sample because that is the level at which the RIN tax obligation varies.

The results of estimating Equation (1) are presented in Table 3. Columns 1 and 3 displays the average relationship between gasoline prices (conventional and reformulated) and the RIN tax obligation for 2012-2014 using fixed effects and first differences models respectively. The dependent variable in columns 2 and 5 is the price of ultra-low-sulfur diesel (ULSD).[15] The results using the fixed effects model indicate that a 1¢ per gallon increase in the RIN tax obligation resulted in a 0.971¢/gallon increase in gasoline prices and a 0.781¢/gallon increase in ULSD prices respectively. The first difference point estimates are slightly different from the fixed effects estimates but none of the gasoline or diesel results are not statistically different from one.

Columns 3 and 6 of Table 3 show that non-regulated fuel prices were also affected by the RFS. Specifically, a 1¢ per gallon increase in the RIN tax obligation decreased the jet fuel price by 0.56¢ per gallon. The effect on jet fuel prices may be attributed to increased production of jet fuel causing jet fuel prices to fall.[16]

Unsurprisingly, Brent spot prices are also nearly fully passed-through to wholesale petroleum product prices. On the other hand, refinery specific crude prices exhibit much lower pass-through rates. Estimates of columns 1-3 of Table 3 using refinery specific crude costs in place of Brent spot prices are presented in Table 4. In a recent paper, Muehlegger and Sweeney (2017) fully explore the mechanisms behind this result using similar data and a longer time period.[17] They show that the pass-through rate of input cost shocks in the refining industry depends on the geographic scales of the input and output markets.

[14] Using the Dickey-Fuller test for a unit root in the RIN tax obligation easily rejects the null of non-stationarity.

[15] Results pooling ultra-low-sulfur, low-sulfur, and mid to high-sulfur diesel are similar.

[16] Estimating equation (1) with varying combinations of fixed effects has little effect on the coefficient estimates with the exception of the month fixed effect. Omitting month fixed effects increases the magnitude of the coefficients but does not change the sign.

[17] See Muehlegger and Sweeney (2017) for a detailed discussion on refinery specific crude costs reported on EIA-14.

For instance, refineries in the Mountain West (PADD 2) have access to relatively cheap crude from North Dakota when crude oil transportation infrastructure from North Dakota to the Gulf Coast is at capacity. This means that regional oil gluts in the Mountain West can lower refinery specific crude oil input prices relative to benchmark crude prices such as Brent, sometimes as much as $30/barrel.[18] On the other hand, output markets tend to be more competitive and less geographically isolated meaning output prices will respond more to movements in input prices that vary at the national level, such as the Brent spot price or RIN prices. Thus, I use Brent spot prices as the primary measure of input costs.

5.2 Heterogeneous Pass-Through

In this section I explore several dimensions of pass-through heterogeneity. First, I estimate pass-through by firm production capacity.[19] The EPA grants small refineries exemptions (SRE) from RFS compliance.[20] Table 3 indicates that the RIN tax obligation is fully passed-through to gasoline and diesel prices nationwide. This implies that small, exempt refineries that do not comply with RFS blending requirements, and therefore do not pay the RIN costs but receive higher output prices, may receive substantial benefits from the policy. To test whether small and large refineries are equally passing-through the RIN tax obligation, I estimate the primary fixed effects model including interactions between indicators for capacity quartiles and the RIN tax obligation. The omitted category is the 4th capacity quartile or the group of refineries with the largest capacities. The results are presented in Table 5. I find the pass-through rates of the smallest and largest firms are not statistical different from one another in the gasoline market. However, I find the smallest firms have slightly higher pass-through rates than the largest firms in the ULSD market while firms in the 3rd quartile have slightly lower pass-through rates than the largest firms in the gasoline market.

One possible reason firms in the 3rd quartile of capacity exhibit lower pass-through in the gasoline market is that 72% of the 3rd quartile capacity firms are located in PADDs 1, 3, and 5. Each of these regions exhibit (statistically insignificantly) lower pass-through

[18] In conversation with an employee at a Wyoming refinery, I was told that refineries can pay as much as plus or minus $30/barrel for crude oil relative to benchmark prices.

[19] Firm capacity is defined as the total refining production capacity of a firm within a PADD.

