Pass-Through of Alternative Fuel Policy Incentives: Evidence from Diesel and Biodiesel Markets, the U.S. Renewable Fuel Standard, and Low Carbon Fuel Standards in California and Oregon

December 2022

A White Paper from the National Center for Sustainable Transportation

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16. Abstract
Biodiesel and hydrotreated renewable diesel (RD)—or collectively biomass-based diesel (BBD)—have become integral components of compliance with policies aiming to reduce U.S. transportation sector greenhouse gas emissions. Such policies include the U.S. Renewable Fuel Standard (RFS), California's Low Carbon Fuel Standard (LCFS), and Oregon's Clean Fuel Program (CFP). These policies, along with a federal Blender's BBD Tax Credit (BTC), provide financial incentives for BBD. In this white paper, the authors study pass-through of implicit taxes and subsidies, introduced by federal and state policies, to a variety of diesel and soy biodiesel fuel prices in the context of the U.S. diesel sector, focusing on fossil diesel and soy biodiesel. They apply time series methods techniques to estimate how a variety of diesel fuel price spreads across the country and in California and Oregon responds to changes in the implicit taxes placed on petroleum diesel and the implicit subsidies awarded to biodiesel. The results presented in this paper point to some inefficiencies in the RFS, LCFS, and CFP. The primary contribution of this paper was providing the first set of estimates of pass-through of LCFS implicit taxes and subsidies, and doing so for the diesel sector, a critical player in LCFS compliance.

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Disclaimer

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Table of Contents

List of Tables

List of Figures

Pass-Through of Alternative Fuel Policy Incentives: Evidence from Diesel and Biodiesel Markets, the U.S. Renewable Fuel Standard, and Low Carbon Fuel Standards in California and Oregon

EXECUTIVE SUMMARY

More than one billion barrels of diesel fuels were produced in the United States in 2021, over 50 million (six percent) derived from biomass. Two decades ago, less than half of one percent came from biomass.[1] Biodiesel and hydrotreated renewable diesel (RD)—or collectively biomass-based diesel (BBD)—have become integral components of compliance with policies aiming to reduce U.S. transportation sector greenhouse gas (GHG) emissions. Such policies include the U.S. Renewable Fuel Standard (RFS)[2], California's Low Carbon Fuel Standard (LCFS)[3], and Oregon's Clean Fuel Program (CFP)[4]. These policies, along with a federal Blender's BBD Tax Credit (BTC)[5], provide financial incentives for BBD.[6]

In 2021, over 1.6 billion gallons of biodiesel and 1.5 billion gallons of RD were supplied to the U.S. transportation sector, although growth in RD production has positioned it to become the most produced and used BBD fuel starting in 2022. Biodiesel production increased seven-fold over the first half of the 2010s before becoming relatively stagnant over the second half. [7]

The U.S. Energy Information Administration (EIA) projects the BBD supply to grow by more than one billion gallons from 2021 to 2050, identifying the RFS and LCFS programs as leading drivers of BBD growth.[8] Further, Bushnell et al. (2020) found that between 310 and 410 million metric

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[1] See https://www.eia.gov/todayinenergy/detail.php?id=51778.

[2] The U.S. Renewable Fuel Standard (RFS) is administered by the U.S. Environmental Protection Agency (EPA) and requires a certain volume of renewable fuel that meets carbon intensity reduction threshold requirements to displace petroleum-based transportation fuel, heating oil or jet fuel. For more information, see https://www.epa.gov/renewable-fuel-standard-program/overview-renewable-fuel-standard.

[3] California's Low Carbon Fuel Standard (LCFS) is administered by California Air Resources Board (CARB) and requires the carbon intensity of transportation fuels used in the state to decline 20% below 2010 levels by 2030. For more information, see https://ww2.arb.ca.gov/our-work/programs/low-carbon-fuel-standard/about.

[4] Oregon's Clean Fuels Program (CFP) is administered by Oregon's Department of Environmental Quality (DEQ) and requires the carbon intensity of transportation fuels used in the state to decline 10% below 2015 levels by 2025. For more information, see https://www.oregon.gov/deq/ghgp/cfp/Pages/CFP-Overview.aspx.

[5] The Blender's BBD Tax Credit (BTC) allows qualified taxpayers to claim a tax credit equal to $1/gallon against their federal liability when blending biodiesel or renewable diesel with petroleum diesel. For more information, see https://www.law.cornell.edu/uscode/text/26/6426.

[6] Incentives from the RFS and BTC stack with those from the LCFS and CFP in California and Oregon, respectively, meaning all are available for each gallon of BBD provided in those states.

[7] See https://www.eia.gov/todayinenergy/detail.php?id=51778.

[8] See https://www.eia.gov/todayinenergy/detail.php?id=51778.

tons (MT) worth of credits would need to be generated from 2019 to 2030 for the low carbon fuel standard to be met, with BBD likely providing an increasing share of those credits.

BBD is expensive to produce and blend relative to petroleum diesel, meaning that costs of complying with alternative fuel policy have been substantial. RFS compliance costs have ranged from $5 billion to $15 billion between 2016 and 2020, and they are expected to be much higher—over $30 billion—in 2021.[9] Rising RFS compliance costs since 2020 are due to record-high prices for Renewable Identification Numbers (RINs), which are the RFS compliance credits. Compliance costs of the LCFS and CFP in 2020 were nearly $3 billion and $100 million, respectively (Mazzone et al., 2021). The substantial costs of compliance with these policies elucidate the importance of understanding the policies' cost-effectiveness—whether as implemented they are performing as expected.

In this white paper, we study pass-through of implicit taxes and subsidies, introduced by federal and state policies, to a variety of diesel and soy biodiesel fuel prices. We refer to the cost of purchasing or selling compliance credits are implicit taxes or subsidies because they act as such from an economic perspective, even though they may not fit the legal definition of taxes or subsidies. We study biodiesel, and only soy biodiesel, due to data availability, recognizing that soy has historically played a small role in the LCFS, and renewable diesel will likely play a greater role than biodiesel in the future. We believe lessons learned from biodiesel will be relevant to RD, although there will also likely be a lot of differences. For example, some of the mechanisms leading to pass-through findings here may not exist for RD, due to different production processes and fungibility with the displaced diesel fuel.

We apply time series techniques to estimate how a variety of diesel fuel price spreads across the country and in California and Oregon responds to changes in the implicit taxes placed on petroleum diesel and the implicit subsidies awarded to biodiesel. Since implicit taxes and subsidies from the RFS stack with those from the LCFS and CFP in California and Oregon, respectively, we evaluate them both separately and together, as a sum of federal and state incentives. If actors along the supply chain have market power, they have the incentive to shift compliance costs, leading to an inefficient outcome.

Our results are summarized as follows. Implicit taxes associated with RIN obligations are completely (or nearly completely) passed through to wholesale diesel prices, on average, in most major spot markets analyzed nationally. The exception is San Francisco, where the 95 percent confidence interval includes both zero and complete pass-through.

Implicit taxes associated with LCFS deficits accrued to petroleum diesel are not completely passed through to wholesale diesel prices in California (Los Angeles and San Francisco) spot markets. Pass-through of the tax is greater in Los Angeles than in San Francisco, but the confidence interval of our estimate of pass-through in Los Angeles ranges from around zero to one-half. We find that, although the implicit LCFS diesel tax is not passed through to wholesale prices, it was completely passed through to rack prices at California fuel terminals until April of

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[9] See https://www.afpm.org/newsroom/blog/rins-disappear-2021-rfs-compliance-could-hit-30-billion.

2020. Therefore, we find that, prior to the COVID-19 pandemic, refiners and fuel importers exercised their ability under the LCFS regulation to trade their LCFS deficits downstream to blenders, and those blenders completely passed through the cost of LCFS deficit obligations.

Pass-through of the RIN subsidy for biodiesel (focusing on soy methyl ester (SME) due to data availability) is complete in the Midwest, and incomplete in the East Coast, West Coast, and Gulf Coast. Pouliot et al., (2020) find incomplete pass through of the RIN subsidy in some markets for blended gasoline. They conjecture that the RIN subsidy may not have been salient to buyers of blended gasoline, which allowed rack sellers to keep the subsidy rather than pass it through. The findings of incomplete RIN subsidy pass-through in our sample, which includes data from the last six years, over regimes of high and low RIN prices, suggest that lack of salience of the policy mechanism may not be the explanation. Additionally, incomplete pass-through of the RIN subsidy in the Gulf Coast differs from findings in the blended gasoline sector (Pouliot et al., 2020).

We find pass-through of the LCFS subsidy for biodiesel in California to be incomplete on average but highly uncertain. However, we find rack sellers pass through less of the subsidy when selling blends with higher biodiesel content by volume, which is consistent with blenders exercising market power in higher blends. For the combined RFS and LCFS incentive, pass-through is also incomplete: we find that 68 percent of the combined subsidy is passed through to rack prices in California in the long-run on average. Salience (as described above) as the cause of incomplete pass-through of both subsidies in California would require that all costs be passed through at the same rate (Pouliot et al., 2020), which is inconsistent with results (as demonstrated by the unrestricted model results shown in Figure A-3).

CFP tax pass-through is not studied here due to lack of data. Spot prices for diesel are especially volatile in the Pacific Northwest, which creates noisy margins in Oregon. At the same time, CFP biodiesel subsidies lack substantial variation, therefore estimates of pass-through are very imprecise in Oregon. With that caveat, the analysis showed CFP pass-through to be incomplete on average and exhibits similarities to the LCFS.

The primary contribution of this paper is estimating to what extent implicit taxes and subsidies for diesel and biodiesel, respectively, are passed through to fuel prices. Analysis, however, did require applying assumptions about how market actors addressed the volatility of the BTC, and did focus on the situation with soy biodiesel, while a major feedstock nationally, the least-used in California's LCFS. Bearing in mind those caveats, we present evidence that some credit value is retained by fuel blenders, pointing to some inefficiencies in the RFS, LCFS, and CFP. Explanations for their ability to capture rents when blending biodiesel will require further research. However, some explanations are ruled out, such as rack buyers not fully understanding how the policies affect margins of rack sellers.

This study was bounded by significant data limitations, especially in California and Oregon. Our sample of rack prices had no associated volumes, meaning it is unclear to what extent our results can be generalized to the United States or any region considered in this study. Additionally, rack sellers didn't always disclose how LCFS/CFP credits were accounted for in their reported prices. An important limitation of this study was a lack of California- and Oregon-specific spot prices for biodiesel, which meant we were unable to calculate accurate rack margins. Data on the cost of biodiesel in California and Oregon would greatly assist researchers study policy incentive pass-through in the diesel sector. There were also no feedstock-specific biodiesel spot prices in California or Oregon available to us. Feedstock-specific costs would allow for more accurate calculations of implicit subsidies and rack margins, and for estimating pass-through for diesel blended with biodiesel produced from feedstocks with much larger market shares in California and Oregon, such as tallow and used cooking oil.

Introduction

Renewable and low carbon fuels are becoming an important part of decarbonization strategies worldwide. Three policies, one federal and two state, have been implemented in the United States. The U.S. Renewable Fuel Standard (RFS) requires certain quantities of renewable fuels be used each year. California's Low Carbon Fuel Standard (LCFS) and Oregon's Clean Fuels Program (CFP) set targets to reduce the carbon intensity (CI) of transportation energy in their states. The RFS, LCFS, and CFP all rely on systems of tradeable credits for compliance which prompt implicit tax-subsidy schemes in fuel markets. Via credit trading, firms pay a penalty on their petroleum products and the revenue is transferred to alternative fuel producers effectively in the form of a subsidy. The efficacy and efficiency of these policies hinge on the implicit taxes and subsidies propagating through fuel supply chains: they must be fully passed through to fuel prices to have their full intended impact on the fuel mix.

This paper studies the pass-through of the implicit taxes and subsidies in the context of the U.S. diesel sector. We estimate how a variety of diesel fuel price spreads responds to changes in the implicit taxes placed on petroleum diesel and the implicit subsidies awarded to biodiesel. Implicit taxes and subsidies from the RFS stack with those from the LCFS and CFP in California and Oregon, respectively, and therefore are evaluated both separately and together.

There are three points in fuel supply chains where pass-through must be complete to achieve maximum efficacy and efficiency of the policies. This paper studies two of them: the wholesale market to blenders and blenders to retailers. This paper does not investigate the third; pass-through from retailers to consumers, which must also be complete to achieve efficacy of the policies. The pass-through of biodiesel subsidies to retail prices of blended diesel is an important area for future research, especially given evidence of incomplete pass-through of ethanol RIN subsidies to E85 retail prices in the literature (Lade & Bushnell, 2019; Li & Stock, 2019).

U.S. crude oil refiners and petroleum importers are required to purchase Renewable Identification Numbers (RINs), the compliance credits in the RFS, for each gallon of gasoline and diesel supplied for U.S. consumption, which act as an implicit tax.[10] California and Oregon refiners and importers face a similar obligation under the LCFS and CFP, respectively, namely deficits that are generated for each gallon of gasoline and diesel consumed in-state. The total tax payments reflect the cost of compliance of the policies. There are robust markets for RINs, LCFS, and CFP credits and the market price, along with the stringency of the policies, determine the level of the taxes and therefore the cost of compliance.

Fuel blenders purchase biofuels with a RIN attached to it. Once the fuel is blended, the RIN is separated from the fuel and can be sold on the RIN market. The value of the RIN then acts as an implicit subsidy on the biofuel, since the blender can sell RINs in the RIN market, and sell the biofuel for lower than its marginal cost of production (enabling a fuel to enter the market).

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[10] We refer to the cost of purchasing or selling compliance credits are implicit taxes or subsidies because they act as such from an economic perspective, even though they may not fit the legal definition of taxes or subsidies.

Refiners must purchase RINs for every gallon of gasoline and diesel they produce and will therefore raise prices for their products by the amount of this implicit RIN tax, if fully passed through. This increases the cost of blending petroleum fuels by the amount of the tax and will therefore increase the price of blended fuel if fully passed through to retailers. Therefore, if blenders have market power in selling RINs, they have the incentive to drive up RIN prices when blending biodiesel, which in turn, raises compliance costs for refiners and consumers.

A similar relationship between the tax and subsidy is present in the LCFS and CFP; however, there are important differences that must be accounted for in the pass-through analysis such as flexibility in transferring compliance obligations. This paper is the first to analyze RIN pass-through on both sides of the tax-subsidy mechanism, the first to examine pass-through of biodiesel subsidies, and the first to consider either the LCFS or CFP.

Indeed, most studies to date on pass-through for implicit taxes and subsidies for fuels have focused on the federal RFS and the gasoline industry, with much less focus on state policies and the diesel industry. Diesel fuels accounted for 27 percent of total transportation energy in 2020.[11] Biomass-based diesel (BBD)—comprising fatty acid methyl ester (FAME) biodiesel (BD) and hydrotreated esters of fatty acid (HEFA) renewable diesel (RD)—earns a plurality of credits in California's LCFS and a growing proportion in Oregon's CFP, making diesel an important piece of the transition to lower carbon fuels. Furthermore, pass-through results from the gasoline industry may not hold for the diesel industry because of differences in costs, production, storage, and blending constraints, demand and supply elasticities, and market structure.

The first contribution of this paper is estimating the extent to which implicit RIN taxes, LCFS diesel taxes, and CFP diesel taxes have been passed through to wholesale diesel prices from 2015 through mid-2021. The issue of RIN pass-through has been of particular interest recently. RFS compliance costs reached an all-time high in 2021, strengthening the already substantial concern of potential harm on consumers and the refining industry, especially amidst a global pandemic. Senator Pat Toomey and his senate colleagues sent a letter to the Environmental Protection Agency (EPA)—the administrator of the RFS—asking them to waive or reduce the 2020 volume requirements to mitigate the "unprecedented burden" placed on consumers and refiners via RFS compliance costs.[12] EPA responded in kind, reducing the 2020 mandate retroactively in 2021.[13]

Still, some in the refining industry have argued that the RFS has made it harder to produce gasoline and diesel domestically, according to a recent article in Reuters.[14] Refiners indeed saw much larger RFS bills in 2021; one Pennsylvania refinery had a $350 million RIN obligation in the first three months of 2021, 500% higher than their total 2019 of $58 million.[15] In 2021, refiners

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[11] See EIA: https://www.eia.gov/energyexplained/diesel-fuel/use-of-diesel.php.

[12] See https://www.toomey.senate.gov/newsroom/press-releases/toomey-and-colleagues-urge-epa-to-waive-biofuel-blending-requirements.

[13] See https://asmith.ucdavis.edu/news/biofuel-policy-explained for a discussion of the

[14] The Reuters article can be found here: https://www.reuters.com/business/energy/us-oil-refiners-bet-farm-biden-will-back-them-biofuels-2021-11-11/.

[15] See https://www.afpm.org/newsroom/blog/rins-disappear-2021-rfs-compliance-could-hit-30-billion.

paid an implicit tax upwards of 20 cents per gallon of gasoline and diesel. Smaller refiners have been granted exemptions by EPA for their RIN obligations for several years. This high RIN tax came at a time when gasoline and diesel prices both reached their highest levels since 2014. The Biden administration has announced that the Department of Energy will release 50 million barrels of oil from the Strategic Petroleum Reserve to combat the high fuel prices. As of November 2021, the average U.S. retail price of diesel was $3.72/gallon and gasoline, $3.49/gallon.[16]

To estimate pass through of the RIN tax, we take the approach used in Knittel et al. (2017) which exploits the fact that wholesale diesel and jet fuel prices only differ in their RIN obligation. Their sample of Gulf wholesale prices covers 2013-2015, whereas ours covers 2015-2021 for all major spot markets, therefore providing a larger and more recent sample to leverage. We find that, on average, refiners fully passed through the cost of their RIN obligations to wholesale buyers of diesel over the last six years. The average result does not preclude other patterns in subsections of the data, in other words, findings of incomplete pass-through. However, prior work suggests that smaller refineries have been able to pass through the cost of their RIN obligations on gasoline and diesel at the same rate as large refineries (Burkhardt, 2019). In addition, the unprecedented growth in RIN prices mentioned above was driven by soybean prices nearly doubling from summer of 2020 to summer of 2021 as U.S. exports to China ramped up.[17] This raises speculation as to whether the subsection of the data covering that period of the sample could drive any result of incomplete pass-through in a regional market or overall, given its large variation in RIN prices relative to the rest of the sample. However, we present results where that period is dropped from the sample and find lower rates of RIN pass-through, not higher. In fact, the striking increase in compliance costs during that period were largely passed through to (borne by) market players downstream from refiners (e.g., blenders, retailers, and consumers) in most U.S. regions.

Refiners of fuel for California and Oregon face an additional cost due to deficit obligations under the LCFS and CFP, respectively. The additional cost levied on petroleum diesel blending in California from the LCFS approximately matches that from the RIN; the implicit tax associated with their LCFS deficits were also upwards of 20 cents per gallon in 2021, on average.[18] In this paper, we find that refiners have passed through little to none of the LCFS tax to wholesale diesel prices. However, we find that the LCFS tax has been fully passed through to rack prices by blenders, which suggests that some refiners have exercised their ability to trade their deficit obligations downstream to blenders, an action not available under the RFS. This result raises the question of why obligated parties and downstream blenders decide to transfer the obligation. We do not attempt to determine the incentives driving this behavior.

Our finding that the LCFS diesel tax is fully passed through to rack prices of diesel suggests that LCFS compliance costs on diesel, as RIN compliance costs on diesel, are ultimately borne by

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[16] Average retail petroleum prices can be found at https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_w.htm.