[20] The EPA does not publicly disclose which refineries are exempt.

than the Midwest according to Table 6. Overall however, these results suggest that pass-through rates are generally consistent across firm size, which means that small refineries that do not purchase RINs are possibly benefiting from the policy. It is important to note that data limitations, specifically monthly observations for only a three-year time span, may limit the power of the analysis. Moreover, the EPA generally grants waivers to small refineries and not firms. However, in some cases entire firms are granted waivers if they own sufficiently small refineries. Therefore, the firm-PADD level capacity measures used in this section imperfectly reflect the relationship between individual refinery size and the EPA SRE policy.

I also estimate RIN pass-through by PADD to explore regional heterogeneity. To do so, I interact PADD dummies with the RIN tax obligation. The omitted PADD is PADD 2, the Midwest, as most ethanol is produced in PADD 2 and Pouliot, Smith, and Stock (2017) find rack level pass-through rates are highest in this region. The results are presented in Table 6. I estimate complete pass-through in the Midwest, the Gulf States, the Rocky Mountain Region, and the West Coast with no statistical differences between each region. On the other hand, I estimate incomplete pass-through in PADD 1 (the Eastern States). Appendix B displays firm production capacity summary statistics by PADD. Firms in PADD 1 have the second largest production capacity on average, which is consistent with lower pass-through rates for firms in the 3rd quartile of capacity.

5.3 Production Decisions and the RIN tax obligation

In a final application I evaluate the effect of changes in RIN prices on the mix of refinery outputs. To do so, I regress the log of the production of a given product on the log of the RIN price.[21] The regression is the following:

$$\ln Q_{ijt} = \gamma_0^j + \gamma_1^j \ln RFS_t + \gamma_2^j \boldsymbol{X}_{it} + \sigma_{iy} + S_s + \nu_{ijt}, \tag{2}$$

where $\ln RFS_t$ is the log of the RIN tax obligation and $\boldsymbol{X}_{it}$ includes the log of the Brent crude price and the quality of crude oil, such as API gravity and sulfur content as lower

[21] Using product shares yields similar results. However, I am interested in volumetric changes in output, not relative changes. For example, jet fuel product shares may increase simply because the demand for gasoline and diesel decreases when gasoline and diesel output prices increase.

quality crude oil will produce more lower quality products. Standard errors are clustered by month-of-sample.

The results, presented in Table 7 provide suggestive evidence that refinery production decisions respond to changes in the RIN tax obligation. A 10% increase in the RIN tax obligation is associated with a 0.67% decrease in ultra-low sulfur diesel production and associated with a 0.77% increase in jet fuel production. Interestingly, changes in the RIN tax obligation do not appear to impact the production of any other fuel including mid and low-sulfur diesel.

The changes in the production mix have potentially important policy implications. When environmental regulations fail to account for industry specific nuances, a wide range of unexpected and unintended outcomes can occur (Lipsey and Lancaster 1956). For example, policies can increase production cost inefficiencies across heterogeneous producers (Borenstein, Bushnell, and Wolak 2002), or in the present case, across products within firms. Likewise, policies that apply to only a subset of products within an industry allow firms to substitute non-regulated production for regulated production leading to potential emissions leakage (Fowlie 2009; Auffhammer and Kellogg 2011).

Refineries carefully choose output mixtures to balance production costs with expected profits from the slate of products being produced. A uniform carbon price, like the California cap and trade program or the European Union Emission Trading Scheme, increases production costs across all products. If such a carbon price is fully passed through to all product prices, then the policy should not affect the production mix. On the other hand, the RFS increased production costs for only two of roughly sixty products produced by refineries. Thus, the RFS has the potential to alter production decisions, which could lead to cost inefficiencies and unintended production and emissions. Though the results presented in this section are suggestive, they highlight the potential for firms to avoid compliance with an incomplete regulation.

6 Conclusions and Policy Implications

In this paper, I provide evidence of the effects of the RFS on the US oil refining industry. The oil refining industry generated over $730 billion in revenue in 2014 and is characterized by a complex multi-product production process and large barriers to entry. As a consequence, it is complicated to regulate and policies that apply to only a subset of products refineries produce, such as the RFS, can lead to unintended consequences.

This paper has several important findings. First, I find that changes in the RIN tax obligation were fully passed through to wholesale gasoline and diesel prices on average, which is an important condition for ensuring the effectiveness of the RFS. Second, I estimate pass-through heterogeneity across several dimensions including firm capacity and region. The results indicate that rack level pass-through is generally complete with the largest exception being firms on the East Coast. Third, I find that increases in the RIN tax obligation are associated with increased jet fuel production, a non-regulated product, and lower ultra-low-sulfur diesel production. Correspondingly, I find that jet fuel prices decreased in response to increases in the RIN tax obligation, consistent with an outward shift in the supply curve for jet fuel.

The EPA grants small refineries with production capacities less than 75,000 barrels/day (3,150,000 gallons/day) exemptions from RFS compliance. I find full pass-through of RIN costs to nationwide output prices on average, and no statistical difference between pass-through rates for large and small refineries. These two findings suggest that exempt refineries that do not bear the burden of the RFS tax obligation, but enjoy increased output prices, may incur substantial benefits from the policy. To gain a sense of the magnitude of these potential benefits, consider the average RIN tax obligation during the sample period ($0.0519) and the average amount of obligated fuel produced from a barrel of oil (78.3%).[22] If RIN costs were fully passed through to output prices during this period, exempt refineries could have made an additional $120,667/day.[23] These back of the envelope calculations should be considered upper bounds, however, as smaller refineries are likely less efficient, and therefore have higher marginal costs and lower average margins, than larger more efficient refineries. Moreover, not all exempt refineries process 75,000 barrels/day.

Back of the envelope calculations can also elucidate the magnitude of the production substitution estimated in Section 5.3. Using the coefficient estimates from Table 7 and av-

[22] According to the EIA, the average refinery produces about 20 gallons of gasoline and 11 gallons of ULSD from a 42-gallon barrel of oil, or roughly 78.3% of the average barrel of crude is taxed under the RFS.

[23] $0.0519/gallon*73.8%*3,150,000gallons/day=$120,667/day.

erage product prices and outputs, I find that the estimated reduction in ULSD production results in a loss of revenue of approximately \$102,383/month. The corresponding increase in jet fuel production results in a gain of revenue of approximately \$45,933/month. If one is willing to extrapolate to other fuels, this would result in additional revenue of \$20,460/month for conventional diesel and a loss of revenue of \$81,071/month for gasoline. Combined, these changes result in a net loss of \$117,061/month for the average refinery across all four fuels, or a net loss of \$56,449/month for the average refinery across ULSD and jet fuel only.[24]

The result in this paper, combined with previous estimates in the literature, begin to illustrate the voyage of RIN prices from the refiner to the pump. Three other papers have evaluated wholesale level pass-through (Knittel, Meiselman, and Stock 2017; Pouliot, Smith, and Stock 2017; Knittel, Meiselman, and Stock 2016). Knittel, Meiselman, and Stock (2017) use daily spot price data and find that approximately 70% of the RIN tax obligation is passed-through to wholesale gasoline and diesel spot prices on the same day, with complete pass-through occurring between 2 and 10 business days. Pouliot, Smith, and Stock (2017) estimate RIN pass-through to E10 rack prices in 57 major cities across the US. They find the RIN tax obligation was fully passed-through in the Midwest and the Gulf regions and less than fully passed-through in the East. Their West Coast estimates are imprecise but do not rule out full pass-through. Similarly, I find that RIN pass-through to wholesale rack prices is complete for all regions except the East.

Pouliot, Smith, and Stock (2017) provide two possible explanations for the finding of incomplete pass-through along the East Coast. First, Florida is not on the petroleum pipeline network and second, Atlanta requires a specific blend of low-sulfur gasoline. These unique properties could lead to more volatility in the price of blended gasoline, which would lead to lower pass-through rates. Consistent with the second explanation, I do not find statistically significantly lower pass-through rates in the ULSD and jet fuel markets in PADD 1. Together, these results imply the wholesale gasoline market on the

[24]Average gas, diesel, ULSD, and jet fuel prices during the study period were \$2.93/gallon, \$3.3/gallon, \$3.06/gallon, and \$3.022/gallon respectively. Average production of each fuel was 1,646,000 bbls/month, 121,000 bbls/month, 1,189,000 bbls/month, and 470,000 bbls/month respectively. Using the coefficient estimates from Table 7, combined with the average production and prices per gallon, I can determine the approximate revenue losses/gains. For example, the reduction in ULSD production results in a loss of revenue of approximately 0.00067*1,189,000bbls/month*42gallons/bbl*\$3.06/gallon = \$102,383/month.

East Coast is moderately isolated from the rest of the US market. Regardless of the mechanism, the results in this paper show that incomplete pass-through of the RIN tax obligation to wholesale gasoline prices along the East Coast is driven by the refineries in that region.