[17] See https://asmith.ucdavis.edu/news/i-hear-rd-train-comin.

[18] This quantity represents the marginal compliance cost. Inframarginal firms may achieve compliance at lower cost by, for example, self-generating credits.

retailers and/or consumers. While the Oregon CFP implicit tax on diesel averaged 8 cents per gallon in 2021, estimates of CFP pass-through to spot diesel prices are too noisy to conclude anything and, due to data limitations, we are unable to estimate pass-through of the implicit CFP tax to rack diesel prices.

The second contribution of this paper is estimating the extent to which implicit subsidies from the RFS, LCFS, and CFP are passed through to rack prices diesel blended with biodiesel. Pass-through of RIN subsidies to biodiesel has been acknowledged in previous work as worth studying but empirical analysis sidestepped due to data limitations and the unknown interactions between the RFS and the Blender's Tax Credit (BTC). The BTC awards blenders a $1 tax credit against their federal liability for every gallon of biomass-based diesel blended in the U.S. and it is realized in addition to the RIN, and the LCFS credit or CFP credit in California and Oregon, respectively. The BTC was implemented in 2005 and expired four times since, but retroactively reinstated each time. When the BTC expired, blenders and biodiesel producers formed contracts to share the expected future credit, which had unknown impacts on the blenders' margins and RIN prices. However, with straightforward assumptions about the BTC, we can identify the pass-through of RIN subsidies to blended diesel prices.

Of existing literature, the subsidy pass-through analysis undertaken here is most like Pouliot et al. (2020), which studies pass-through of ethanol RIN subsidies to blended gasoline prices at racks across the country from January 2012 to May 2016. They find incomplete pass-through in some regions and attribute it to lack of salience for buyers of blended fuel on how the subsidies affect seller's profit margins. Buyers may not bid down the price if they are unaware of the subsidy being received by sellers. We extend their empirical framework to estimate the pass-through of RIN, LCFS, and CFP subsidies to blended biodiesel prices at fuel terminals in eight U.S. cities. We utilize daily pricing data from the Oil Price Information Service (OPIS) and Bloomberg on rack prices and spot prices of diesel, biodiesel, RINs, and LCFS and CFP credits to calculate daily profit margins for blenders. If a subsidy is fully passed through, blenders' profit margins should move one-for-one with changes in said subsidy.

There are significant heterogeneities in the pass-through of biodiesel subsidies across space, time, and policy. RIN subsidy pass-through is complete in the Midwest, and incomplete on the West Coast, Gulf Coast, and East Coast. These results are partially consistent with Pouliot et al., (2020): although they find incomplete pass-through only in the eastern U.S., price spreads in the West Coast were too volatile to provide reliable estimates. Volatility in the West Coast pricing was due to an extreme event at the end of their sample in 2015—the Exxon Mobil refinery explosion in California. Our sample follows the explosion and accounts for the LCFS, allowing for more precise estimates of pass-through on the West Coast. The finding that pass-through is still incomplete on the East Coast may suggest that incomplete RIN subsidy pass-through stems from a mechanism other than lack of salience, since RIN markets have been active since 2013, giving ample time for learning by market participants. As with the RIN tax, we find RIN subsidy pass-through to be less complete when dropping observations during the RIN price shock due to increased soybean prices.

LCFS subsidies exhibited considerably less variation over our sample, leading to estimates of pass-through with relatively wide confidence intervals. We find pass-through of the LCFS subsidy alone to be zero on average in San Francisco and Los Angeles; however, the confidence interval includes one. Therefore, complete pass-through can't be ruled out. When narrowing the sample to higher-level biodiesel blends, pass-through coefficients are slightly lower. Blends with greater biodiesel content (generally above 20 percent) exhibit costly barriers to supply, such as storage and transportation constraints, and to demand, such as vehicle engine capabilities. With fewer terminals able to handle the higher blends, this result is consistent with market power being exerted in supply of blends with high percentages of biodiesel (Pouliot et al., 2020). Among the smaller California cities in our sample, pass-through tends to be more complete; we estimate a pass-through coefficient of 0.61 for the LCFS subsidy that is statistically significant at the 5 percent level.

During 2015, the first year of our sample, when the LCFS subsidy was very small, estimates of pass-through were higher (but statistically insignificant) than in later years when the LCFS subsidy was larger. This might suggest the incomplete pass-through results can't be explained by market participants lacking salience about how LCFS credit prices affect their margins. Given the shorter sample of CFP subsidies, their pass-through is estimated with very little precision, but point estimates generally follow a similar pattern as the LCFS results.

Taken together, the results outlined above can be summarized as follows. The RFS largely operates as intended in the diesel sector because the full RIN tax on diesel is passed through to wholesalers and the full RIN subsidy for biodiesel blending is passed through to retailers (or other rack buyers of blended diesel) in much of the country. On the other hand, we find that blenders pass through approximately two-thirds of the RIN subsidy in California and Oregon, when using our full sample. In California/Oregon, we present some evidence that pass-through of both the RIN tax and the LCFS/CFP tax is complete but of both the RIN subsidy and LCFS/CFP subsidy is incomplete. This behavior is consistent with blenders exercising local market power and raising RFS, LCFS, and CFP compliance costs for consumers. Our findings also suggest that pass-through of the LCFS subsidy is lesser for blends with higher biodiesel content, suggesting commercial buyers pay higher prices for the blended fuel.

In addition, we estimate the combined subsidy for California (LCFS+RFS) and Oregon (CFP+RFS) because the federal and state subsidies stack and, in theory, rack margins under pass-through would reflect the sum of the additional policy costs. Therefore, the changes to the combined subsidy may be more salient to blenders than any individual subsidy. On average, only 68 percent and 66 percent of the combined subsidies are passed through in California and Oregon, respectively, tending to echo the "RIN-only" findings due to variation in the combined measure being characterized by the higher variability in RIN prices than LCFS and CFP credit prices.

The remainder of the paper is structured as follows. Section 1 provides background information and institutional context on the RFS, LCFS, CFP, and the BTC. Section 2 describes markets for diesel and biomass-based diesel. Section 3 describes the data used to execute the empirical strategy. Section 4 describes the empirical strategy for and presents results from estimating pass-through of the implicit taxes from the RFS, LCFS, and CFP. Section 5 describes the empirical strategy for and presents results from estimating pass-through of the implicit subsidies from the RFS, LCFS, and CFP. Section 6 concludes and discusses policy implications of the findings.

1. Policy Background

1.1. The U.S. Renewable Fuel Standard

The RFS was enacted in the 2005 Energy Policy Act and was revised and expanded as part of the Energy Independence and Security Act of 2007, sometimes referred to as RFS2. The RFS is administered by the U.S. Environmental Protection Agency (EPA) and specifies a fraction of U.S. petroleum transportation fuel consumption that must be displaced by renewable fuels. Using projections of gasoline and diesel consumption from the Energy Information Administration (EIA), the mandate is communicated as an annual volume requirement for renewable fuels. These volumetric mandates are called Renewable Volume Obligations (RVOs).

RVOs are set separately each for conventional (D6), advanced (D5), BBD (D4), and cellulosic (D3) categories. Refiners or fuel importers, the obligated parties under the RVO, can either produce biofuels or purchase credits, called Renewable (fuel) Identification Numbers (RINs), generated from the production of renewable fuels. Each refiner must retire (submit to EPA) a certain number of each type of RIN each year for each gallon of gasoline or diesel that they sell. For example, in 2018, for every 100 gallons of gasoline or diesel sold, refineries had to retire a total of 10.67 RINs, including at least 2.37 advanced biofuel (D5) RINs, 1.74 BBD (D4) RINs, and 0.16 cellulosic (D3 or D7) RINs. The remaining 8.14 RINs that had to be retired could be of any category; typically, these come from corn ethanol (D6) RINs and BBD (D4) RINs. Corn ethanol is the lowest-cost renewable fuel, however the E10 “blendwall” (some vehicles can’t accommodate gasoline finished with more than 10 percent ethanol by volume, and waivers for potential air quality impacts, in place for E10, at higher blends were recently rejected in court).[19] forces the market to use the next lowest-cost option, BBD, for much of the conventional RVO.

Since refiners must purchase RINs for every gallon of gasoline and diesel they sell, RINs act as a tax that is used to subsidize renewable fuels. The magnitude of the taxes and subsidies depend on the economics of the underlying fuel markets. Since each category relies on different types of renewable fuels, each type of RIN has its own market price. Generally, the market price for each type of RIN reflects the expected cost of supplying the marginal gallon of the relevant renewable fuel needed to meet the RVO, relative to the cost of gasoline or diesel. Since advanced and cellulosic biofuels are much more expensive than conventional biofuels, the market price for their RINs are relatively expensive. Since BBD has been used to satisfy the conventional (D6) RVO, the market price for D6 RINs has converged to the market price for D4 RINs.

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[19] See www.forbes.com/sites/rrapier/2021/07/04/a-setback-for-the-ethanol-industry/.

RINs can be traded freely before being retired for annual compliance, and 20 percent of RINs generated in one year can be banked for compliance in the next year. In an efficient RIN market, these features cause future expectations around fuel markets and policy to influence RIN prices. Lade et al., (2018) show that RIN prices follow a random walk and respond quickly to EPA announcements that change expectations around future compliance.

The point of policy incidence is at the fuel terminal for the RFS. The fuel terminal is the midpoint in the supply chain of RINs. Renewable fuel producers generate RINs with every gallon of renewable fuel they supply. When RINs are generated, they are "attached" to the renewable fuel, meaning that whoever purchases that fuel receives the RIN certificate with the purchase. Terminals purchase the renewable fuels with the attached RINs and blend the renewable fuel with petroleum, which separates the RIN from the fuel. When the RIN is separated, it can be traded freely. When blenders separate RINs, they sell them to refiners who must retire RINs to EPA for compliance. Since blenders can sell RINs once separated, they are willing to pay a premium for renewable fuels. Figure 1 shows the movement of fuel and RINs through the supply chain in the context of diesel.

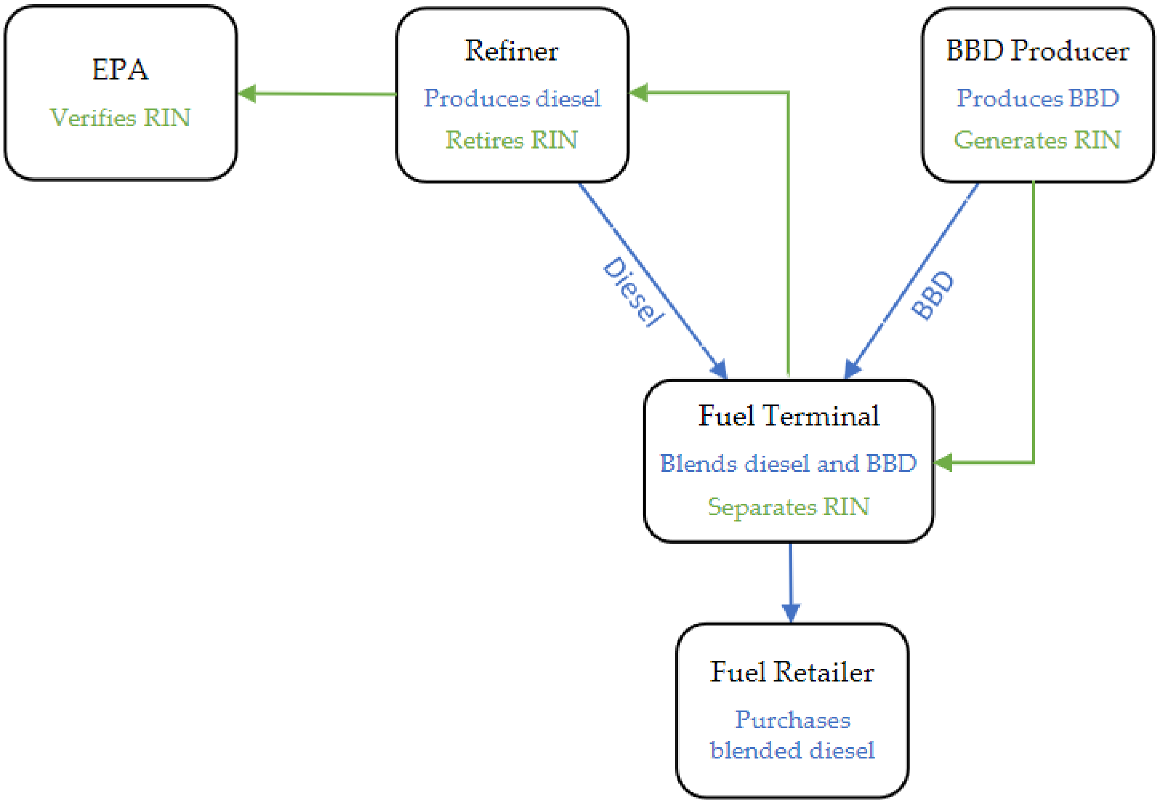

Figure 1. Supply Chain of Fuel and RINs

RINs can be generated by domestic BBD producers, foreign BBD producers, and domestic BBD importers. The majority of biodiesel consumed in the U.S. is produced domestically. In 2016, nearly a quarter of biodiesel was imported, however in recent years imports fell below an eighth of total consumption, making up 10 percent in 2020. The recent decline in biodiesel imports is driven by antidumping duties levied on Argentinian and Indonesian biodiesel imported to the United States, starting in 2018.[20] Almost no RINs generated from U.S. biodiesel consumption are awarded to foreign producers. In California, 28 percent of biodiesel consumed in 2019 was produced in the state.[21]

Most other biomass-based diesel used in the United States, and especially in California, came from abroad in the early years of the LCFS, but domestic production has grown in recent years. The share of U.S. renewable diesel consumption that is domestically produced nearly doubled from 2013 (27 percent) to 2020 (55 percent). In California, three percent of RD consumed in 2019 was produced in the state, and in 2020, California consumed about 61% of total RD generating RINS under the RFS.[22]

1.2. California's Low Carbon Fuel Standard

The LCFS was approved by the California Air Resources Board (CARB) in 2009. CARB then implemented the LCFS in 2011, amended it in 2013, re-adopted it in 2015, and extended it in 2018 to set targets through 2030. The LCFS was designed to lower the carbon intensity (CI) of transportation fuel in the state. To that end, CARB specifies an annual CI standard, measured in grams of CO2 equivalent per megajoule (gCO2e/MJ) of energy, that the California transportation fuel pool must satisfy. Currently, CARB has specified a CI target for transportation energy of 20 percent reduction below 2010 levels by 2030. Beginning in 2019, this entails the CI target declining 1.25 percent annually.

The LCFS relies on a system of tradeable credits for compliance like the RFS, but with important differences. Fuels with a CI score above the standard generate deficits and fuels with a CI score below the standard generate credits. Compliance requires that every deficit be met with a credit. The supply chain of LCFS credits can follow a similar path as RINs described in Figure 1, but aren't restricted to it like RINs are. Refiners and importers are the obligated parties who generate deficits; however, the obligation can be traded to other entities, for example from refiners to blenders.[23] Similarly, alternative fuel producers generate LCFS credits, but that status may also be transferred downstream, and the fuel needn't be sold with the credit "attached."

Each year petroleum and other higher-CI fuels generate more deficits per gallon as the standard tightens. Similarly, alternative fuels generate fewer and fewer credits each year, unless producers can demonstrate they have achieved, and are assigned, a lower CI value. This dynamic is intended to incentivize innovation in reducing the CI of fuels. Alternative fuel

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[20] See https://www.usitc.gov/press_room/news_release/2018/er0403ll927.htm.

[21] This is true for both biodiesel from residue and crop sources. This, and the similar number for RD below, are calculated using data from CARB's LCFS Data Dashboard. 2019 is the most recent year with full data in their spreadsheet. See http://ww3.arb.ca.gov/fuels/lcfs/dashboard/figure10_043021.xlsx.

[22] This is calculated by combining program data from EPA and CARB.

[23] See § 95483(a)(2) of 2020 California LCFS regulation which can be found at https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf

producers must demonstrate the lifecycle CI value of their fuel via third-party verification of the inputs used to make the calculation. Producers apply for “pathways” which track the lifecycle carbon intensity of fuels from "well to wheel." When a fuel pathway application is approved, the fuel earns the CI score associated with the pathway.

LCFS credits can be banked freely and are fully fungible, so credits generated from any type of fuel can be used to cover deficits generated from any type of fuel. As of 2021 Q1, approximately 7.86 million credits sat in a LCFS "credit bank"; systemwide credits held by regulated parties not yet used for compliance. In mid-2020, CARB instituted a credit price ceiling on reported trades of $200/MT in 2016 dollars, tied to inflation thereafter.[24] The ceiling for all trades was added to an LCFS Credit Clearance Market (CCM) instituted in 2016, with the same price ceiling that is evoked when obligated parties have credit shortfalls at the end of the compliance year, and that effectively set a soft credit price ceiling. LCFS credits were trading between $20/MT and $100/MT in early years of the program but hovered near the ceiling between 2018 and 2020 before falling as the COVID-19 pandemic reduced transportation, which reduced demand for LCFS credits from gasoline and diesel consumption, as well as supply of LCFS credits associated with biofuels in the gasoline and diesel blends, and electric vehicles), and as expectations grew around expanding renewable diesel capacity (Mazzone et al., 2021).

A range of alternative fuels generates LCFS credits. Figure 2 depicts the annual percentages of energy (bottom) and credits (top) coming from each alternative fuel type since the LCFS began in 2011. Ethanol made up the majority of both energy and credits among alternative fuel sources in the earlier years of the program. A much larger percentage of credits now come from biomass-based diesel, electricity, and biogas. Electricity and biogas crediting has grown in large part due to lower CI pathways becoming available, along with expansion of crediting opportunities beyond on-road EVs. Growth in renewable diesel crediting has come from substantially increased use in the state, in the context of increased demand for renewable fuels to meet state and federal mandates and increased supply of renewable diesel due to expansion of production capacity.

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[24] The price ceiling can be backstopped, if needed, through the advance of a limited amount of residential electricity credits for future EV charging, which utilities must pay back over time (Bushnell et al., 2021).