An important limitation of the present study is that the data does not extend beyond 2014. Pouliot, Smith, and Stock (2017) find that pass-through is higher post-2013, the period with the largest RIN price volatility. Thus, the results in my paper should include the caveat that refiner-level pass-through between 2015-2018 may differ from pass-through in 2013 and 2014. Taken together, these papers suggest the RIN tax obligation is fully passed-through to wholesale spot and rack prices on average and that the pass-through rate does not generally depend on firm size. However, RIN pass-through to wholesale product prices does vary to some extent across time periods, regions, and branded and unbranded producers (Pouliot, Smith, and Stock 2017).

Moving down the supply chain, three papers examine pass-through of the RIN tax obligation or ethanol subsidy to retail fuel prices (Lade and Bushnell 2019; Li and Stock 2019; Knittel, Meiselman, and Stock 2017). Li and Stock (2019) estimate wholesale cost pass-through to E10 and E85 retail prices in Minnessota. Lade and Bushnell (2019) estimate ethanol subsidy pass-through to E85 retail prices in several states in the Midwest. Both papers find that, on average, the ethanol subsidy is fully passed-through to retail E85 prices. In contrast to wholesale level estimates (Pouliot, Smith, and Stock 2017), Lade and Bushnell (2019) and Li and Stock (2019) show that retail level E85 pass-through depends on the level of local competition with urban areas exhibiting significantly higher pass-through rates. At the wholesale level, Knittel, Meiselman, and Stock (2017) find that changes in the RIN subsidy were not passed-through to E85 spot prices between 2013-March 2015. A possible explanation for the discrepancy between Knittel, Meiselman, and Stock (2017) and the other two papers is the geographic scope of the analyses (national E85 spot prices used by Knittel, Meiselman, and Stock (2017) versus Midwest gas stations use by Lade and Bushnell (2019) and Li and Stock (2019)).

Overall, the current state of literature suggests that RIN costs are fully passed-through to wholesale prices on average. Likewise, the ethanol subsidy created by RIN sales is also fully passed-through to retail E85 prices on average, with some heterogeneity caused by local competition. These findings suggest that the market for RINs is functioning as expected and as the market for higher blends of ethanol fuels matures (e.g., E85), pass-through will likely continue to converge toward complete.

This paper is not without limitations. While Knittel, Meiselman, and Stock (2017), Lade and Bushnell (2019), and others observe daily or weekly price variation, I observe monthly prices. Likewise, I only observe data through 2014. These shortcomings limit the precision of my estimates and my ability to explore more nuanced questions. For instance, I cannot estimate distributed lag models to determine how quickly the RIN tax obligation is passed-through to rack prices nor can I differentiate between the effects of RIN cost increases and decreases (Borenstein and Shepard (2002)). The production decision results presented in Section 5.3 likely suffer the most from the data limitations. Additional years of data would likely further illuminate the estimates in Section 5.3, either bolstering the results in this paper or showing that the production mix does not respond to changes in the RIN tax obligation in the long-run.

While this paper provides evidence of some effects of the RFS, future work might explore the mechanisms behind the pass-through estimates for non-regulated products. For example, the RFS is one of many policies that currently impact the petroleum product industry. One could assess the impact of input cost shocks, or estimate long run tax, marginal cost, and crude oil price pass-through to understand if the results are unique to RIN costs.

Acknowledgments

This research is not supported by outside funding. I am grateful to my committee members Matt Kotchen, Ken Gillingham, and Penny Goldberg for their guidance, patience, and encouragement. I also thank Kerry Smith for being a great mentor and for useful comments. I would also like to thank Jim Bushnell for planting the seeds of this project in my head and Sharat Ganapati, Chris Goemans, Alessandro Bonanno, and Chuck Mason for extensive conversations and insights. I want to thank Rahul Deb, Gabe Lade, Meredith Startz, Matthew Grant, Anders Munk-Nielsen, Paige Weber, Stefan Lamp, Nathan Chan, and participants at the Yale Environmental Economics Seminar, NBER Summer Session, and Camp Resources conferences for many useful comments. The data used in this paper were obtained under a researcher information access agreement with the Energy Information Administration, and executed with extensive support from Joseph

Conklin of EIA. The views and analysis herein, including any errors, are mine alone.

References

Auffhammer, Maximilian and Ryan Kellogg (2011). “Clearing the air? The effects of gasoline content regulation on air quality”. *The American Economic Review*, pp. 2687–2722.

Borenstein, Severin, James B. Bushnell, and Frank A. Wolak (2002). “Measuring Market Inefficiencies in California’s Restructured Wholesale Electricity Market”. *American Economic Review* 92.5, pp. 1376–1405.