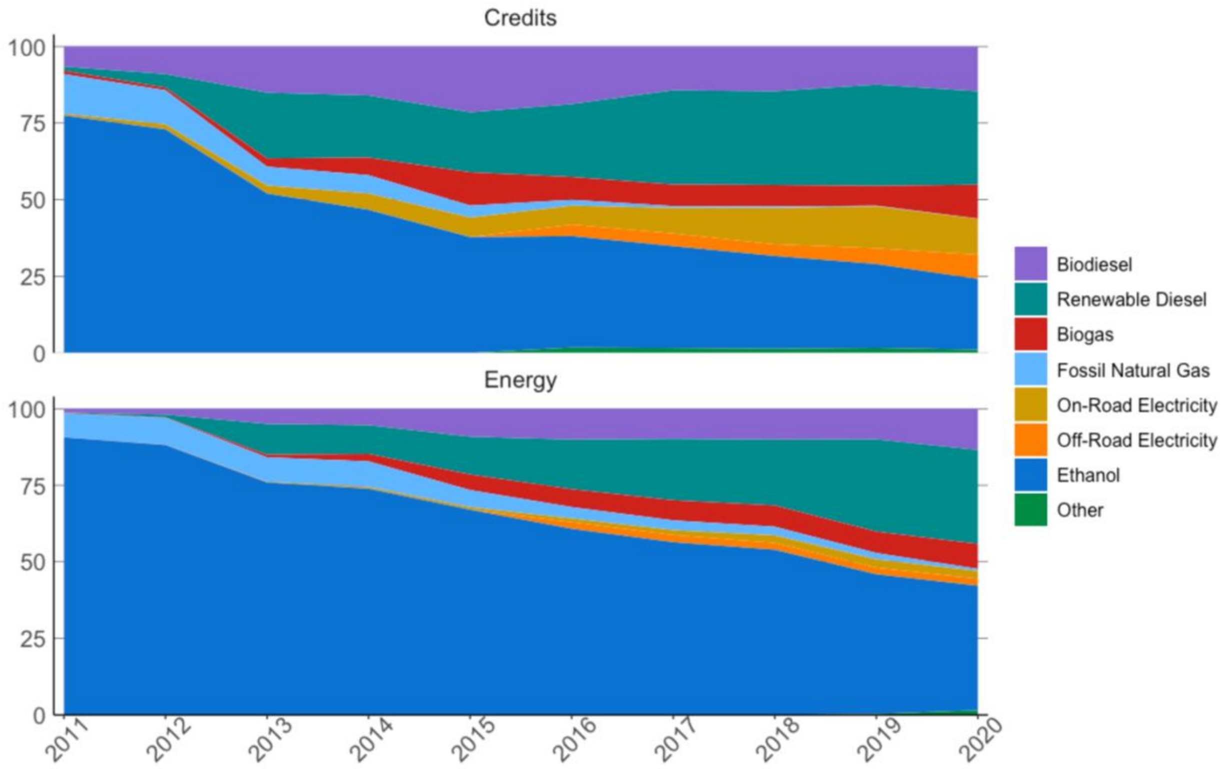

Figure 2. Share of Alternative Fuel Energy and Credit Shares by Fuel Type

Since 2011, there have been approximately 3.5 billion gallons of finished diesel consumed in California each year. However, the portion made up of biomass-based diesel grew from approximately 0.3 to 24 percent over the decade. The 855.4 million gallons of biomass-based diesel consumed in the state has been produced from a variety of feedstocks, including vegetable oils, waste oils, and animal fats. Soybean oil is by far the most prominent feedstock for biomass-based diesel in the U.S. but has been rarely used in California due to its relatively high CI score—which is in large part due to its adverse effects on land use, captured by the indirect land use change (ILUC) score.[25] The vast majority of biodiesel consumed in California is produced from corn oil (a by-product of corn ethanol production) and used cooking oil. The volume-weighted average reported CI of all biodiesel is shown later in Figure 5, along with the average CI score of soy oil-specific biodiesel. This paper is concerned with the LCFS insofar as the costs it places on petroleum diesel and incentives provided to biodiesel, and in particular soy biodiesel; a more detailed description of the policy and the other fuel types can be found in Mazzone et al., 2021.

1.3. Oregon's Clean Fuels Program

The CFP sets an annual CI standard, similar to the LCFS, and was implemented in 2016 by Oregon's Department of Environmental Quality (DEQ). It specifies a 10 percent reduction in the state's transportation fuel CI by 2025 from 2015 levels. A recent executive order laid out an

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[25] Use of soy oil RD has been rising the last few years in California, however (Mazzone et al., 2021).

extension of the CFP target 20 percent reduction by 2030 and 25 percent by 2035, although it has indicated that it may adopt a more stringent target of 37 percent by 2025. Although it goes by a different name, Oregon’s CFP is very similar to California’s LCFS and is in large part designed after it. The CFP accepts certified LCFS pathways, adjusted for differences in transportation.

Figure 3 shows the percentage of energy and credits from each fuel type and shows a much more static picture than the LCFS, although the CFP has existed for only half as long as the LCFS. Ethanol and biomass-based diesel make up the majority of both alternative fuel energy and CFP credits. Biodiesel has contributed over a quarter of both alternative fuel energy and credits over the lifetime of the program. Unlike California, biodiesel is still blended more than renewable diesel in Oregon. The majority of biodiesel consumed in Oregon is produced from canola oil and used cooking oil. Canola oil pathways are generally associated with higher CI scores than corn oil, which is why the CI score of the average gallon of biodiesel is higher in Oregon than California.

CFP credits are also fungible and freely banked, with 709.5k CFP credits in the bank as of 2021 Q1. CFP credit prices have been generally lower than but have followed a similar path as LCFS credit prices, since trading began in 2017. CFP credits started trading around $50/MT, rose to $100/MT in 2019, peaked around $170/MT, and settled around $130/MT in 2021. The CFP uses a credit clearance market (CCM) which sets a soft price ceiling of $200/MT indexed to 2017 dollars, but market prices haven’t neared it yet. For more information on Oregon’s CFP, we refer the reader to Witcover & Murphy (2019) and Mazzone et al. (2021).

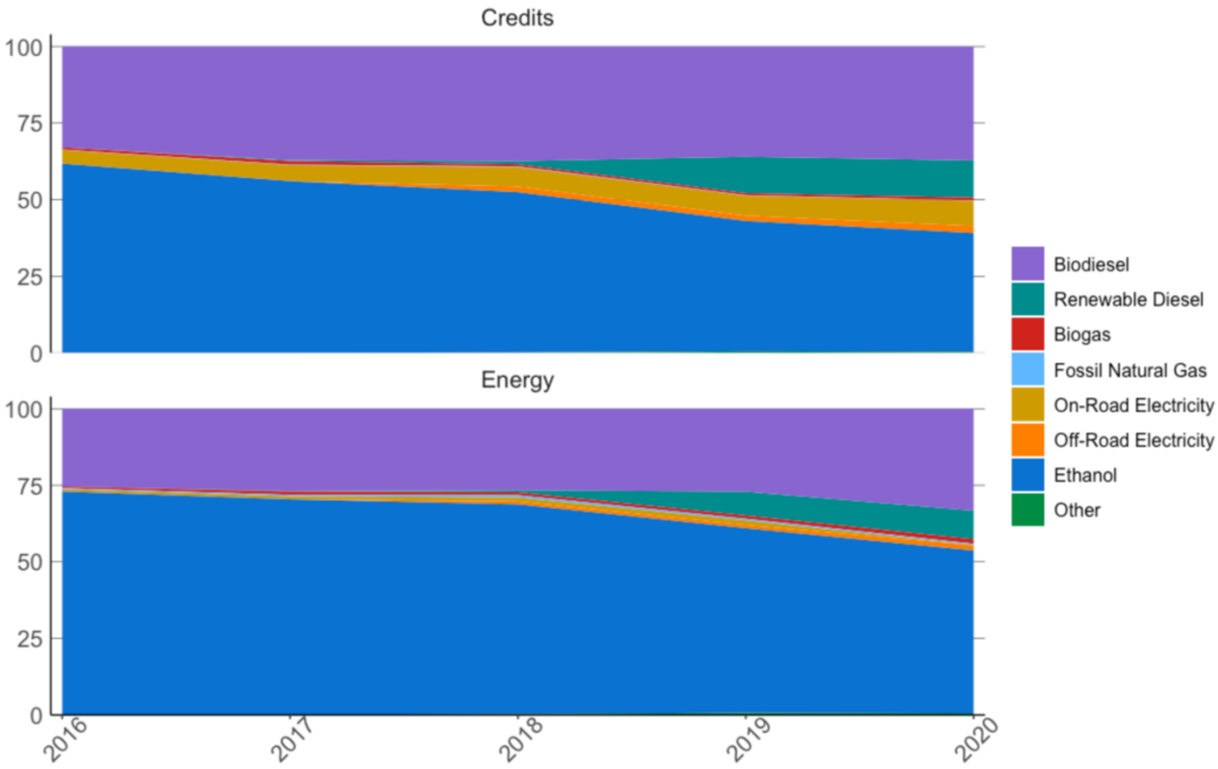

Figure 3. Alternative Fuel Energy and CFP Credit Shares

1.4. Blender's Tax Credit

The biodiesel Blender's Tax Credit (BTC) was implemented in 2005 and issues blenders of biomass-based diesel a credit of $1 per gallon against their U.S. federal tax liability. The BTC was the first major policy promoting BBD in the U.S. Like the RFS, the BTC has fallen subject to considerable political uncertainty, which has rippled through the BBD market in ways important to answering the research questions at hand. Congress allowed the BTC to expire four times since its implementation, at the end of 2009, 2011, 2013, and 2016.

The BTC was in place in 2016, taken away in 2017, retroactively reinstated for 2017, taken away again in 2018 and most of 2019, the retroactively reinstated again in December 2019 for both 2018 and 2019, and then extended for 5 years thereafter. Blenders and BBD producers formed contracts in response to the expiration of the BTC, agreeing to share the credit if and when reinstated. Often, suppliers and blenders would bear equal risk with a 50/50 split of the expected $1 future revenue stream (Irwin 2017). The way the BTC is shared will matter when analyzing the pass-through of RIN prices since they are stacked. The handling of the BTC is discussed further in Section 5.

2. Diesel Fuels and their Supply Chains

In 2020, 56.17 billion gallons of ULSD were consumed by the US transportation sector. In California, the comparable figure is 2.73 billion gallons, or 5 percent of total U.S. consumption. Oregon's market is much smaller, consuming 672.52 million gallons, or 1.2 percent of total U.S. consumption in 2020. For context, 117.71 billion gallons of motor gasoline were used in the U.S. in the same year.[26] Diesel is refined from crude oil like gasoline. Diesel fuels, with few exceptions, are consumed by commercial consumers like heavy duty trucks. Diesel products are often available at most retail fuel stations that offer gasoline. However, they are also distributed to commercial sites, card stations, and other outlets. The average U.S. retail price of diesel (including federal and state taxes) was $2.55/gallon in 2020, and $3.38/gallon in California.[27] California state taxes were more than double the average state tax in 2020, not including the implicit taxes from the LCFS and California's GHG emissions cap-and-trade program.[28]

Federal and state environmental policies, described in Section 1, have supported the transition to diesel fuels made from biomass due to their policy assessment as having a lighter carbon footprint. BBD encompasses two types of fuels: biodiesel and renewable diesel. Both fuels are currently produced from largely the same sources– soybean oil, corn oil, canola oil, used cooking oil (UCO), and tallow. Figure 4 plots biodiesel (top) and renewable diesel (bottom) consumption in California, Oregon, and the rest of the United States (ROUS) using administrative data from the RFS, LCFS, and CFP—described in greater detail in Section 3. Around 2 billion gallons of biodiesel were consumed nationwide in 2020, 266.5 million gallons in California, and 68.4 million gallons in Oregon. California accounted for around 13 percent of U.S. biodiesel consumption, but over half of U.S. renewable diesel consumption. Renewable diesel has become more popular because as a "drop in" fuel it can overcome blending restrictions faced by biodiesel. The market for renewable diesel is young but is expected to grow substantially in the next five years according to plans for new production capacity to be built. According to the Energy Information Administration (EIA), total U.S. production capacity of renewable diesel would reach over 5 billion gallons by 2024 if all announced and proposed projects are seen through.[29] Under business-as-usual conditions, LCFS compliance could require biomass-based diesel to reach between 60 and 80 percent of finished diesel by 2030 (Bushnell et al., 2020).

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[26] U.S. ultra-low sulfur diesel and gasoline consumption was collected from EIA prime supplier sales data, which can be accessed at https://www.eia.gov/dnav/pet/pet_cons_prim_dcu_nus_m.htm. California and Oregon numbers are collected from the quarterly summaries released by CARB and DEQ, respectively.

[27] Retail diesel prices are collected from EIA Weekly Retail Gasoline and Diesel Prices data, which can be accessed at https://www.eia.gov/dnav/pet/pet_pri_gnd_dcus_nus_a.htm. EIA doesn't report the average retail diesel price in Oregon.

[28] See https://www.eia.gov/petroleum/marketing/monthly/xls/fueltaxes.xls.

[29] See https://www.eia.gov/todayinenergy/detail.php?id=48916 for more information on the announcements for planned renewable diesel capacity proposed to become operational by 2025.

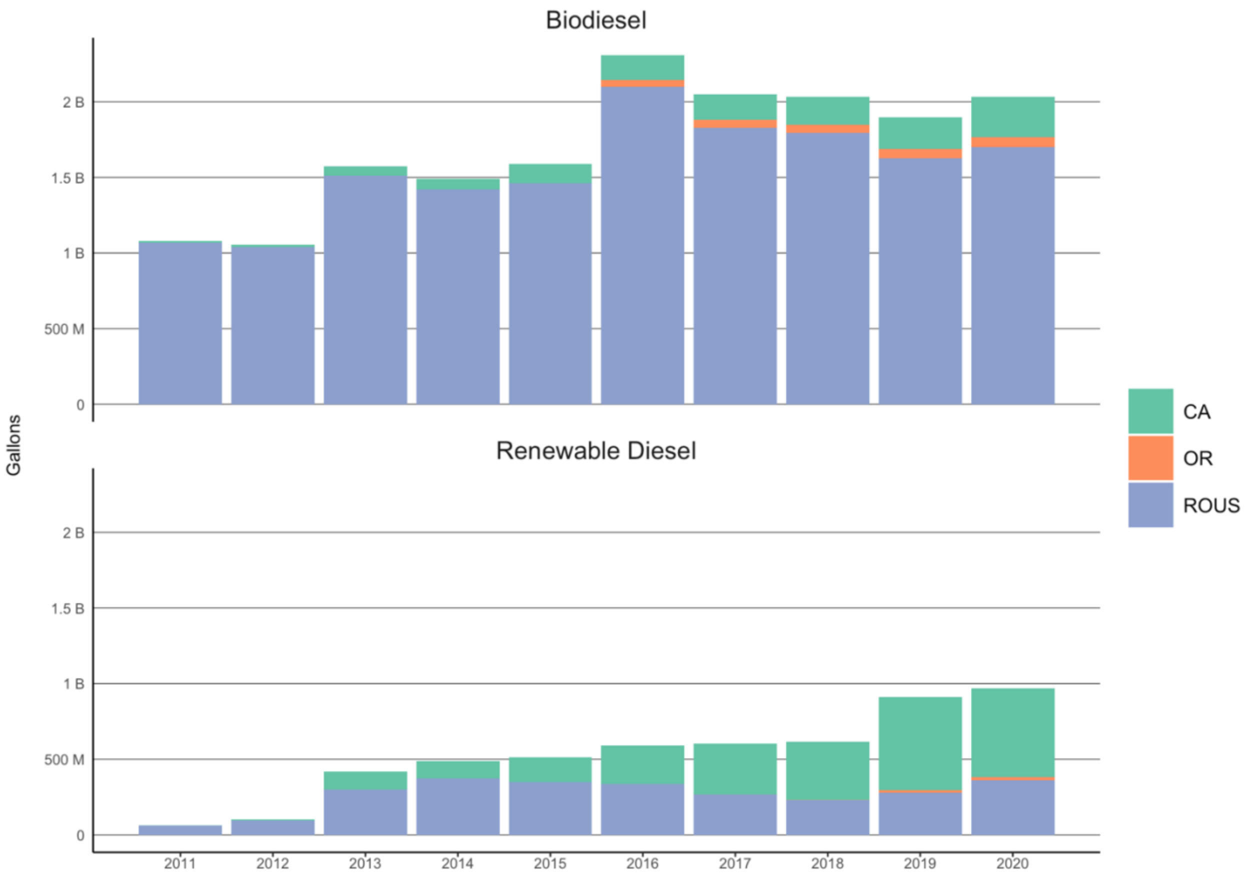

Figure 4. U.S. Biomass-Based Diesel Consumption by Region. ROUS = rest of the United States.

Soy methyl ester (SME) biodiesel, which is produced from soybean oil, has been the predominant form of BBD in the U.S. due to feedstock availability. However, biodiesel production from non-crop, waste feedstocks such as used cooking oil (UCO), distiller's corn oil, and animal fats has grown because result in lower lifecycle emissions than biodiesel produced from crop oils and therefore receive low CI ratings and higher implicit subsidies in policies such as the LCFS. However, use of such waste feedstocks haven't scaled to meet demand for BBD (Malins & Sandford, 2022).[30] Limited supply of waste feedstocks will likely result in soybean oil continuing to account for the majority of the BBD supply in the U.S. and a growing share in California and Oregon (Mazzone et al., 2021).

2.1. Labeling, Storage, and Distribution of Diesel Fuels

Like ethanol, biodiesel faces blending restrictions for several reasons. Most importantly, higher concentrations of biodiesel can adversely affect diesel engines and void manufacturer warranties. For example, higher biodiesel blends may gel in cold temperatures, leading to performance problems or engines being inoperable until the fuel is heated. Labeling,

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[30] See also https://www.reuters.com/business/energy/used-cooking-oil-renewable-fuels-feedstock-nearly-tapped-out-us-valero-2021-04-22/.

distribution, and storage regulations differ by the percentage of the finished fuel that contains BBD, and by jurisdiction. These differences affect both the demand and supply of biodiesel, and BBD more broadly.

2.1.1. Labeling

All BBD sold in the U.S. must comply with Federal Trade Commission (FTC) fuel rating regulations. Although renewable diesel is a drop-in substitute to diesel and biodiesel is not, they are treated equivalently under FTC labeling requirements. BBD blends containing no more than 5 percent BBD are exempt, and the percentage of BBD is not required to be specified. A diesel blend containing up to 5 percent biodiesel is referred to as B5. Similarly, a diesel blend containing between 6 and 20 percent biodiesel by volume is labeled B20. Diesel blends containing more than 20 percent biodiesel by volume must be labeled according to the exact amount of biodiesel, i.e., above 40 percent must be labelled B40, 50 percent must be labelled B50, and so on (ECFR :: 16 CFR Part 306). The labels for renewable diesel are analogous, using R in place of B (e.g., R5 instead of B5). State labeling requirements can be slightly more stringent. For example, labels for diesel blends above 5 percent biodiesel by volume must state "THIS FUEL CONTAINS BIODIESEL. CHECK THE OWNER'S MANUAL OR WITH YOUR ENGINE MANUFACTURER BEFORE USING" in California.[31]

2.1.2. Storage

EPA allows B20 to be stored in underground storage tanks (USTs) in the U.S. [32] In some states, however, UST regulations were stricter. California, for example, only allowed up to 5 percent biodiesel blends in USTs until 2019 when the California Water Board amended their regulation, increasing the limit for storage to 20 percent biodiesel by volume, matching federal requirements.[33] Prior to the 2019 amendment, annual industry-, state-wide consumption of finished diesel never surpassed 5 percent biodiesel by volume. In 2020, biodiesel accounted for 7.5 percent of finished diesel in California.

2.1.3. Distribution

Petroleum gasoline and diesel are distributed from refineries to terminals, typically via pipeline. There are two types of terminals: bulk terminals and local terminals. Bulk terminals are in the six major bulk markets for diesel: New York Harbor, Chicago, Group 3 (Great Plains states), the Gulf Coast, West Coast, and Pacific Northwest (PNW). Local fuel prices are set according to a basis relative to a bulk market price. Fuel coming into bulk markets can either be sold to retailers at bulk terminals or redistributed to local terminals. Pipeline systems run from bulk markets to local terminals. Three of the bulk petroleum markets are also bulk biodiesel markets; New York Harbor, Chicago, and the Gulf Coast bulk markets trade soy methyl ester

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[31] See https://www.cdfa.ca.gov/dms/notices/petroleum/2018/P-18-02.pdf.

[32] See https://www.epa.gov/ust/emerging-fuels-and-underground-storage-tanks-usts.

[33] https://www.biodiesel.org/news-resources/biodiesel-news/2019/08/07/California-Approves-B20-Biodiesel-in-Underground-Storage-Tanks

(SME) B100. These are the only bulk market prices available for biodiesel. There are no bulk markets for renewable diesel at the time of writing.

Biodiesel, except for B5, can't be distributed through existing pipeline systems because pipelines that distribute diesel are also used for jet fuel, which can't be mixed with fatty acid methyl ester (FAME). Instead, biodiesel is transported from producers to terminals by truck, rail, or barge. USTs and other storage infrastructure have been installed at terminals to allow blending of BBD with petroleum diesel to take place. Rack sellers can purchase bulk petroleum diesel and BBD and blend them, then sell the blended fuel to retailers at the rack. Retailers, or rack buyers, can also purchase bulk petroleum diesel and BBD above the rack and store and blend the fuels at the retail station.

3. Data Description

3.1. Calculating implicit taxes and subsidies

The RFS requires all refiners to retire a bundle of RINs, consisting of a certain number of each "D" category, for each gallon of gasoline and diesel sold. The RIN obligations for each category are determined according to the percentage standard set out in EPA's annual RFS rulemaking.[34] The cost of purchasing the RIN bundle acts as an implicit tax per gallon of gasoline and diesel. Since the RFS mandate is nested, the RIN tax per gallon of ULSD is:

$$R_t^u = P_t^{D3}V_t^{D3} + P_t^{D4}V_t^{D4} + P_t^{D5}(V_t^{D5} - V_t^{D3} - V_t^{D4}) + P_t^{D6}(V_t^{D6} - V_t^{D5}) \tag{1}$$

where V_t^x is the percentage standard for RIN category x and P_t^x is the RIN price. Daily spot prices for D3, D4, D5, and D6 RINs are collected from a Bloomberg Terminal.[35] The Bloomberg data has missing observations for D3 and D5 RIN prices in 2021, so the implicit RIN tax is calculated using only the D4 and D6 obligations, which account for most of the total RIN tax. Results in later sections are robust to ignoring the D3 and D5 obligations in earlier years.

The blender's ability to sell D4 RINs acts as an implicit subsidy for the act of blending biodiesel. The EPA assigns an equivalence value (EV) to each alternative fuel that specifies the energy content of that fuel relative to ethanol. Biodiesel's EV is 1.5, so each gallon earns 1.5 D4 RINs. Therefore, the RIN subsidy for blend k, with δ^k percent biodiesel, on day t is:

$$R_t^k = P_t^{D4} \times \delta^k \times 1.5 \tag{2}$$

Unlike the RIN tax, the LCFS and CFP taxes for ULSD are specific to diesel and reflect the cost of purchasing enough credits to cover the deficits generated from one gallon of ULSD. The prices of LCFS and CFP credits are measured in USD per metric ton (MT) of CO2 equivalent (CO2e) and the number of deficits generated per gallon of ULSD is determined according to the CI score of

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[34] RFS annual rulemakings can be found at https://www.epa.gov/renewable-fuel-standard-program/regulations-and-volume-standards-renewable-fuel-standards.

[35] D7 RIN prices and volumes aren't publicly available.

ULSD relative to the diesel CI standard and the energy density (ED) of ULSD, which are program specific. We calculate the LCFS (and CFP) tax as:

$$L_t^u = -Credit\ Price_t * (CI_t^s - CI_t^u) * ED^u * 10^{-6} \tag{3}$$

where CI_t^s is the diesel standard, CI_t^u are the reference CI scores of ULSD, ED^u is the energy density of ULSD, and 10^{-6} translates gCO2e into metric tons of CO2e. Daily average spot prices of LCFS and CFP credits are purchased from the Oil Price Information Service (OPIS) covering January 1st, 2013, to July 31st, 2021. Annual CI standards, reference CI scores, and EDs are taken from the LCFS and CFP regulations.[36]

In California's LCFS, in 2021, for example, petroleum diesel had a reference CI score of 100.5 gCO2e/MJ and the diesel standard is 91.7 gCO2e/MJ, and the energy density of diesel is 134.47 MJ/gallon. Therefore, refiners accrued $(100.5 - 91.7) * 134.47 * 10^{-6} = .0011836$ MT of deficits per gallon of diesel they supplied to the CA transportation sector based on the diesel reference CI score.[37]

As we will show in Section 4, blenders both pay the tax on the ULSD and receive the subsidy on the biodiesel, so they realize a net subsidy. The LCFS net subsidy is:

$$L_t^k = \delta^k * Credit\ Price_t * \left(CI_t^s - CI_t^b\right) * ED^b * 10^{-6} - (1 - \delta^k) L_t^u \tag{4}$$

Where CI_t^s is the diesel standard in the LCFS or CFP; CI_t^b is the average reported CI score for SME biodiesel; ED^b is the energy density of biodiesel. L_t^u is the implicit tax on ULSD and is defined in (3).

The CI scores used for ULSD in calculations above are the diesel reference scores in the LCFS and CFP, listed in the respective regulations. The CI scores used for biodiesel in calculations above is the volume-weighted average CI score of SME biodiesel, which is solved using quarterly LCFS credit generation data and the credit-generating equation.[38] We focus on SME because the only available biodiesel spot prices are for SME, which are crucial to the empirical strategy (see Section 5). Data from CARB's quarterly summaries spans 2011-2021 Q1 and DEQ's quarterly summaries from 2016-2021 Q1. Figure 5 plots the diesel standards, diesel reference scores, and average reported biodiesel CI scores for California and Oregon. Figure 5 shows that

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[36] More details on the credit generating equation used to calculate implicit taxes and subsidies for the LCFS can be found in § 95486 of the LCFS regulation. See https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf.

[37] As of 2020, petroleum diesel in California's LCFS also accrues incremental deficits, due to an assessed increase in the three-year average California crude CI score, of 0.23gCO2e/MJ that year, and 0.42gcO2e/MJ in 2021 (https://ww2.arb.ca.gov/resources/documents/lcfs-crude-oil-life-cycle-assessment). Incremental deficits are not included in the CI score or analysis presented in the main text; they accounted for approximately 3% of diesel deficits in 2020, and 4.5% in 2021.

[38] It isn't possible to calculate average CI scores by feedstock in the Oregon CFP because the number of credits generated by feedstock is not reported by DEQ. Therefore, we assume the CI of a feedstock/fuel combination is the same in the Oregon CFP as it is in the California LCFS. This is a reasonable assumption since both jurisdictions use the same basic lifecycle emissions calculation method (GREET), although tailored for each jurisdiction, and, for soy, the same value for ILUC, and share many of the same pathways.

the diesel standard is tighter in California and reference CI scores for diesel have been about the same. The average reported CI of all biodiesel in California is lower than Oregon's because canola oil is the primary feedstock in Oregon, which has a relatively high CI score. SME biodiesel was about 20 gCO2e/MJ higher than the biodiesel average in 2020.

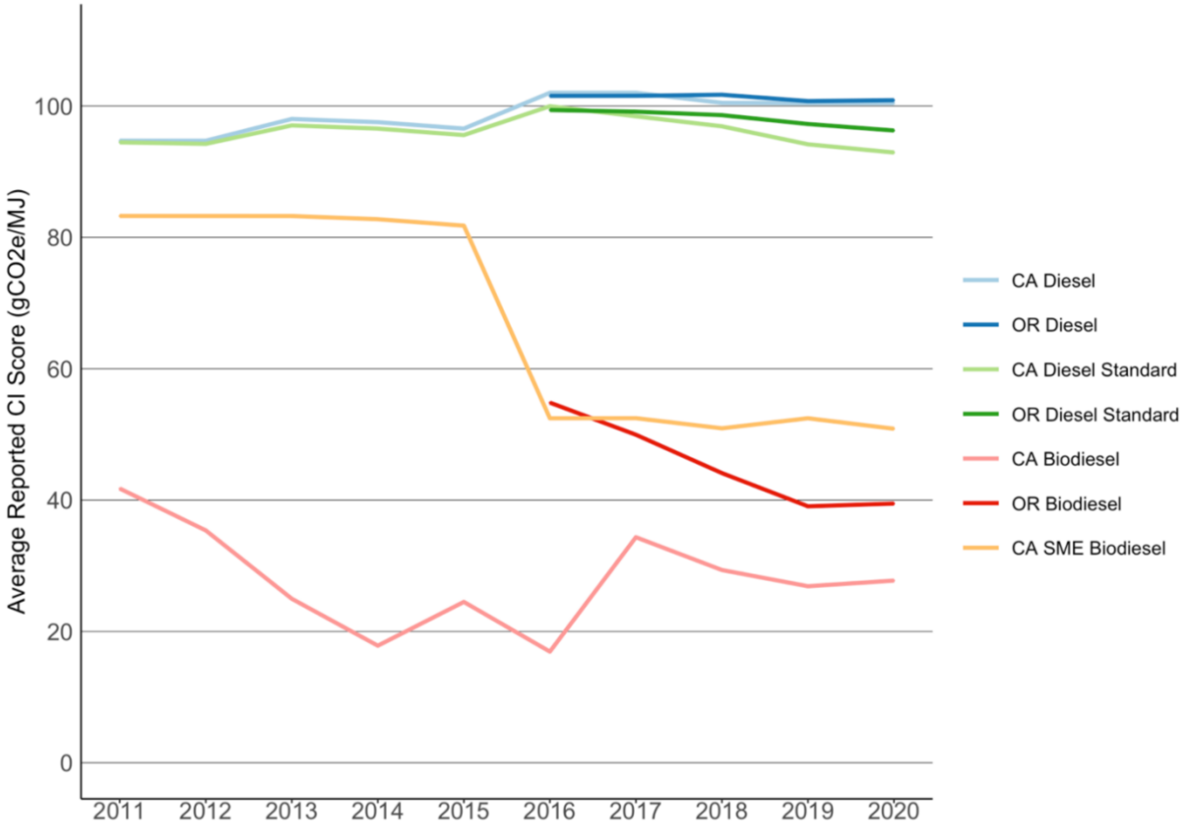

Figure 5. Average Reported Carbon Intensity Score of Diesel Fuels in California and Oregon

Figure 6 plots the sample of ULSD taxes and biodiesel subsidies from the RFS, LCFS, and CFP. The RIN tax for ULSD reached an all-time high in 2021, coming in over 20 cents/gal due to the sharp increase in D4 and D6 RIN prices brought on by rising soybean and soybean oil prices (discussed below). The LCFS tax, coincidentally, sat around 20 cents/gal in 2021 also. Oregon's CFP tax at the same time was much smaller, still below 10 cents/gal. The RIN subsidy also reached an all-time high in 2021 of $3/gal. The LCFS and CFP subsidies have remained less than $1/gal in 2021.

Figure 6 introduces five time periods of interest, which we refer to as: Low LCFS Price (1/2013-12/2015), Mid LCFS Price (1/2016-3/2018), High LCFS Price (4/2018-2/2020), COVID Shock (3/2020-5/2020), and RIN Price Shock (6/2020-7/2021). LCFS credit prices rose significantly for the first time in the Mid LCFS Price period and sat around $1/gal less than the RIN subsidy. The stark jump in the subsidy in the beginning of 2016 coincides with CARB's modeling change that resulted in a lower CI for SME biodiesel, as well as resolution of an important court case that had frozen the standard from 2013 (Figure 5). LCFS credit prices varied widely in this period

(Figure A-1), ranging between around $50/MT to $150/MT, which also affected the net subsidy on blended biodiesel.[39]

In the High LCFS Price period, LCFS and CFP credit prices reached their highest levels since implementation. LCFS credit prices approached the program's credit price ceiling of $200/MT indexed to 2016 dollars. CFP credit prices surpassed $150/MT in 2019. During that time, the credit subsidy for SME biodiesel was just above and below $1/gallon in California and Oregon, respectively. During that period D4 RIN prices fell to their lowest level since 2014, leading to SME biodiesel subsidies from LCFS and CFP credits surpassing the subsidy from the D4 RIN.

The COVID Shock period is short and is used to control for irregularities in fuel markets occurring from the impact of the COVID-19 pandemic. The RIN Price Shock period describes the shock to D4 RIN prices brought on by increased exports of corn and soybeans to China combined with production shortfalls elsewhere causing soybean prices to rise drastically (Irwin & Janzen, 2022).[40] The price of soybean oil has historically been lower than soybean meal. However, in the RIN Price Shock period, soybean oil prices grew by approximately 120%, and meal by 50%.[41] In 2021, oil and meal reached near-parity in 2021; the increase in the relative price of oil to meal is likely due to a boom in renewable diesel production capacity.[42] The soybean boom of 2020/2021 had an appreciable impact on both the RIN subsidy and tax. The RIN subsidy leapt to $3/gallon in 2021 and the tax increased to 20 cents/gallon, doubling its previous high.[43]

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[39] For more information on trends in LCFS and CFP credit markets, see (Mazzone et al., 2021).

[40] For additional context, see https://asmith.ucdavis.edu/news/chinas-buying-us-corn-again-are-we-winning-trade-war-now and https://asmith.ucdavis.edu/news/good-times-down-farm.

[41] See https://asmith.ucdavis.edu/news/i-hear-rd-train-comin.

[42] See https://www.agriculture.com/news/business/renewable-diesel-boom-is-wild-card-for-us-soybeans.

[43] The analysis excludes outliers, as explained in Section 5.1 (Table 4 notes) below.

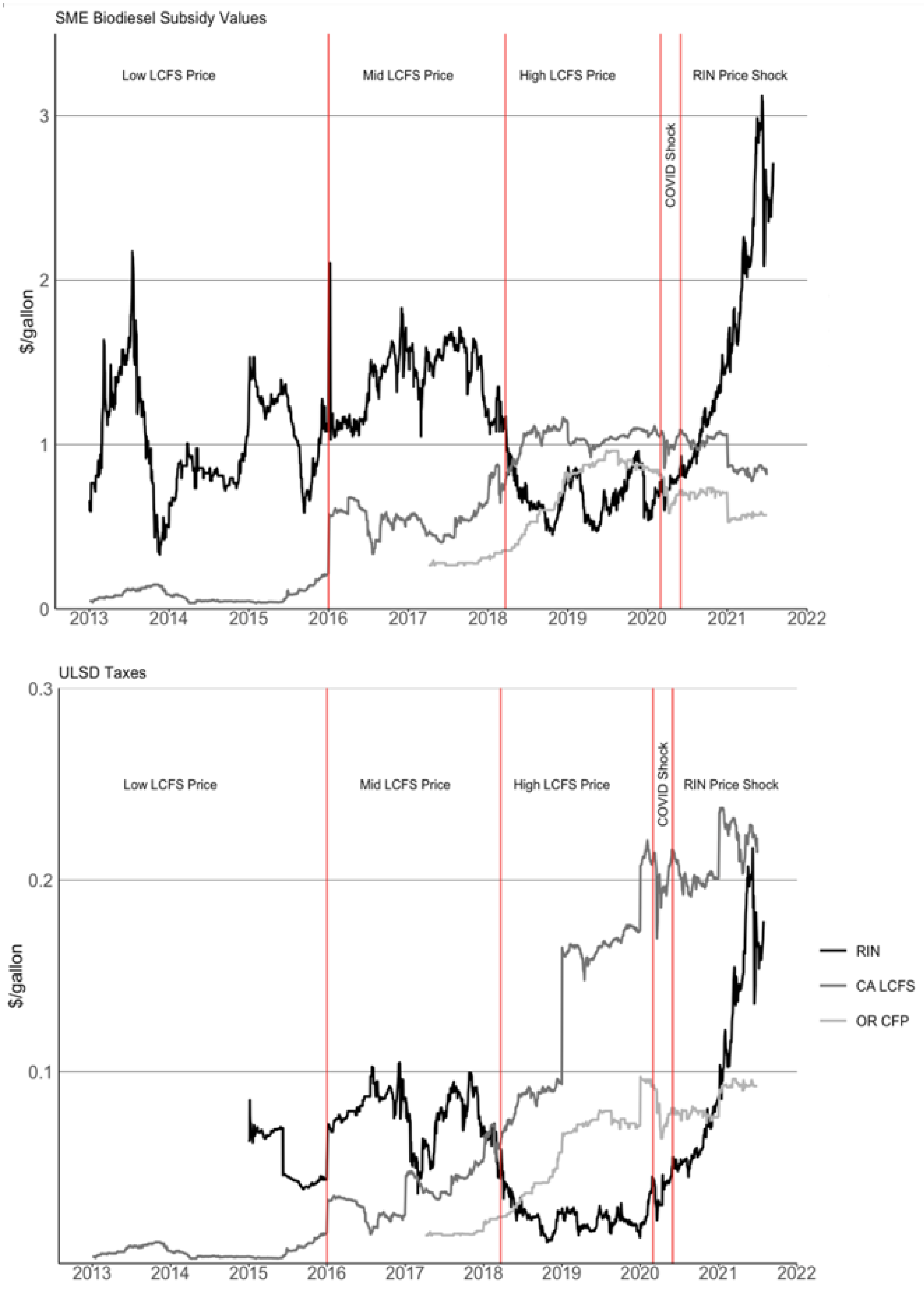

Figure 6. Implicit Taxes and Subsidies

3.2. Spot Prices

For both the tax and subsidy pass-through analyses, we utilize daily spot prices for ULSD, jet fuel, and biodiesel (B100) in the major U.S. spot markets purchased from OPIS. We obtained spot prices for ultra-low sulfur diesel (ULSD) and jet fuel from the following markets: Los Angeles, San Francisco, Pacific Northwest, Gulf Coast, Group 3, and New York Harbor Barge. Three of those spot markets—Chicago, NY Harbor, and Gulf Coast—also post spot prices for soy methyl ester (SME) B100. Spot markets only exist for SME B100 because, as mentioned in Section 1.1, soybean oil makes up the majority of biodiesel used in the U.S. for RFS compliance. The sample includes observations from each spot market covering business days from 1/1/ 2015 to 7/31/ 2021.

Table 1 summarizes the sample of spot prices. ULSD spot prices range from $1.63/gal (Los Angeles) to $1.75/gal (PNW) on average over the entire sample. Jet fuel spot prices are slightly lower than ULSD, ranging between $1.57/gal (Los Angeles) and $1.68/gal (PNW) on average. SME B100 spot prices are almost twice as large as ULSD on average. Section 4 shows that ULSD prices exceed the jet fuel price by the amount of the RIN tax on ULSD, on average. Section 5 shows that B100 prices exceed ULSD prices by the amount of the RIN subsidy for B100.

Table 1. Average ULSD and B100 Spot

	Avg. Spot Price ($/gal)		
Spot Market	**ULSD**	**Jet Fuel**	**B100**
Chicago	1.66	1.65	3.21
Group 3	1.66	1.62	-
Gulf Coast	1.63	1.57	3.14
Los Angeles	1.71	1.66	-
NY Harbor Barge	1.68	1.62	3.20
Pacific Northwest	1.75	1.68	-
San Francisco	1.71	1.65	-

3.3. Rack Prices

For our analysis we purchased several types of pricing data from OPIS. This data includes supplier-level, daily prices paid for blended diesel fuels at rack terminals in six cities: Los Angeles, CA; San Francisco, CA; Bakersfield, CA; Stockton, CA; Portland, OR; Eugene, OR; Wood River, IL; Trenton, NJ; Dallas, TX; St. Louis, MO. Rack prices are differentiated by the blend level and feedstock type. Biodiesel is assigned one of three feedstock types in the OPIS data: soy methyl ester (SME), yellow grease methyl ester (YGME), and a mix of multiple feedstocks (MULT). To make the analysis internally consistent, we only utilize rack prices for SME biodiesel blends, since B100 spot prices are only available for SME-based biodiesel (Section 3.2).