Borenstein, Severin and Andrea Shepard (2002). “Sticky prices, inventories, and market power in wholesale gasoline markets”. *RAND Journal of Economics* 33.1, pp. 116–139.

Brown, Jennifer et al. (2008). “Reformulating competition? Gasoline content regulation and wholesale gasoline prices”. *Journal of Environmental Economics and Management* 55.1, pp. 1–19.

Burkholder, Dallas (2015). “A Preliminary Assessment of RIN Market Dynamics, RIN Prices, and Their Effects”. *Office of Transportation and Air Quality, US EPA, at http://www. regulations. gov.*

C.F.R. (2015). *Code Federal of Regulations, Title 40, Chapter 1, Subchapter C, Part 80, Subpart M, Section 80.1407.*

EPA (2015a). “Renewable Fuel Standard”. *online publication.*

Fowlie, Meredith L (2009). “Incomplete environmental regulation, imperfect competition, and emissions leakage”. *American Economic Journal: Economic Policy* 1.2, pp. 72–112.

Irwin, Scott (2014). “Rolling Back the Write Down of the Renewable Mandate for 2014: The RINs Market Rings the Bell Again”. *farmdoc daily* 4.148.

— (2018). “The Grand Bargain? Trading an E15 RVP Waiver for a RINs Price Cap”. *farmdoc daily* 8.35.

Knittel, Christopher R., Ben S. Meiselman, and James H. Stock (2016). *The Pass-Through of RIN Prices to Wholesale and Retail Fuels under the Renewable Fuel Standard: Analysis of Post-March 2015 Data. Working Paper.*

Knittel, Christopher R, Ben S Meiselman, and James H Stock (2017). “The pass-through of RIN prices to wholesale and retail fuels under the renewable fuel standard”. *Journal of the Association of Environmental and Resource Economists* 4.4, pp. 1081–1119.

Lade, Gabriel E and James Bushnell (2019). “Fuel Subsidy Pass-Through and Market Structure: Evidence from the Renewable Fuel Standard”. *Forthcoming in the Journal of the Association of Envirionmental and Resource Economists.*

Lade, Gabriel E, C-Y Cynthia Lin Lawell, and Aaron Smith (2018). “Policy shocks and market-based regulations: Evidence from the Renewable Fuel Standard”. *American Journal of Agricultural Economics* 100.3, pp. 707–731.

Li, Jing and James H Stock (2019). “Cost pass-through to higher ethanol blends at the pump: Evidence from Minnesota gas station data”. *Journal of Environmental Economics and Management* 93, pp. 1–19.

Lipsey, R. G. and Kelvin Lancaster (1956). “The General Theory of Second Best”. English. *The Review of Economic Studies* 24.1, pp. 11–32.

Marion, Justin and Erich Muehlegger (2011). “Fuel tax incidence and supply conditions”. *Journal of Public Economics* 95.9-10, pp. 1202–1212.

Muehlegger, Erich (2006). “Gasoline price spikes and regional gasoline content regulation: A structural approach”.

Muehlegger, Erich and Richard L Sweeney (2017). *Pass-Through of Input Cost Shocks Under Imperfect Competition: Evidence from the US Fracking Boom*. Tech. rep. National Bureau of Economic Research.

Pouliot, Sébastien and Bruce A Babcock (2015). "Compliance path and impact of ethanol mandates on retail fuel market in the short run". *American Journal of Agricultural Economics* 98.3, pp. 744–764.

Pouliot, Sebastien, Aaron Smith, and James H Stock (2017). "RIN Pass-Through at Gasoline Terminals".

Stolper, Samuel (2016). "Who bears the burden of energy taxes? The critical role of pass-through". *manuscript, Harvard Kennedy School*.

Sweeney, Richard L. (2015). "Environmental Regulation, Imperfect Competition and Market Spillovers: The Impact of the 1990 Clean Air Act Amendments on the US Oil Refining Industry". *Job Market Paper*.

7 Tables

Table 1: Output Price and Refinery Specific Crude Oil Cost Summary Statistics in $/gal

Fuel Type or Region	Mean	Std. Dev.	Min.	Max.	N
Panel A: Summary Statistics by Fuel Type					
Gasoline	2.927	0.229	2.19	3.921	6,446
ULSD	3.066	0.171	2.492	3.856	5,147
Jet Fuel	3.031	0.173	2.182	3.666	2,636
Panel B: Output Price Summary Statistics by Region (PADD)					
East Coast (1)	2.991	0.164	2.54	3.575	2,059
Midwest (2)	2.989	0.193	2.183	3.504	2,588
Gulf Coast (3)	2.966	0.175	2.368	3.42	2,378
Rocky Mountain (4)	3.03	0.237	2.215	3.635	1,333
West Coast (5)	3.036	0.231	2.234	3.921	1,902
Panel C: Crude Oil Price Summary Statistics by Region (PADD)					
East Coast (1)	2.527	0.186	1.941	2.998	429
Midwest (2)	2.305	0.205	1.117	3.524	2,080
Gulf Coast (3)	2.486	0.182	2.021	3.262	2,101
Rocky Mountain (4)	2.035	0.238	1.2	2.526	956
West Coast (5)	2.473	0.204	1.22	2.922	1,486

Notes: Output prices include rack, bulk, or sales for resale prices from 2012-2014. Gasoline includes conventional and reformulated. Diesel includes ultra-low-sulfur diesel. Crude oil prices are refinery specific crude oil costs in $/gallon reported on survey form EIA-14. Observations are at the firm-PADD level.

Table 2: Production Data Summary Statistics (2012-2014)

Variable	Mean	Std. Dev.	Min.	Max.	N
Net Production Gas (1000's of bbls)	1906.961	1508.03	1	10899	3,878
Net Production Mid & Low Diesel (1000's of bbls)	397.071	590.675	1	2503	946
Net Production Ultra-Low Diesel (1000's of bbls)	1448.762	1243.032	1	8542	2,567
Net Production Jet Fuel (1000's of bbls)	643.858	608.286	1	3317	2,507
API Gravity	31.405	6.825	16.24	50.95	9,898
Sulfur Percent	1.259	0.936	0.01	7.03	9,898
Atmospheric Capacity (bbls/CD)	150441.467	120916.009	33	600250	9,898

Notes: bbls/CD represents barrels per calendar day. Low inputs or outputs can be attributed to refineries reporting zero inputs or outputs for a given month, possibly due to scheduled or unscheduled shutdowns. All observations are at the refinery-product level.

Table 3: Pass-through to Wholesale Prices

	Gas FE (1)	ULSD FE (2)	Jet FE (3)	Gas FD (4)	ULSD FD (5)	Jet FD (6)
RIN	0.971***	0.781***	-0.563**	1.317**	0.645*	-0.092
	(0.373)	(0.267)	(0.225)	(0.552)	(0.350)	(0.331)
Brent Spot	0.676***	0.812***	0.879***	0.720***	0.832***	0.783***
	(0.039)	(0.033)	(0.039)	(0.053)	(0.036)	(0.035)
Firm-Year FE	Y	Y	Y	NA	NA	NA
Product FE	Y	NA	NA	Y	NA	NA
Month FE	Y	Y	Y	Y	Y	Y
Region FE	Y	Y	Y	Y	Y	Y
R-squared	0.738	0.713	0.789	0.629	0.679	0.680
N	6446	5147	2636	6374	5047	2535

Notes: Columns 1 and 4 pool conventional and reformulated gasoline prices. The dependent variable in Columns 2 and 5 is ultra-low-sulfur diesel prices. All units are ($/gallon). Standard errors clustered by month-of-sample. *** indicates 1% significance, ** indicates 5% significance, * indicates 10% significance.

Table 4: Pass-through Using Refinery Specific Crude Costs

	Gas (1)	ULSD (2)	Jet (3)
RIN	0.892*	0.840***	-0.699***
	(0.528)	(0.317)	(0.239)
Cost Per Barrel	0.288***	-0.054	0.433***
	(0.045)	(0.042)	(0.054)
Firm-Year FE	Y	Y	Y
Product FE	Y	NA	NA
Month FE	Y	Y	Y
Region FE	Y	Y	Y
R-squared	0.516	0.745	0.511
N	2857	1927	1353

Notes: This table replicates columns 1-3 of Table 3 but replaces Brent spot prices with refinery specific crude prices. The number of observations declines substantially from the main regressions because refineries do not always report crude input prices. See Appendix A for a discussion on data cleaning and Muehlegger and Sweeney (2017) for a discussion on refinery specific crude costs. Column 1 pools conventional and reformulated gasoline prices. The dependent variables in columns 2 and 3 are ULSD and jet fuel prices respectively. All units are ($/gallon). Standard errors clustered by month-of-sample. *** indicates 1% significance, ** indicates 5% significance, * indicates 10% significance.