Suppliers enter and exit the sample in all cities. For this reason, we aggregate to city-blend averages, instead of using the supplier-level data. We only include suppliers with a complete series of prices over at least a one-year period. Therefore, the unit of observation when studying rack margins is a city-blend-day. This process is done separately for branded and unbranded products, as done in Pouliot et al., 2020 due to potential for different levels of pricing behavior (and market power) in these two situations, however there is very little coverage of blended products in the OPIS data. For each rack market, the number of suppliers is listed in Table A-2.

As shown in Figure 6, the implicit taxes and subsidies have varied significantly over the sample. Rack spreads between the price of blended fuel at the rack and blendstocks on the spot market also vary over time, and across markets and blends. Additionally, different cities have different blend offerings (Table A-2). Table 2 summarizes the sample of rack margins in the subsamples outlined in Figure 6 and the full sample. A general trend is that rack margins are negative for many blends and inversely correlated with the percentage of biodiesel in the blend. They are also lower in subsamples where the RIN subsidy is higher. This reflects the fact that RIN subsidies are being fully passed through at the rack, because suppliers can sell more RINs for a higher blend, and therefore, can accept a lower price. In California and Oregon, this trend does not always hold, and margins are generally much higher than the rest of the country. Higher margins in California and Oregon are consistent with incomplete pass-through of LCFS and CFP credits. The pass-through of RIN, LCFS credit, and CFP credit subsidies is discussed in detail in Section 5.

Table 2. Blended Biodiesel Policy Incentive and Rack Margin Summary Statistics

Subsidies/Taxes from Policies	**Low LCFS 1/15-12/15**	**Mid LCFS 1/16-3/18**	**High LCFS 4/18-2/20**	**COVID Shock 3/20-5/20**	**RIN Shock 6/20-7/21**	**Full Sample**
CA LCFS Subsidy	0.09	0.56	1.04	1.01	0.95	0.71
CA LCFS Tax	0.01	0.04	0.14	0.2	0.21	0.10
OR CFP Subsidy	-	0.29	0.74	0.69	0.64	0.61
OR CFP Tax	-	0.02	0.06	0.08	0.08	0.06
D4 RIN Subsidy	1.12	1.40	0.68	0.76	1.59	1.15

Unbranded Rack Spreads

Rack City	**Blend**		`				
Trenton	B2	0.03	0.01	0.06	0.04	0.02	0.03
	B5	0	-0.04	0.03	0	-0.06	-0.02
	B10	-0.08	-0.14	-	-	-0.22	-0.14
	B20	-0.21	-0.34	-	-	-0.52	-0.34
	B99	-1.22	-1.78	-	-1.80	-2.44	-1.83
Dallas Metro	B0-5	-	0.08	0.06	0.06	0.09	0.07
	B5	0.01	0	0.03	-0.01	-0.04	0
	B20	-	-	-0.04	-0.24	-0.4	-0.2
	B99	-	-1.61	-0.65	-1.53	-2.44	-1.45
Wood River	B2	0.07	0.02	0.04	0.04	0.03	0.04
	B5	0.05	-0.02	0.02	0.01	-0.06	0
	B20	-0.04	-0.24	-0.04	-0.2	-0.42	-0.18
	B50	-0.18	-0.63	-0.11	-0.53	-1.07	-0.52

Subsidies/Taxes from Policies		Low LCFS 1/15-12/15	Mid LCFS 1/16-3/18	High LCFS 4/18-2/20	COVID Shock 3/20-5/20	RIN Shock 6/20-7/21	Full Sample
St. Louis	B0-5	-	0.05	0.06	-	-	0.05
	B2	0.07	0.02	0.04	0.05	0.02	0.04
	B5	0.05	-0.02	0.03	0.02	-0.05	0
	B11	0.01	-0.11	0	-0.09	-0.2	-0.07
	B20	-0.04	-0.24	-0.03	-0.19	-0.41	-0.18
	B50	-	-0.57	-0.11	-0.53	-1.07	-0.51
Eugene	B5	-0.01	-0.03	0.06	0.04	0	0.01
	B20	0.2	0.04	0.11	-0.04	-0.21	0.04
Portland	B5	-0.03	-0.04	0.04	0.01	-0.03	-0.01
	B10	0.05	-0.04	0.02	-0.06	-0.14	-0.03
	B20	-0.04	-0.17	0.04	-0.26	-0.47	-0.15
	B50	-0.35	-0.63	-0.25	-0.7	-1.06	-0.56
Bakersfield	B20	-	-0.31	-0.16	-	-	-
Los Angeles	B0-5	0.06	0.06	0.16	0.19	0.08	-0.21
	B100	0.82	0.36	1.4	0.58	0.52	0.1
San Francisco	B1	0.35	0.37	0.48	0.45	0.34	0.81
	B5	0.39	0.38	0.53	0.47	0.36	-
	B20	0.49	0.42	0.71	0.53	0.43	0.41
	B50	0.43	0.2	0.77	0.34	0.27	0.44
	B100	0.83	0.34	1.37	0.53	0.51	0.54
Stockton	B0-5	-	-	0.19	0.08	-0.01	0.44
	B5	-	0.62	0.63	-	-	0.79
	B10	-	-	0.06	-0.1	-0.29	0.08
	B100	-	0.33	1.12	-	-	0.62

Notes: $/gal. Subsidies measured per gallon of SME B100; taxes measured per gallon of ULSD. Branded spread summary statistics are listed in the Appendix. B0-5 is for blends up to B5 but the exact blend may or may not be identified and is assumed to be B0 in this paper since subsidies are unlikely to be collected for these blends.

4. Diesel Tax Pass-Through

Refiners and petroleum importers are the obligated parties in each policy, meaning they must purchase RINs and LCFS credits proportional to their output, which in turn act as implicit taxes for them. Refiners sell ULSD in the major spot markets, meaning the implicit tax created from their RIN obligation will be embedded in spot market prices to the extent refiners pass through the cost. In this section, we test whether obligated parties fully pass through the implicit taxes created by the RFS and LCFS in spot market transactions. We extend the methodology developed in Knittel et al. (2017) analyzing spreads between ULSD and jet fuel spot prices.

ULSD and jet fuel are nearly identical products, so their prices tend to move together.[44] Figure A-2 shows daily ULSD and jet fuel spot prices since 2015 in the major spot markets. The only substantive difference between the two is their policy treatment: ULSD has a RIN obligation and generates LCFS/CFP deficits in California and Oregon, whereas jet fuel does not. Other federal and state taxes may differ between the two fuels but are assessed below the rack, so those differences won't be captured in the spot prices. Additionally, spreads are calculated within spot markets, so transportation costs will not differ between ULSD and jet fuel. The spread between ULSD and jet fuel may capture fluctuations other than changes in the RIN tax, but we assume that any such differences are constant over time. This provides an ideal empirical setting where one of two identical products receives different policy treatment.

Figure 7 plots the daily spreads between ULSD and jet fuel prices along with the RIN tax, and where applicable, the LCFS/CFP tax. The RIN tax is calculated according to (1) and the LCFS/CFP taxes are calculated according to (3). The Gulf Coast and NY Harbor have the most efficient spot markets for ULSD and jet fuel; in those markets it is easy to see that the spread tends to equal the RIN tax, suggesting the tax is fully passed through. Group 3 exhibits a similar pattern, but the spread exhibits more noise. Spreads in California and the Pacific Northwest are also very noisy, however Figure 7 clearly shows that the spreads generally follow the RIN tax while seemingly unaffected by LCFS and CFP taxes. If the LCFS and CFP taxes were fully passed through, we would see that the sum of the LCFS tax and the RIN tax would equal the ULSD-jet spread in California. The PNW price includes but is not limited to Oregon, so the CFP would be expected to affect the spread to some degree.

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[44] ULSD and jet fuel consist primarily of kerosene; however, ULSD has lower sulfur content, primarily due to EPA regulations, and contains added lubricants. Jet fuel is more similar to no. 1 diesel than no. 2 diesel, which is used for transportation fuel.

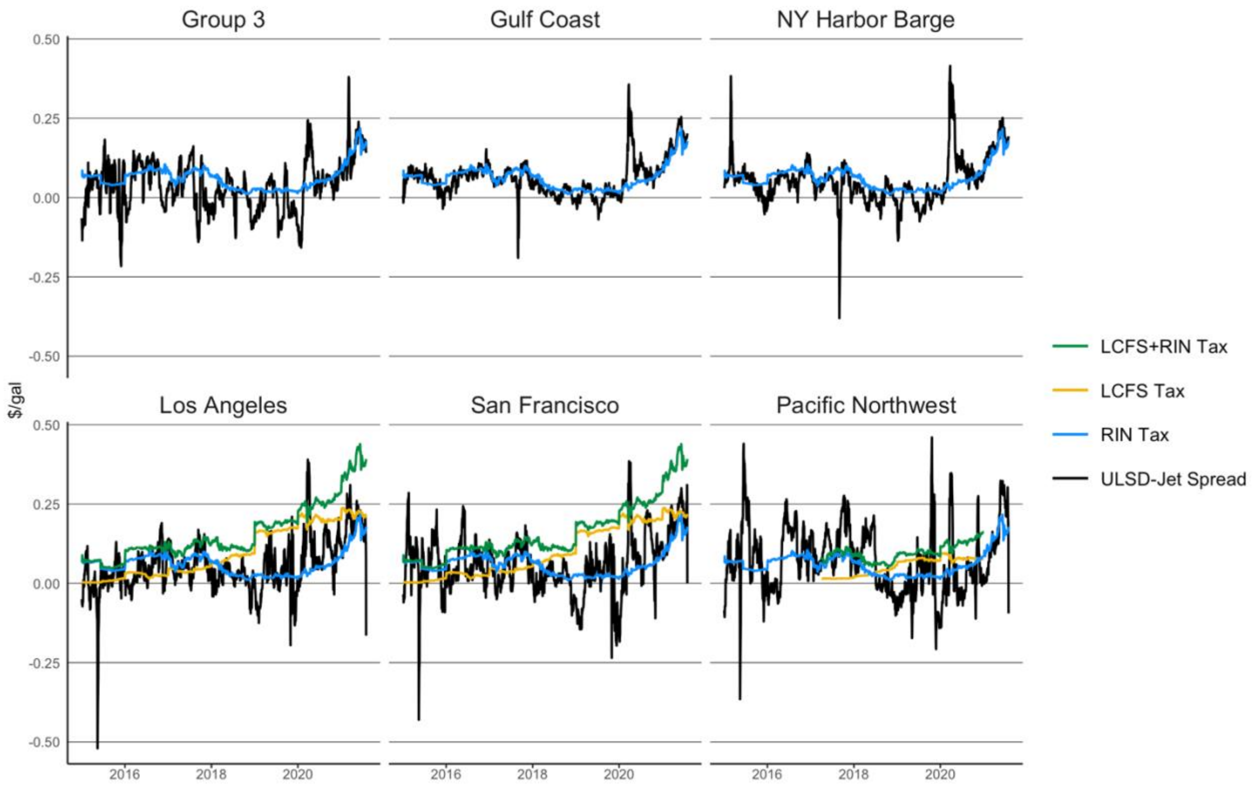

Figure 7. ULSD-Jet Spreads and Implicit ULSD Taxes. The LCFS tax in Los Angeles and San Francisco are from the CA LCFS and the LCFS tax in the Pacific Northwest is from the OR CFP tax.

To test whether the RIN tax and LCFS/CFP taxes are passed through to ULSD spot prices, we estimate the following model:

$$S_{it} = \alpha_i + \sum_{d=0}^{D-1} \theta_d^R \Delta R_{t-d}^u + \theta_D^R R_{t-D}^u + \sum_{d=0}^{D-1} \theta_d^L \Delta L_{t-d}^u + \theta_D^L L_{t-D}^u + \mathbf{\Theta} \boldsymbol{X}_t + e_{it} \qquad (5)$$

Where S_{it} is the ULSD-jet spread in spot market i on day t, Δ is the first-difference operator, R^u and L^u are the RIN and LCFS taxes, respectively, for ULSD; α_i are spot market fixed effects; $\boldsymbol{X}_t$ is a vector of seasonal and other controls; and e_{it} is the idiosyncratic error term. We impose θ=0 in cities not subject to the LCFS or CFP. In line with Knittel et al. (2017), $\boldsymbol{X}_t$ includes the first four harmonic frequencies to control for seasonality. Specifically, we include the following eight control variables in all subsequent regression models.

$$SEASON_t = \sum_{k=1}^{4} \nu_c \cos\left(\frac{2\pi tk}{366}\right) + \sum_{k=1}^{4} \nu_s \sin\left(\frac{2\pi tk}{366}\right) \qquad (6)$$

Where t corresponds to the day of the year. $\boldsymbol{X}_t$ also includes a dummy variable for the COVID-19 pandemic (dates according to the COVID Shock period in Table 2), when applicable. The coefficients of interest in (5) are the long-run pass-through coefficients θ_D, where a coefficient equal to zero corresponds to none of the tax being passed through and a coefficient equal to one corresponds to the tax being fully passed through in the long run. Results are presented in Figure 8. Using the full sample, long-run pass-through of the RIN tax is complete in some markets and more than complete in others. However, when dropping the RIN Price Shock Period (6/20-7/21), pass-through in the Gulf Coast and NY Harbor are tightly estimated around full pass-through. Dropping this period diminishes the signal in Group 3 and Los Angeles, although full pass-through remains in the 95% confidence interval. The estimates in San Francisco and PNW become much noisier, making it difficult to make conclusions about RIN tax pass-through in those regions when dropping the RIN Price Shock period.

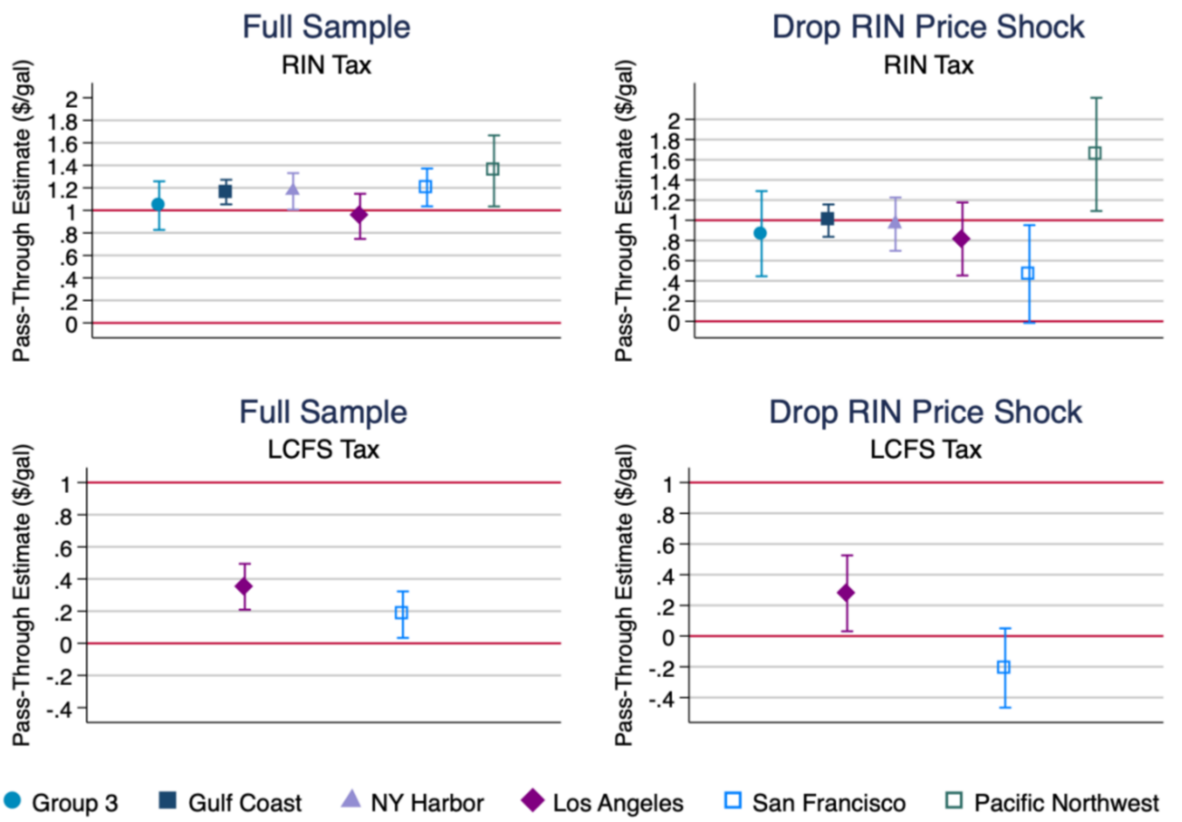

Figure 8. Pass-Through of Implicit ULSD Taxes to Spot Prices. Point estimates and 95% confidence intervals are plotted. The dependent variable is the ULSD-jet spread. There are 10 lags of the both the RIN tax variable and the LCFS tax variable. A dummy variable controls for the COVID Shock Period, which is March 2020 through May 2020. Standard errors are clustered at the month-year level. The results in the first column use data in the interval January 2015 through July 2021, results in the second column are restricted to January 2015 through May 2020.

The bottom panels of Figure 8 present estimates of the LCFS tax pass-through in Los Angeles and San Francisco, which show that little to none of the LCFS tax is passed through to ULSD spot prices in California. Using the full sample, a $1/gal increase in the LCFS tax results in a 37 cents/gal increase in the spot price in Los Angeles on average, 16 cents/gal in San Francisco. When dropping the RIN Price Shock Period, which is the preferred specification because spreads are volatile in that period, the coefficients for Los Angeles and San Francisco fall to 0.28 and -0.2, respectively, and pass-through is statistically indistinguishable from zero in San Francisco. Even for Los Angeles, where results show some pass-through, the 95 percent confidence interval is [0.03, 0.53] when dropping the RIN Price Shock Period. These results suggest that much of the LCFS tax is not passed through to spot prices. It does not suggest, however, that refiners are eating the cost. In the remainder of this section, we present evidence that LCFS deficit obligations are transferred downstream to blenders, and they completely pass through the LCFS tax to rack prices. As described in Section 1.2, obligated parties under the LCFS are allowed to transfer their status as the deficit generator to another entity if agreed upon by both parties. If deficit obligations are transferred to a different point in the supply chain, the tax would be expected to be priced in at the new point. Additionally, in some cases, refineries also own blending operations, which would lead to the same results—the LCFS tax being passed through at the rack rather than the spot market.

Blenders may agree to fulfill the deficit obligation as they already trade credits. If refiners exercise this option, blenders will incur the LCFS deficit obligation and pass through the tax to the rack price. There is no rack price for pure ULSD in the OPIS rack pricing data. However, there are rack prices for B0-5—ULSD that may contain up to 5 percent biodiesel by volume but doesn't earn credits because the amount of biodiesel is unidentifiable. This is essentially ULSD sold at the rack. We calculate the margin at the rack for B0-5 in city i on day t using the previous day's nearest spot price of ULSD.

$$m_{it}^{u} = p_{t}^{B0-5} - p_{t-1}^{u} \tag{7}$$

Figure 9 plots the daily rack margins, calculated according to (7), for both branded and unbranded ULSD in Los Angeles—the only city in California or Oregon with consistent reporting of B0-5 rack prices. On average, from January 2015 to April 2020, unbranded ULSD rack prices were higher than the spot price by around the amount of the LCFS tax. The branded ULSD rack margin is less noisy than its unbranded counterpart but is marked-up slightly above the amount of the LCFS tax for the same period. This is consistent with the fact that branded rack buyers are limited to purchasing diesel that is of their brand and may therefore exhibit a higher willingness to pay than unbranded buyers who have more options (Pouliot et al., 2020).

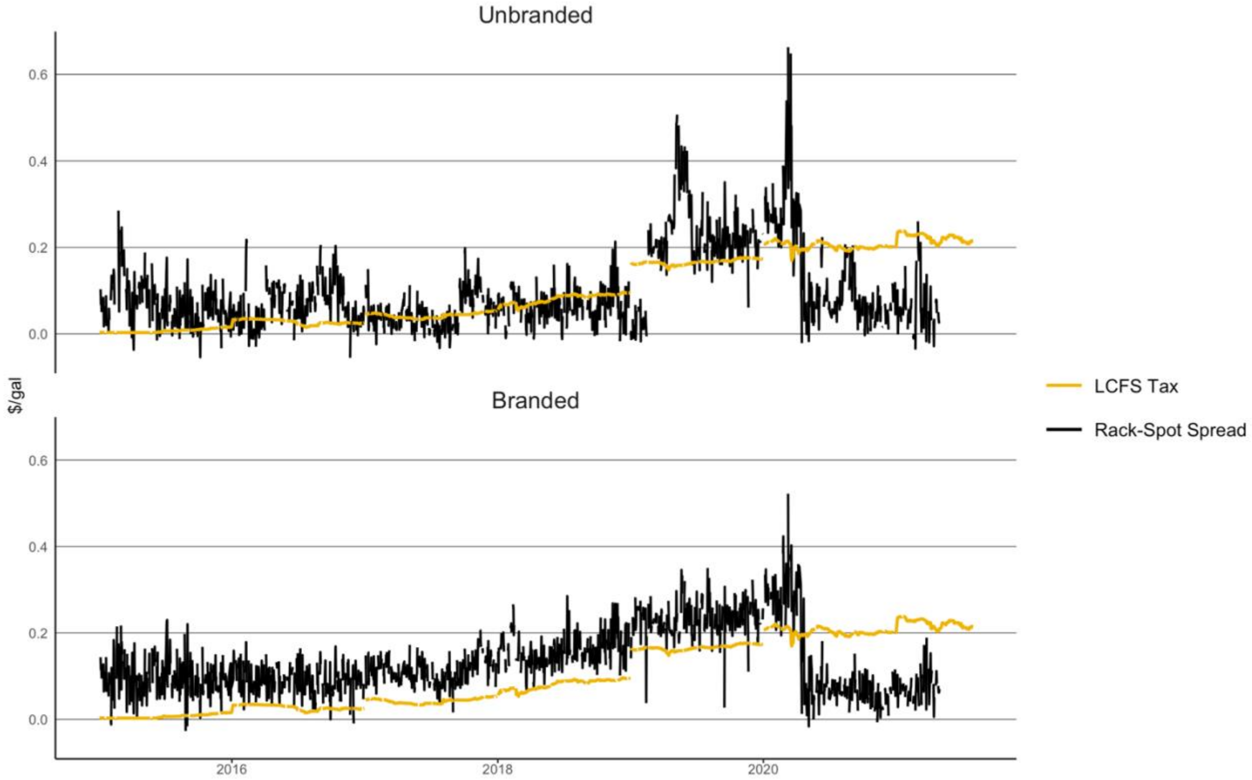

Figure 9. ULSD Rack Margins in Los Angeles, CA.

The level of the LCFS tax in terms of metric tons per gallon of diesel (and, absent a decline in the LCFS credit price, in monetary terms) shifts upward at the start of each year with the annual decline in the diesel CI standard, and the reference diesel CI score often changes annually. The standard has been laid out in advance and changes to reference CI scores are specified by CARB and are not determined in any way by rack margins; therefore, they act as exogenous shifters in this setting. The most striking rise in the tax was on January 1st, 2019. The CI reference score for ULSD fell only slightly from 100.48 to 100.45 in 2019; the diesel CI standard fell from 96.91 to 94.17.[45] The standard decreasing by nearly three full points, coupled with a record-high market price for LCFS credits, led to an average LCFS tax that was, on average, 6.72 cents/gallon higher in January 2019 than December 2018. In the same two-month period (late 2018 to early 2019), the rack margin for branded ULSD rose 6.13 cents/gallon. Rack margins for unbranded ULSD also responded to the change in the tax but later, around mid-March of 2019. It is unclear why the response in unbranded ULSD rack margin was delayed, and it did not occur at all in any other year.

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[45] The relatively large drop in the standard was due to the resumption of the compliance schedule in 2018 after a court ruling had frozen the diesel standard in 2018 at 2017 levels (Mazzone et al. 2021).

The following regression model is used to estimate the long-run pass-through of the LCFS tax to ULSD rack margins, as calculated in (7) and where, as in the RIN tax estimation above, the final two terms represent seasonality and other controls, and idiosyncratic error, respectively:

$$m_{it}^{u} = \sum_{d=0}^{D-1} \beta_d^L \Delta L_{t-d}^{u} + \beta_D^L L_{t-D}^{u} + \Theta \boldsymbol{X}_t + \epsilon_{it} \tag{8}$$

Results from this model are presented in Table 3. We estimate (8) for both branded and unbranded rack ULSD spreads, yielding pass-through coefficients of 0.24 and 0.4, respectively. However, this result is heavily driven by the downward shock to rack ULSD spreads beginning in mid-April 2020, likely due to the COVID-19 pandemic. Therefore, columns 3 and 4 of Table 3 present results from the preferred specification, which includes a dummy variable for observations after April 15th, 2020.[46] This set of results presents evidence that refiners transfer their LCFS deficit obligation downstream and is consistent with complete pass-through of the LCFS tax at racks in California.

Table 3. Long-Run Pass-Through of Implicit LCFS Tax to Rack Spread

	Branded (1)	Unbranded (2)	Branded (3)	Unbranded (4)
L_{t-10}^{u}	0.24**	0.40***	0.93***	1.00***
	(0.12)	(0.13)	(0.03)	(0.13)
$1[t > 4/15/2020]$			-0.20***	-0.17***
			(0.01)	(0.02)
Constant	0.11***	0.06***	0.08***	0.03***
	(0.01)	(0.01)	(0.00)	(0.01)
Observations	927	921	927	921
R-squared	0.15	0.21	0.72	0.50

Notes: The dependent variable is the rack B0-5 spread. Standard errors are clustered at the month-year level.
* Statistically significant at the 10% level, ** Statistically significant at the 5% level, *** Significant at the 1% level.

Table 3 also highlights the potential impact that the COVID-19 pandemic had on ULSD rack margins, which were around 20 cents lower on average following mid-March of 2020 than their long-run average since 2015. Evident from Figure 9, since the pandemic started in spring 2020, rack sellers were either unable to continue to pass through the full cost of the LCFS tax at the rack or they were able to pass their obligation even further downstream. The rack pricing data for Portland and Eugene do not include B0-5, so this exercise can't be done for Oregon and the CFP. However, given the similarities between the Oregon and California programs, and given no

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[46] The period after April 15th, 2020, differs from the COVID Shock period outlined in Table 2. Rack margins for ULSD in Los Angeles fell to near-2016 levels, seemingly in lagged response to the COVID-19 pandemic, and it persisted through the end of the sample. The model is estimated with and without observations after April 15th because pass-through is estimated to be complete when excluding those observations.

clear visual pattern of spot ULSD-jet spreads in PNW responding to the CFP tax on diesel (Figure 7), it is plausible that CFP obligated parties act in similar fashion.

There are three important findings that emerge from the analysis in this section. First, the RIN tax appears to be fully passed through to ULSD spot prices, consistent with previous studies (Burkhardt, 2019; Knittel et al., 2017). ULSD-jet spreads are noisy in most of the major spot markets except for the Gulf Coast, where the long-run pass-through coefficient θ_D^R equals 1.00, and its 95 percent confidence interval is [.84, 1.16]. This implies that refiners have still been able to recoup the cost of RFS compliance, even as RIN prices have reached all-time highs.

Second, less than half of the implicit tax from LCFS deficit obligations is passed through to ULSD spot prices because refiners trade their obligation downstream to blenders or own their own blending operation. However, Figure 8 and the regression analysis show that, in Los Angeles especially, some of the LCFS tax is passed through to the spot price of ULSD. This could occur because some refiners don’t own blending operations or don’t trade their deficit obligations, and the coefficients represent an average of these behaviors. This result raises interesting questions about how and why these agreements emerge but these questions are outside the scope of this paper.

Third, blenders have passed through the full LCFS tax to rack buyers for both branded and unbranded ULSD. Together, these findings suggest that *the tax side* of these policies operate as intended. That is, raising the price of petroleum for blenders and, ultimately, consumers. Complete pass-through of the taxes is necessary but not sufficient to conclude that the policies operate effectively and efficiently.

5. Biodiesel Subsidy Pass-Through

Section 4 presented an empirical framework for estimating pass-through of taxes implicitly levied on ULSD through RIN and LCFS deficit obligations and found they were generally fully passed through to diesel prices, except for the LCFS tax after April 2020. This raises the price of the petroleum product so that blenders and, if passed through to retail prices, consumers demand less of it. This suggests effectiveness of one prong of the two-pronged approach of these policies. The implicit taxes have made petroleum more expensive, but have the implicit subsidies made the alternatives cheaper? In this section, we shift focus to the second prong; pass-through of biodiesel subsidies from the RFS, LCFS, and CFP is estimated.

Racks provide an ideal setting to study pass-through because the marginal cost of producing the blended fuel is observed daily. The marginal revenue for the blender is the rack price and the marginal cost is the wet cost of the component fuels. The wet cost is the sum of the petroleum and biofuel costs associated with one gallon of blended fuel. Spot prices are a good measure of the true marginal cost because they reflect the cost of replacing a gallon of fuel on a given day. We use the previous day's spot price when calculating the wet cost because that is the most recent information available to rack participants on the day of the transaction. Let j denote the city of the rack market, t denote days, and k denote the biodiesel blend. The wet cost is then

$$w_{jt}^{k} = \delta^{k} p_{j,t-1}^{b} + (1-\delta^{k}) p_{j,t-1}^{u} \tag{9}$$

The wet cost is denoted by j, but the spot prices are not unique to the city of the terminal. We map each city in the rack pricing data to its nearest spot market, displayed in Table A-1. Each rack city has a robust spot market for ULSD in close proximity, but only three of them also post spot prices of B100: Chicago, NY Harbor, and Gulf Coast. In California and Oregon, we use the NY Harbor B100 spot price to calculate the wet cost because it is often used as a basis for spot gallons on the west coast.[47] Only SME biodiesel is sold in B100 spot markets, so the analysis is restricted to that feedstock. The blender's margin for SME biodiesel blend k is

$$m_{jt}^{k} = p_{jt}^{k} - w_{jt}^{k} \tag{10}$$

The rack margin for B20, for example, would be the rack price of B20 minus 0.2 times the spot price of B100 and 0.8 times the spot price of ULSD. If the value of the RIN subsidy is fully passed through at the rack, the margin will move one-for-one with changes in the negative of the RIN value. The same goes for the LCFS and CFP credit subsidies. We employ a Cumulative Dynamic

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[47] This is based on anecdotal evidence and conversations with businesses that sell fuel into California. However, results are robust to using any of the three spot markets. From another data source, there is a spot price of biodiesel on the west coast, but it captures an average price over several feedstocks. It may be that the NY Harbor price plus a transportation cost is a better approximation of the cost of blending a gallon of SME biodiesel in California or Oregon, than the ambiguous west coast price. The results, however, are also robust to using that price as the SME biodiesel cost component.

Multiplier (CDM) model to estimate both the short- and long-run pass-through of RFS, LCFS, and CFP incentives. Specifically, we estimate the following model:

$$m_{it}^{k} = \alpha_i + \sum_{d=0}^{D-1} \beta_d^R \Delta R_{t-d}^{k} + \beta_D^R R_{t-D}^{k} + \sum_{d=0}^{D-1} \beta_d^L \Delta L_{t-d}^{k} + \beta_D^L L_{t-D}^{k} + \Theta \boldsymbol{X}_t + \varepsilon_{it}^{k} \qquad (11)$$

Where Δ is the first-difference operator, α_i are city fixed effects, and ε_{it}^{k} is the idiosyncratic error term. We impose β^L=0 in cities not subject to the LCFS or CFP. R^k and L^k are the RIN and LCFS subsidies, respectively, for blend k. Both the rack margins and subsidies are measured in $/gal, so the long-run coefficients can be interpreted such that a $1\gal increase in the RIN subsidy results in the rack margin decreasing by $$\beta_D^R$/gal. Similarly, for the LCFS and CFP, a $1/gal increase in the LCFS or CFP net subsidy results in the rack margin decreasing by $$\beta_D^L$/gal. Since RIN and LCFS incentives stack in California and Oregon, the additive incentives will be salient to rack market participants. Therefore, we also estimate the following model to explore pass-through of the total incentives in California and Oregon.

$$m_{it}^{k} = \alpha_i + \sum_{d=0}^{D-1} \beta_d \Delta (R_{t-d}^{k} + L_{t-d}^{k}) + \beta_D (R_{t-D}^{k} + L_{t-D}^{k}) + \boldsymbol{\Theta X}_t + u_{it}^{k} \qquad (12)$$

One important confounding factor is the Blender's Tax Credit (BTC), which acts as an additional implicit subsidy for biodiesel realized by the rack seller. The nature and timeline of the BTC is described in Section 1.4. As mentioned, within the sample used in this paper, the BTC was in place some years and retroactively reinstated in others. In years that it wasn't in place, the market formed expectations around the likelihood it would be retroactively reinstated which led to risk-sharing contracts between rack sellers and buyers. These year-to-year changes directly affect the observed margin in (10) and may be correlated with RIN prices.

To see this, consider a scenario where the BTC is taken away and the market forms expectations around its reinstatement, and the biodiesel producer and the blender form a 50/50 sharing contract. If the biodiesel producer passes through the full value, their spot price will fall by 50 cents/gal of B100. In this case, the observed margin of the blender rises by $\delta^k \times$ 50 cents/gal. The blender still receives $\delta^k \times$ 50 cents/gal from their half of the BTC, so the RIN price will remain unchanged. This relationship would severely bias the estimates of the β coefficients if between-year variation in rack margins and the RIN subsidy is used. Since the level of the adjustment of the margin is directly proportional to the blend level δ^k, we include blend-by-year dummy variables to account for changes to the BTC. This means that implied subsidy pass-through is identified from within-year and within-blend variation in rack margins.

The identification strategy outlined above requires additional assumptions about how the BTC affects margins and RIN prices. The first assumption we make is that blenders and biodiesel producers expect the tax credit to be reinstated with probability one throughout each year that it's not in place. The other assumption is that sharing contracts are 50/50 split throughout the year. If either is violated, the resulting impacts on margins will be erroneously attributed to the RIN subsidy. These assumptions seem reasonable since the tax credit had already been retroactively reinstated three times prior to the beginning of my sample, in 2010, 2012, and 2014.

Similarly, we assume that pass-through of the BTC to biodiesel spot prices is complete in years when the BTC expired. Irwin (2017), looking at a sample of biodiesel prices from Iowa plants in the months before and after the BTC expired (including 2016/2017), suggests that it hadn't been passed through in previous years. In the example above, if none of the BTC was passed through to biodiesel spot prices, we would see no change to the biodiesel cost and the observed margin, and an increase in the D4 RIN subsidy. In my sample, however, biodiesel spot prices and rack margins do appear to respond to the BTC expiration in 2017, and the RIN subsidy remains constant (Figure 10). Similarly, in 2020 when the BTC was reinstated, observed rack margins fell, consistent with the retroactive BTC being completely passed through. The RIN subsidy fell at the same time, but this likely reflects the decline in ULSD prices rather than the BTC.

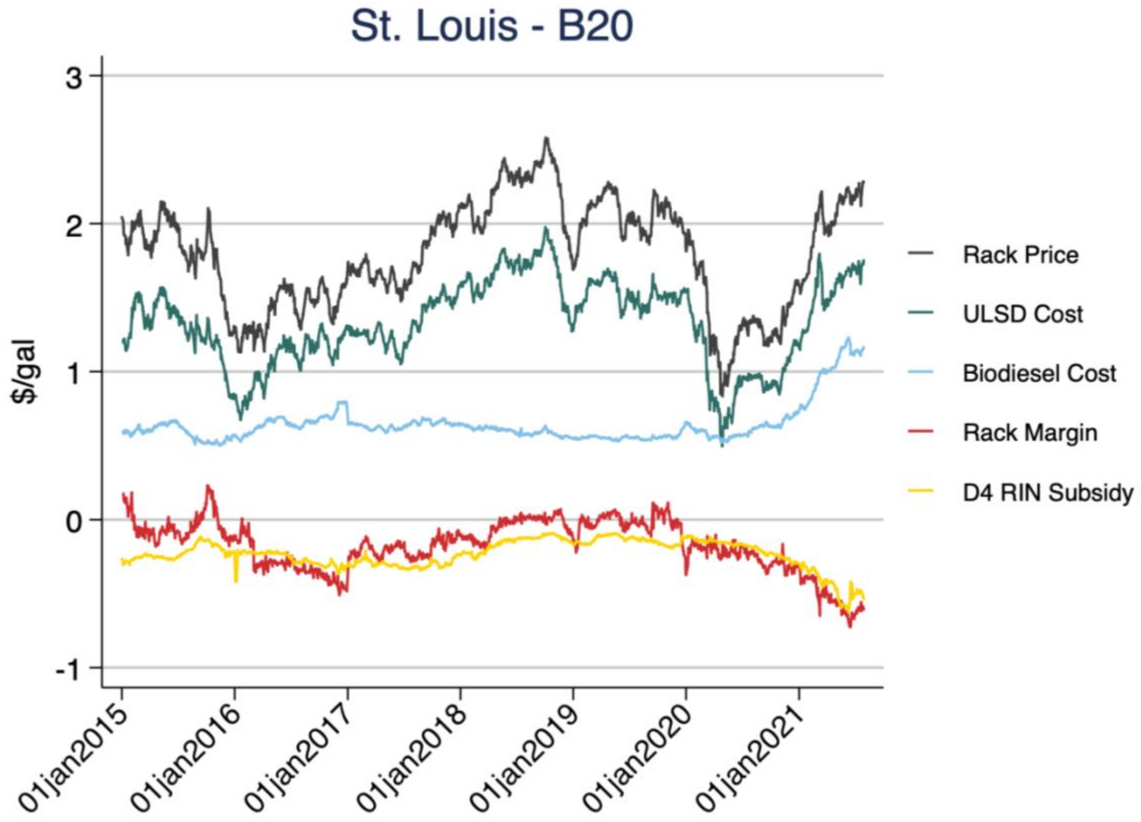

Figure 10. Prices, Costs, and RIN Subsidy for B20 in St. Louis.

In addition to the confounding effects of the BTC outlined above, anticipation of changes to the BTC may create similar issues. The spot price of B100 rose starkly at the end of 2016, which may have resulted from blenders purchasing and blending excess biodiesel before the tax credit expired. A similar but more modest pattern emerged at the end of 2019 prior to the 2020 reinstatement. Therefore, we also include blend-specific dummy variables for these two anticipation periods for robustness. Results are not sensitive to the inclusion of these variables. Outside of the anticipation periods, we assume nothing about the BTC is changing within years.