Table 5: Heterogeneous Pass-through by Production Capacity

	Gas	ULSD	Jet
	(1)	(2)	(3)
RIN	0.956**	0.747***	-0.585***
	(0.376)	(0.285)	(0.216)
RIN*1(cap 1st quartile)	0.271	0.199*	0.093
	(0.199)	(0.109)	(0.148)
RIN*1(cap 2nd quartile)	0.191	-0.111	-0.020
	(0.128)	(0.115)	(0.166)
RIN*1(cap 3rd quartile)	-0.370**	0.027	0.029
	(0.174)	(0.140)	(0.129)
Brent Spot	0.677***	0.812***	0.878***
	(0.039)	(0.033)	(0.039)
Firm-Year FE	Y	Y	Y
Product FE	Y	NA	NA
Month FE	Y	Y	Y
Region FE	Y	Y	Y
R-squared	0.738	0.725	0.790
N	6446	5147	2636

Notes: Regressions include an interaction between the RIN tax obligation and quartiles of firm capacity. The omitted category is the 4th quartile. All units are ($/gallon). Standard errors clustered by month-of-sample. *** indicates 1% significance, ** indicates 5% significance, * indicates 10% significance.

Table 6: Heterogeneous Pass-through by Region

	Gas	ULSD	Jet
	(1)	(2)	(3)
RIN	1.331***	0.869***	-0.531*
	(0.439)	(0.325)	(0.307)
RIN*1(PADD1)	-1.153**	-0.380	-0.145
	(0.445)	(0.286)	(0.369)
RIN*1(PADD3)	-0.398	-0.159	0.058
	(0.426)	(0.279)	(0.361)
RIN*1(PADD4)	0.565	0.220	-0.054
	(0.568)	(0.421)	(0.398)
RIN*1(PADD5)	-0.374	-0.070	-0.093
	(0.458)	(0.319)	(0.359)
Brent Spot	0.689***	0.758***	0.848***
	(0.068)	(0.071)	(0.078)
Firm-Year FE	Y	Y	Y
Product FE	Y	NA	NA
Month FE	Y	Y	Y
Region FE	Y	Y	Y
R-squared	0.748	0.728	0.790
N	6446	5147	2636

Notes: Regressions include interactions between the RIN tax obligation and PADD dummy variables. All units are ($/gallon). Standard errors clustered by month-of-sample. *** indicates 1% significance, ** indicates 5% significance, * indicates 10% significance.

Table 7: Production Decisions and RIN Prices

	Gas	Diesel	ULSD	Jet
	(1)	(2)	(3)	(4)
Log RIN Price	-0.045	0.122	-0.067**	0.077**
	(0.045)	(0.096)	(0.029)	(0.033)
Log Brent Spot Price	-0.348	0.055	-0.517***	-0.054
	(0.256)	(0.611)	(0.176)	(0.227)
Firm-Year FE	Y	Y	Y	Y
Seasonal FE	Y	Y	Y	Y
Controls	Y	Y	Y	Y
R-squared	0.468	0.815	0.842	0.873
N	3878	946	2567	2507

Notes: The dependent variables are the logged net outputs of conventional gasoline, reformulated gasoline, regular diesel, ultra-low-sulfur diesel, and jet fuel respectively. Controls include refinery level crude oil quality (API gravity and sulfur content). All units are ($/gallon). Standard errors clustered by month-of-sample. *** indicates 1% significance, ** indicates 5% significance, * indicates 10% significance.

Appendices

A Online Appendix: Data Cleaning

A.1 Number of Observations

This appendix outlines the data cleaning process and describes the number of observations throughout the paper. Table 1 displays summary statistics for firm-region level output prices from 2012-2014 while Table 2 displays summary statistics for refinery-specific production. Firms own multiple refineries so there are a different number of output price observations than refinery specific input/output data observations. In other words, the price data is collected at the firm-PADD level while the production data is collected at the refinery level.

Correspondingly, Table 7 shows the results of regressing physical outputs on the RIN tax obligation. The outputs are at the refinery level rather than the firm-region level as in Table 3 so the number of observations by fuel type do not match the number of observations in Table 3.

Refineries report total crude input costs and the number of barrels used in production and not average crude costs per month. To generate monthly costs per barrel, I divide total crude costs by the number of barrels used each month. I drop observations if the cost per barrel estimate is not within $50 of the Brent spot price for a given month. However, the refinery specific crude costs are only used in Table 4 in the Appendix.