Like jet fuel, blended biodiesel (when the percentage of biodiesel content is small, which is the case in my sample) is nearly a perfect substitute to petroleum diesel. Therefore, since the RIN tax is fully passed through to ULSD prices, B100 (net the BTC) and ULSD prices should only differ by their net RIN obligation, which is the price of 1.5 D4 RINs, if the subsidy is fully passed through at the wholesale level (Knittel et al., 2017). Figure 11 plots the B100-ULSD spread in Chicago, Gulf Coast, and New York Harbor Barge and the D4 RIN price multiplied by 1.5. The two series are nearly identical outside of the years with the BTC in place, which is to be expected under full RIN pass-through to the wholesale price, and if biodiesel is the marginal fuel for D4 mandate compliance. The degree of alignment of the spread and RIN subsidy in Figure 11 highlights SME biodiesel's role as the marginal fuel for compliance in the D4 category, meaning that D4 RIN prices should reflect the marginal cost of D4 compliance.

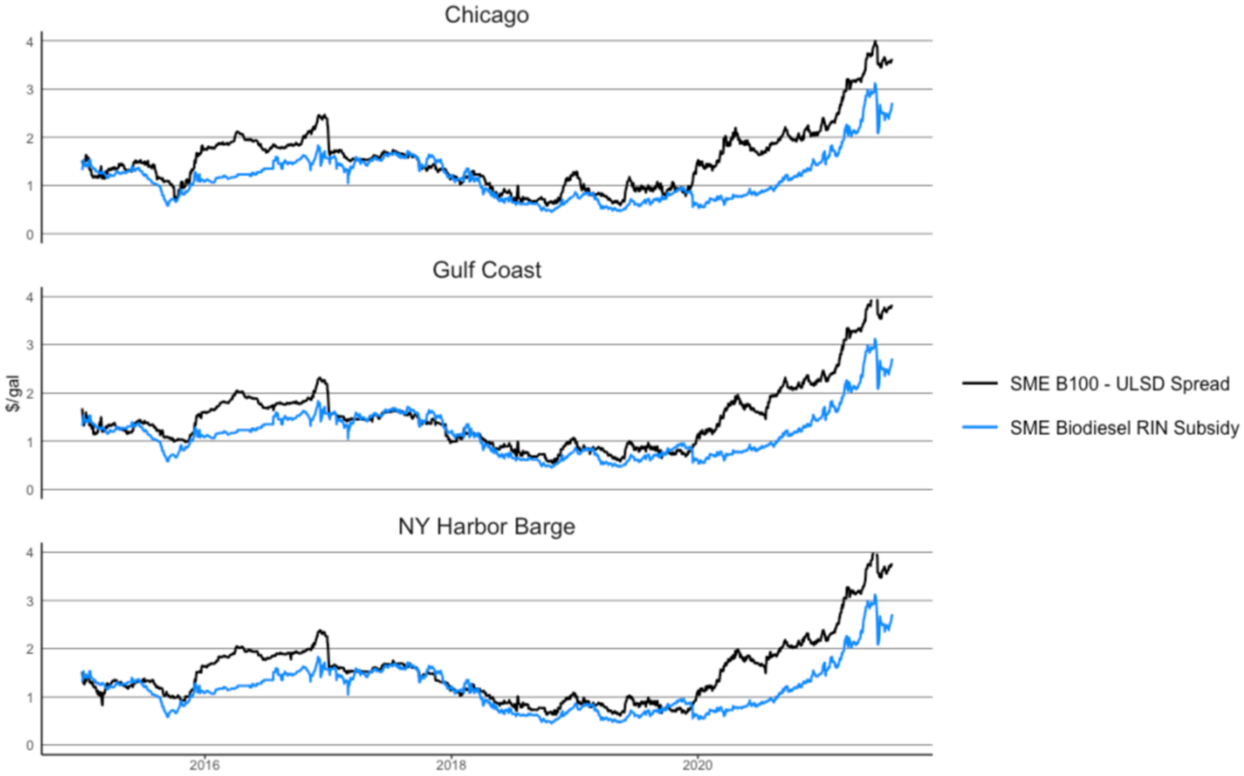

Figure 11. SME Biodiesel - ULSD Spread

Identification in (11) and (12) relies on the assumption that input costs, namely ULSD and B100 spot prices, are fully passed through to rack prices. If this is assumption is invalid, estimates of RIN subsidy pass-through will be biased since input costs are correlated with RIN prices (Figure 11). Incomplete pass-through of B100 prices to the rack, for example, could be erroneously attributed to incomplete pass-through of RIN subsidies. Therefore, we relax this assumption by augmenting (11) to allow input cost pass-through to differ from one: we regress unbranded rack prices on the RHS variables in (11) and input costs. We perform this for wet costs, and separately for biodiesel and ULSD components, shown in (13) and (14), respectively.

$$\begin{aligned} p_{it}^{k} = \alpha_i + \sum_{d=0}^{D-1} \beta_d^R \Delta R_{t-d}^{k} + \beta_D^R R_{t-D}^{k} + \sum_{d=0}^{D-1} \beta_d^L \Delta L_{t-d}^{k} + \beta_D^L L_{t-D}^{k} \\ + \sum_{d=0}^{D-1} \gamma_d^w \Delta w_{t-d}^{k} + \gamma_D^w w_{t-D}^{k} + \boldsymbol{\Theta X}_t + \varepsilon_{it}^{k} \end{aligned} \tag{13}$$

$$\begin{aligned} p_{it}^{k} = \alpha_i + \sum_{d=0}^{D-1} \beta_d^R \Delta R_{t-d}^{k} + \beta_D^R R_{t-D}^{k} + \sum_{d=0}^{D-1} \beta_d^L \Delta L_{t-d}^{k} + \beta_D^L L_{t-D}^{k} \\ + \sum_{d=0}^{D-1} \gamma_d^b \Delta b_{t-d}^{k} + \gamma_D^b b_{t-D}^{k} + \sum_{d=0}^{D-1} \gamma_d^u \Delta u_{t-d}^{k} + \gamma_D^u u_{t-D}^{k} + \boldsymbol{\Theta X}_t \\ + \varepsilon_{it}^{k} \end{aligned} \tag{14}$$

Results from the unrestricted models in (13) and (14) support complete pass-through of input prices in all regions, except for the spot price of B100 in Wood River, and are presented in in Figure A-3. the remainder of this section, results are reported only for the restricted model outlined in (11), since subsidy pass-through estimates are robust to inclusion of input costs as controls.

5.1. RIN Subsidy Pass-Through

Table 4 presents estimates of short- and long-run RIN subsidy pass-through for California, Oregon, and the rest of the U.S. (ROUS)—which consists of Dallas, Trenton, St. Louis, and Wood River. The first three columns utilize the full sample, while the last three drop observations in the RIN Shock Period outlined in Section 3.1. The long-run coefficients suggest regional heterogeneity of RIN subsidy pass-through; using the full sample, of a $1/gal RIN subsidy, only around 60 cents/gal are passed through on the West Coast by day 10 compared to 95 cents/gal in ROUS. When dropping the RIN Shock Period, ROUS RIN subsidy pass-through falls to 77 cents/gallon. Sensitivity of results to inclusion of the RIN Shock Period are discussed later in this section.

Short-run estimates (that is, the estimates for lags shorter than the 10th day estimate, which captures effects from that day forward) in California and Oregon are imprecise and not statistically different from zero. Columns 3 and 6 show that it takes more than one week for the cumulative pass-through of the RIN subsidy to reach its long-run average in ROUS. Only 34 cents/gal are passed through one day after a shock to the RIN price, 21 cents/gal when dropping the RIN Price Shock Period.

Table 4. RIN Subsidy Pass-Through Dynamics

	Full Sample			Drop RIN Shock (6/20-7/21)		
	CA	OR	ROUS	CA	OR	ROUS
	(1)	(2)	(3)	(4)	(5)	(6)
ΔR_t^k	0.02	0.26	0.27***	0.01	0.13	0.11
	(0.10)	(0.17)	(0.10)	(0.10)	(0.29)	(0.12)
ΔR_{t-1}^k	0.07	0.36**	0.34***	0.07	0.30	0.21**
	(0.10)	(0.17)	(0.06)	(0.10)	(0.27)	(0.08)
ΔR_{t-2}^k	0.08	0.33*	0.36***	0.10	0.62**	0.30***
	(0.11)	(0.19)	(0.05)	(0.11)	(0.27)	(0.08)
ΔR_{t-3}^k	0.11	0.37**	0.41***	0.11	0.42	0.29***
	(0.11)	(0.18)	(0.06)	(0.11)	(0.36)	(0.07)
ΔR_{t-4}^k	-0.03	0.40***	0.46***	-0.04	0.27	0.19
	(0.15)	(0.14)	(0.14)	(0.15)	(0.30)	(0.20)
ΔR_{t-5}^k	0.01	0.43**	0.66***	0.02	0.24	0.47***
	(0.16)	(0.20)	(0.09)	(0.17)	(0.40)	(0.11)
ΔR_{t-6}^k	0.09	0.43***	0.66***	0.11	0.37	0.53***
	(0.15)	(0.16)	(0.07)	(0.15)	(0.32)	(0.09)
ΔR_{t-7}^k	0.17	0.43**	0.66***	0.17	0.51	0.55***
	(0.14)	(0.20)	(0.07)	(0.15)	(0.31)	(0.09)
ΔR_{t-8}^k	0.19	0.53***	0.78***	0.19	0.33	0.67***
	(0.15)	(0.14)	(0.11)	(0.16)	(0.25)	(0.16)
ΔR_{t-9}^k	0.23	0.35**	0.77***	0.25	0.23	0.64***
	(0.15)	(0.15)	(0.07)	(0.15)	(0.28)	(0.09)
$\boldsymbol{R_{t-10}^k}$	**0.58*** **	**0.62*** **	**0.95*** **	**0.57*** **	**0.22**	**0.77*** **
	(0.11)	**(0.11)**	**(0.05)**	**(0.11)**	**(0.30)**	**(0.07)**
Constant	-0.79	0.14	0.03	-0.63	1.46	-0.05
	(0.64)	(0.62)	(0.21)	(0.63)	(1.72)	(0.25)
Observations	5,681	3,358	19,162	5,258	2,434	15,275
R-squared	0.90	0.94	0.98	0.89	0.86	0.98

Notes: The dependent variable is the rack margin. Observations are treated as outliers and dropped from the analysis if the first-difference of the margin is greater than 50 cents/gallon. Standard errors are clustered at the month-year level. * Statistically significant at the 10% level, ** Statistically significant at the 5% level, *** Statistically significant at the 1% level.

Table 4 highlights some of the regional heterogeneity in pass-through of biodiesel RIN subsidies, however, heterogeneity is present within the ROUS as well. Figure 12 presents point estimates and 95 percent confidence intervals of long-run pass-through of the RIN subsidy for each region in the sample. Regions are presented in ascending order of long-run pass-through rates using the full sample. Rates in California and Oregon are the lowest nationwide at about

60 cents/gal on average. In the ROUS, for the full sample, average pass-through rates are 0.8, 0.95, and 1.07 in the East Coast, Gulf Coast, and Midwest, respectively; however, the 95 percent confidence intervals include 1 (complete pass-through) for all three regions. The estimates in Figure 12 are robust to controlling for both 5 lags and 30 lags, except for California. In California, confidence intervals for the long-run RIN subsidy pass-through fall to [0.22, 0.61] and [0.25, 0.67] for the full sample and dropping the RIN Price Shock period, respectively, when increasing the number of lags to 30 days. In both cases, the point estimates fall below 0.5, suggesting less than half of the RIN subsidy has been passed through in California. Despite the quantitative differences in results between the two specifications, the qualitative conclusions remain: the RIN subsidy pass-through has only been partial in the state, as well as in neighboring Oregon.

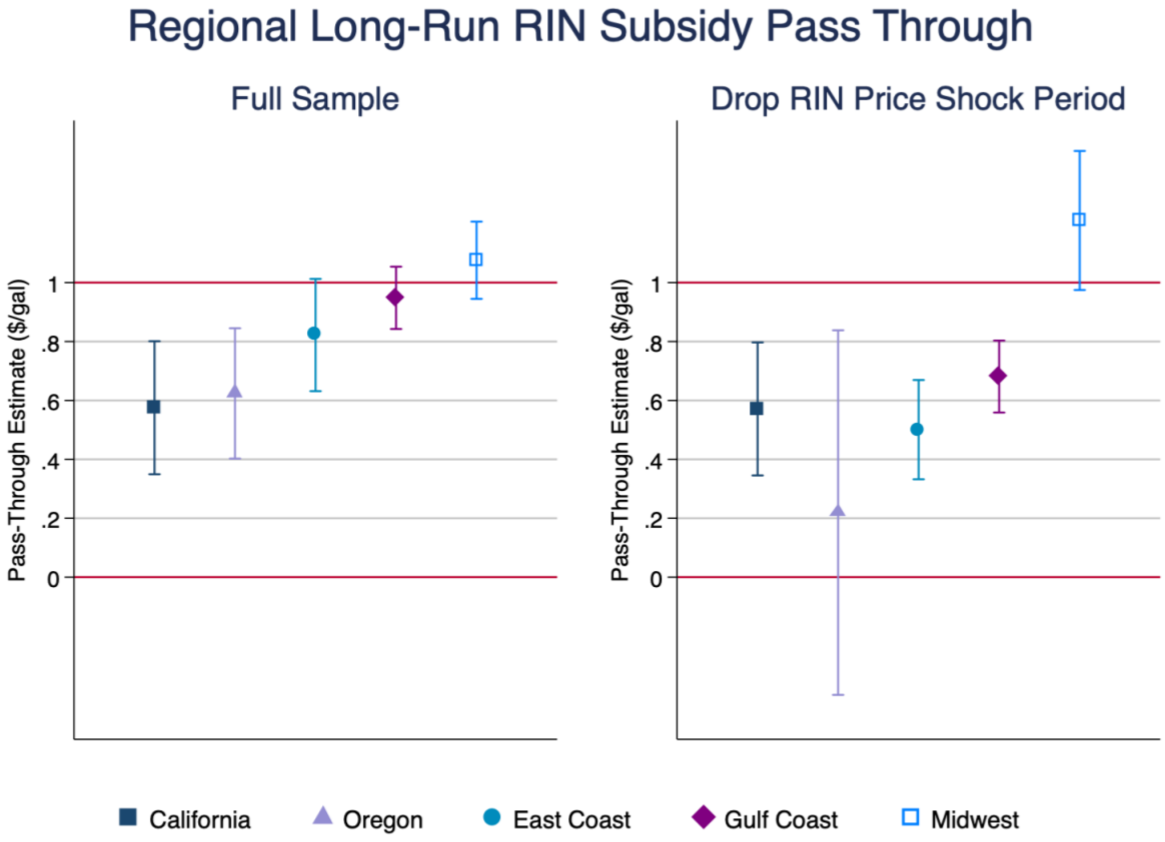

Figure 12. Regional Long-Run Pass-Through of SME Biodiesel RIN Subsidies. Standard errors are clustered at the month-year level. Shapes are point estimates and bars are 95 percent confidence intervals.

Long-run RIN subsidy pass-through results are qualitatively different when ignoring the RIN Price Shock Period and the ordering of regions changes. Pass-through in Oregon becomes very imprecise since CFP prices begin in 2017, leaving a small sample once dropping the period from the analysis. The lowest levels of RIN subsidy pass-through levels where reliable estimation is possible now occur in the East Coast, where only half is passed through on average and the upper bound of the 95 percent confidence interval lies below three quarters of complete pass-through. Using the restricted sample, pass-through in the Gulf Coast is 67 cents/gal on average and the confidence interval no longer includes complete pass-through. Incomplete pass-through of the biodiesel RIN subsidy in the Gulf Coast is a significant finding, as previous studies have consistently found complete pass-through of implicit gasoline taxes and ethanol subsidies from the RFS (Burkhardt, 2019; Knittel et al., 2017; Pouliot et al., 2020).

One concern regarding the results from the Gulf and East Coast is the effect of the Colonial pipeline shutdown in May of 2021 in response to ransomware attack.[48] The Colonial pipeline runs from Texas to New Jersey supplies a substantial amount of fuel to both Dallas and Trenton. The pipeline shutdown on May 7th, 2021, and resumed operation on May 13th, 2021. Estimates for the two cities served by the pipeline aren't sensitive to the inclusion of a blend-specific dummy for the month of May in 2021, therefore we don't control for the event moving forward and differences between the results from the full sample and dropping the RIN Price Shock period shouldn't be attributed to the shutdown.

Another concern about the results presented in Table 4 and Figure 12 is that blend offerings vary across regions (Table A-2), which raises the question of whether or not we are attributing differences in pass-through among blends to regional differences. The portfolio of biodiesel blends exhibits similar characteristics to ethanol, in that there are lower-percentage blends that are commonly used by retail consumers around the U.S. and higher blends that are only used in certain types of engines and have limited availability nationwide. Previous literature is mixed in its findings regarding high- vs low-blend RIN pass-through. A body of work has demonstrated lower pass-through rates of RIN subsidies for E85, gasoline with between 51 and 83 percent ethanol, than the more common blend with less ethanol content, E10 (Knittel et al., 2017; Li & Stock, 2019; Pouliot et al., 2020). This work generally finds E85 pass-through is incomplete. However, more recent work has found that it had been completely passed through (Lade & Bushnell, 2019).

To test for heterogeneity in the pass-through of RIN subsidies across biodiesel blends, we estimate (11) separately for each blend in each region.[49] The long-run coefficients from those regressions are depicted in Figure 13, showing that long-run RIN subsidy pass-through is generally consistent across blends within each region. When point estimates differ in a meaningful way, one of them tends to be much more imprecise than the other. Generally, lower blends are estimated less precisely because variation in the subsidy is smaller in magnitude than for higher blends. Most notably, B5 estimates are much less precise than other blends in most regions.

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[48] Information regarding the Colonial pipeline shutdown can be found here: https://www.energy.gov/ceser/colonial-pipeline-cyber-incident.

[49] Results from Oregon are omitted from the blend-level analysis because they are too imprecise to be informative.