A.2 Calculation of Average Prices

Firms report average output prices of each product by state and by sales type, e.g., rack, resale, bulk, retail, or dealer tank wagon. I only keep sales that are labeled as rack sales, bulk sales, or sales for resale. Other price trends, such as dealer tank wagon, reflect long-term contract negotiations and are less likely to move with the RIN tax obligation. Retail prices are direct sales from refineries to nearby retail outlets. I take the unweighted average of the remaining price observations across each firm-PADD. I average to the firm-PADD level because this is the level at which I observe firm specific crude oil input prices.

B Capacity by PADD

This appendix provides refinery summary statistics by PADD. Refineries with production capacities less than 75,000 barrels/day can request exemptions under the RFS. There are 6 refineries that meet this criteria in PADD 1, 5 refineries in PADD 2, 15 refineries in PADD 3, 14 refineries in PADD 4, and 16 refineries in PADD 5 for a total of 56 possible exempt refineries. In addition, Table A.1 displays refinery capacity summary statistics by

PADD. Firms in PADD 1 have the second largest production capacity on average, which is consistent with lower pass-through rates for firms in the 3rd quartile of capacity.

Table A.1: Refinery Production Capacities by PADD (bbls/day)

	Mean	Std. Dev.	Min	Max
PADD 1	160,019	102,419	10,000	335000
PADD 2	152,329	88,952	5,500	413,500
PADD 3	198,810	150,888	4,100	600,250
PADD 4	39,679	22,171	3,000	90,000
PADD 5	118,794	74,410	2,000	276,000

Notes: These summary statistics are generated from the publicly available capacity data available from the Energy Information Administration.

C Robustness Checks

Table A.2: Pass-through Using Refinery Specific Crude Costs and Brent Prices

	Gas	ULSD	Jet
	(1)	(2)	(3)
RIN	0.991**	0.673**	-0.632**
	(0.414)	(0.315)	(0.244)
Brent Spot	0.613***	0.755***	0.811***
	(0.047)	(0.042)	(0.044)
Cost Per Barrel	0.065**	0.045*	0.042*
	(0.027)	(0.024)	(0.023)
Firm-Year FE	Y	Y	Y
Product FE	Y	NA	NA
Month FE	Y	Y	Y
Region FE	Y	Y	Y
R-squared	0.784	0.779	0.816
N	2857	1927	1353

Notes: This table replicates columns 1-3 of Table 3 but includes refinery specific crude prices. The number of observations declines substantially from the main regressions because refineries do not always report crude input prices. See Appendix A for a discussion on data cleaning and Muehlegger and Sweeney (2017) for a discussion on refinery specific crude costs. Column 1 pools conventional and reformulated gasoline prices. The dependent variables in columns 2 and 3 are total diesel and jet fuel prices respectively. All units are ($/gallon). Standard errors clustered by month-of-sample. *** indicates 1% significance, ** indicates 5% significance, * indicates 10% significance.

Table A.3: Pass-through Using WTI and Brent Prices

	Gas	ULSD	Jet
	(1)	(2)	(3)
RIN	1.320***	0.969***	-0.253
	(0.358)	(0.271)	(0.223)
WTI Spot	-0.180***	-0.098**	-0.163***
	(0.066)	(0.048)	(0.042)
Brent Spot	0.822***	0.891***	1.010***
	(0.069)	(0.053)	(0.051)
Firm-Year FE	Y	Y	Y
Product FE	Y	NA	NA
Month FE	Y	Y	Y
Region FE	Y	Y	Y
R-squared	0.743	0.728	0.797
N	6446	5147	2636

Notes: This table replicates columns 1-3 of Table 3 but includes WTI spot prices. All units are ($/gallon). Standard errors clustered by month-of-sample. *** indicates 1% significance, ** indicates 5% significance, * indicates 10% significance.

Table A.4: Pass-through to Price Spreads

	Gas	ULSD	Jet
	(1)	(2)	(3)
RIN	1.690***	1.198***	-0.294
	(0.390)	(0.268)	(0.218)
Firm-Year FE	Y	Y	Y
Product FE	Y	NA	NA
Month FE	Y	Y	Y
Region FE	Y	Y	Y
R-squared	0.633	0.422	0.415
N	6446	5147	2636

Notes: The dependent variables in each column are the spread of the fuel price minus the Brent spot price. All units are ($/gallon). Standard errors clustered by month-of-sample. *** indicates 1% significance, ** indicates 5% significance, * indicates 10% significance.