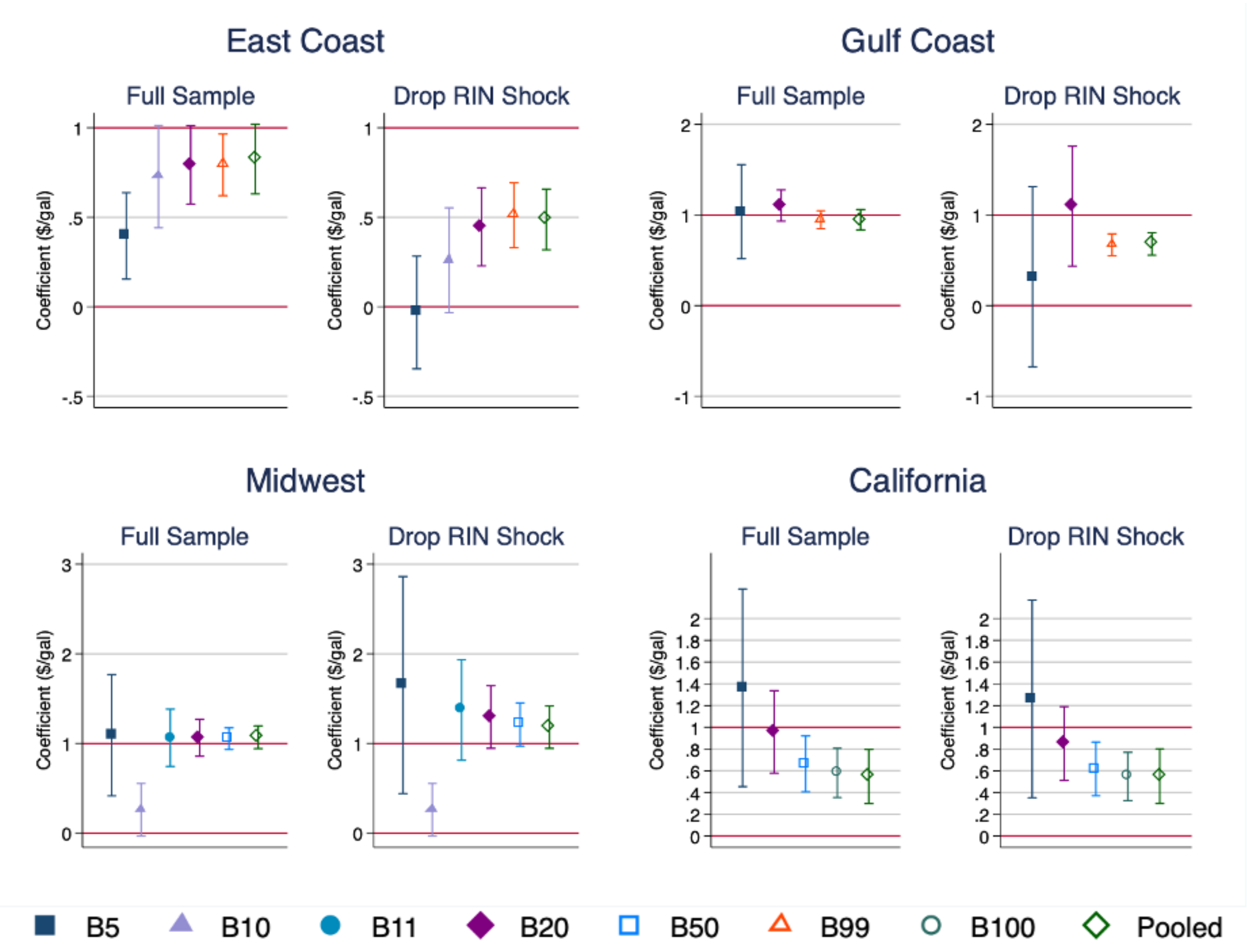

Figure 13. RIN Subsidy Pass-Through by Blend. The estimates for California are from San Francisco. Note the difference in scales for each region. Oregon is omitted because estimates are too imprecise to be plotted, especially when using the smaller sample with the RIN Price Shock period dropped. Standard errors are clustered at the year-month level.

In the East Coast, however, the results for B5 are qualitatively different. This could result from differences in B5 markets relative to other blends, such as less restrictive labeling and infrastructure requirements (see Section 2). B5 can also be blended above the rack in many cases. In California, complete pass-through is ruled out in blends above B20. This is discussed further in conjunction with LCFS subsidies in Section 5.2.

The RIN subsidy pass-through results exhibit some consistencies with previous findings in the literature studying pass-through of RIN subsidies to blended gasoline and some important differences. The finding here of complete pass-through in the Midwest and incomplete pass-through on the East Coast is generally consistent with Pouliot et al. (2017). However, we have a smaller sample of cities and look at a different timeframe. Additionally, their findings are sensitive to whether the blended fuel was branded or unbranded whereas we didn’t have sufficient data for branded products to conduct a similar sensitivity analysis. Comparing our results for unbranded B10 in Trenton, NJ to their results for unbranded E10 in Newark, NJ, we find lower rates of pass-through (0.9 compared to 0.3, in their preferred specification), especially when dropping the RIN Price Shock period.

Like our sample, the sample used in Pouliot et al. (2017) also includes a period with a significant upward shock to RIN prices—the first eight months of 2013—that had a significant impact on estimates of pass-through. In that period, D6 RIN prices rose from under 10 cents/gal to over $1/gal; it was the first time RINs represented a substantial portion of gasoline margins. They argue that the finding of incomplete pass-through can be explained by fuel buyers learning how D6 RIN prices affected rack margins.

Our results, shown in Figure 12, likely can't be explained by the market learning how D4 RIN prices affect rack margins. The soybean boom that began in 2020 put substantial upward pressure on biodiesel prices, and therefore, D4 RIN prices. RIN subsidies for biodiesel surpassed $3/gal in 2021, more than tripling since 2020, and nearly double their all-time high (excluding outliers). Blenders adjusted quickly to this, fully passing through the subsidy as it grew exponentially, suggesting the RIN subsidy for biodiesel is salient to rack buyers. In fact, only when excluding the RIN Price Shock period can we reject complete pass-through in the Gulf and East Coast. Although reaching record highs during the RIN price shock period, the RIN subsidy was still meaningful prior to that; it represented around half the price of B100 for much of the time. Less of the RIN subsidy was passed through before the RIN Price Shock period began than after. If a learning or salience effect were present, we would expect to see the opposite.

5.2. LCFS and RFS Incentive Pass-Through in California

In this section, pass-through of the LCFS subsidy to rack margins for biodiesel is considered. LCFS subsidies exhibited far less daily variation than RIN subsidies in our sample, as seen in Figure 6, which introduces a lack of statistical power, especially in the short run, when we attempt to disentangle LCFS credit and RIN subsidy pass-through. Generally, however, the results presented in this section suggest that LCFS soy biodiesel subsidies are not fully passed through in the California rack markets in our sample.

Table 5 presents short- and long-run estimates from the unrestricted and restricted models in (11) and (12), respectively. Columns 1 and 2 show that all short-run coefficients are statistically insignificant when the LCFS and RIN subsidies are included separately in the model. The coefficients in column 3 for the restricted model, however, are statistically significant and suggest 70 cents/gal per dollar of combined subsidy is passed through in the long-run, and it takes over a week to reach the long-run rate of pass-through. The restricted model is preferred because it is parsimonious and the combined subsidy may better explain variation in rack margins since the individual policy incentives stack and the marginal revenue from selling both LCFS credits and RINs is what's salient to the blender.

Table 5. Subsidy Pass-Through Dynamics in California

	Unrestricted Model		Restricted
	$X_t^k = R_t^k$ (1)	$X_t^k = L_t^k$ (2)	$X_t^k = R_t^k + L_t^k$ (3)
ΔX_t^k	0.02	0.29	0.14
	(0.10)	(0.43)	(0.09)
ΔX_{t-1}^k	0.07	0.30	0.20**
	(0.10)	(0.31)	(0.10)
ΔX_{t-2}^k	0.08	0.02	0.16
	(0.11)	(0.34)	(0.11)
ΔX_{t-3}^k	0.11	-0.07	0.16
	(0.11)	(0.33)	(0.10)
ΔX_{t-4}^k	-0.03	0.23	0.18
	(0.15)	(0.32)	(0.12)
ΔX_{t-5}^k	0.01	0.29	0.24*
	(0.16)	(0.35)	(0.12)
ΔX_{t-6}^k	0.09	0.05	0.25*
	(0.15)	(0.34)	(0.13)
ΔX_{t-7}^k	0.17	0.02	0.29**
	(0.14)	(0.32)	(0.13)
ΔX_{t-8}^k	0.19	0.34	0.34**
	(0.15)	(0.31)	(0.15)
ΔX_{t-9}^k	0.23	0.46	0.40***
	(0.15)	(0.29)	(0.14)
X_{t-10}^k	0.58***	-0.02	0.68***
	(0.11)	(0.26)	(0.12)
Constant	-0.79	-0.79	-0.99
	(0.64)	(0.64)	(0.66)
Observations	5,681	5,681	5,681
R-squared	0.90	0.90	0.89

Notes: Columns 1 and 2 are estimated from the same regression model. All California cities and blends are included, see Table A-2. The dependent variable is the rack margin. Standard errors are clustered at the month-year level. * Statistically significant at the 10% level, ** Statistically significant at the 5% level, *** Statistically significant at the 1% level.

Long-run pass-through of the individual and combined subsidies exhibits heterogeneity within California. Table 6 shows that pass-through is lower in larger cities in the sample (Los Angeles and San Francisco) and higher in the smaller cities (Bakersfield and Stockton). The RIN subsidy is fully passed through in the smaller cities on average, and 60 cents/gal of the LCFS subsidy is passed through on average, but the 95 percent confidence interval includes both zero and one.

The combined subsidy has near-complete or more-than-complete pass-through in the smaller cities, with a 95 percent confidence interval of [0.87, 1.74].

Table 6. Long-Run Subsidy Pass-Through in California

	Large Cities		Small Cities	
	(1)	(2)	(3)	(4)
R_t^k	0.54***		1.10***	
	(0.12)		(0.18)	
L_t^k	0.02		0.61**	
	(0.29)		(0.29)	
$R_t^k + L_t^k$		0.61***		1.30***
		(0.11)		(0.21)
Constant	0.09	0.01	0.05	-1.96
	(0.66)	(0.65)	(1.89)	(1.88)
Observations	4,604	4,604	1,077	1,077
R-squared	0.94	0.93	0.89	0.88

Notes: The dependent variable is the rack margin. Standard errors are clustered at the month-year level.
* Statistically significant at the 10% level, ** Statistically significant at the 5% level, *** Statistically significant at the 1% level.

The majority of California's operational biodiesel production capacity is in Los Angeles, San Diego, and San Francisco (Brown, 2020). Los Angeles and San Francisco also both have major spot market hubs for ULSD. However, there are significantly more blending facilities in Los Angeles than San Francisco.[50] Therefore, the remainder of this section will focus on those larger cities. Only half the RIN subsidy is passed through in the urban markets on average and pass-through of the LCFS subsidy is not statistically different from zero. The confidence intervals for R_t^k, L_t^k, and $R_t^k + L_t^k$ are [0.28, 0.77], [-.056, 0.57], and [0.37, 0.82], respectively. Therefore, complete pass-through is rejected for all three variables.

The results of the LCFS subsidy analysis discussed thus far have been averages over the full sample. So, for example, it could be that those estimates reflect an average of incomplete pass-through in earlier years due to a lack of salience but pass-through becomes complete later in the sample as the market better understands how LCFS credits affect margins (Pouliot et al., 2020). Also, the LCFS subsidies for biodiesel have risen from an average of 9 cents/gal in 2015 to over $1/gal since 2018, so salience of changes in the subsidy may have been less when subsidy levels were low. To explore the issue of salience, we estimate (11) and (12), keeping observations in Los Angeles and San Francisco, for each subsample defined in Table 2. We present those results in Figure 14.

The first observation is the downward shift in the rates of pass-through from the Low LCFS Price period to the Mid LCFS Price period. Pass-through of the RIN subsidy, on average, is close to

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[50] Information on blending facilities can be found here: http://www.edf.org/content/biodiesel-california.

one in the Low LCFS Price period and falls to nearly a quarter in the next period. There isn't much signal in the LCFS subsidy during the Low LCFS Price period, but the point estimate is also close to one. In the Mid LCFS Price period, pass-through of the LCFS subsidy falls to 0.06 but the 95 percent confidence interval includes up to half. Since the LCFS subsidy estimates are so imprecise in the Low LCFS Price period, we're not able to confidently rule out the salience argument, but the near-zero point estimates in later periods, and confidence intervals with upper bounds around a half, suggest that a change in salience is unlikely to be the driver of the finding of incomplete pass-through of the LCFS subsidy when utilizing the full sample.

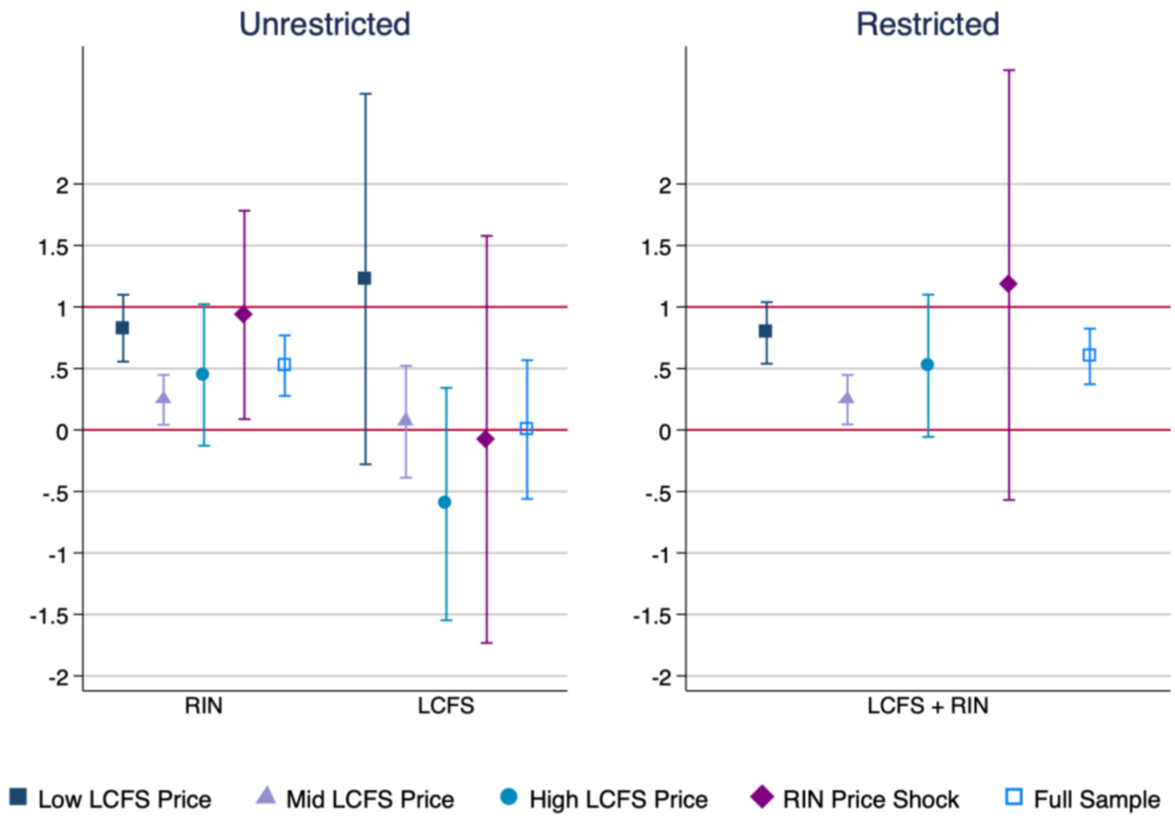

Figure 14. Long-Run Pass-Through of Implicit Subsidies in California by Sub-sample. Results are shown for Los Angeles and San Francisco only. Standard errors are clustered at the year-month level.

Results from the restricted model resemble RIN pass-through from the unrestricted model, which is to be expected as there is more variation in RIN subsidies than LCFS subsidies over most of the sample. These RIN subsidy pass-through estimates are put into context with other cities in the sample in Figure A-4, which shows that RIN subsidy pass-through, apart from the East Coast, was complete or near complete in all subsamples. We also estimate pass-through of the LCFS subsidy for different blends in California. The results are similar to the RIN subsidy analysis above in California; pass-through is slightly less complete for higher blends such as B50 and B100 on average but estimated more precisely. When dropping the RIN Price Shock period, and looking at San Francisco, we find point estimates [95% confidence intervals] of LCFS subsidy pass-through of 0.44 [-0.70, 1.59], 0.30 [-0.35, 0.96], and 0.24 [-0.31, 0.80] for B20, B50, and B100, respectively.

There are two important limitations that could significantly impact the results presented above. First, the lack of a clear understanding of how changes to the BTC affected the relationship between RIN subsidies and rack margins, and whether the effect is different for California relative to other U.S. regions, introduces a potentially significant confounding factor when trying to identify changes in rack margins that can be attributed to changes in the RIN subsidy. Second, the absence of a feedstock-specific spot price of biodiesel in California, limits our ability to accurately estimate the cost of blending biodiesel at California racks. If the assumption that the spot price, or the blender's marginal cost, of SME B100 is equal to a NY Harbor Barge basis plus a constant transportation cost is violated, the estimates of LCFS subsidy pass-through will be biased if California-specific costs are correlated with the LCFS subsidy. Specifically, if transportation costs exhibit a positive relationship with the LCFS subsidy, we will systematically underestimate the rate it is passed through. With the data available at the time of writing, the prevalence of that relationship is untestable. Lastly, margins for diesel blended with SME biodiesel are volatile and data availability limit the analysis to SME biodiesel only, which is rarely used in California. The issue of feedstock- and region-specific spot price data described above also pertains to Oregon.

An advantage of focusing on SME biodiesel, however, is that the volume-weighted average CI of reported volumes has remained relatively constant over time (aside from the 2016 modeling change, Figure 5). Yet, if the CI of SME biodiesel used in California changes significantly within any given year, it will have two direct effects on the models used to estimate subsidy pass-through, (11) and (12). The first is that the true spot price of SME B100 in California will likely move inversely with the CI score, which will violate the assumption that the California spot price equals the NY Harbor spot price plus a constant. The second is that the implicit subsidy calculation in (4) will be inaccurate.[51] However, it's unlikely CI scores of SME biodiesel are changing significantly within years in our sample, aside from the modeling change example.

Accurate, high-frequency biodiesel, as well as renewable diesel, pricing data for feedstocks and localities would allow researchers to study pass-through using prices for fuels that reflect a much more significant market share of the biomass-based diesel consumed in California. Additional data on the CI scores of fuels in the rack pricing data would allow for more accurate calculations of the implicit LCFS subsidies they receive, instead of assuming the volume-weighted average CI score for the listed feedstock. Quantity data would also be particularly useful in the LCFS analysis given how thin the market for SME biodiesel is in California. Many of the rack prices in our sample for California may come from transactions with relatively small

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[51] Take a simplified example. Suppose a lower-CI soy biodiesel enters the California market (and only California). Since we don't observe the true California spot price of biodiesel, the blending margin we calculate in (10) would not change. Our calculation of the daily implicit subsidy in (4) would not capture the change in the CI score, so our calculation of the number of credits per gallon of the biodiesel blend would not reflect the true change. If the lowered biodiesel CI score is associated with an increase in the LCFS credit price, which would be captured in (4), then the estimates of LCFS subsidy pass-through would be attenuated.

quantities of fuel and may not be fully representative of the entire market; this analysis cannot control for the impact of any thinness of market trading on rack prices.

5.3. CFP and RFS Incentive Pass-Through in Oregon

Credit market data for the CFP is only available since 2017 and there hasn't been much variation in credit prices. Additionally, spot prices in the PNW and Oregon rack margins are very volatile. This makes identifying pass-through of the CFP subsidy difficult and results presented here are imprecise. Table 7 presents the short- and long-run estimates from (11) and (12), using the Oregon cities in the sample. Most short-run estimates of CFP pass-through are statistically insignificant. Like California, short-run estimates of the combined subsidy are measured more precisely than either of the individual subsidies.

Table 7. Pass-Through Dynamics in Oregon

	Unrestricted		Restricted
	$X_t^k = R_t^k$ (1)	$X_t^k = L_t^k$ (2)	$X_t^k = R_t^k + L_t^k$ (3)
ΔX_t^k	0.26	1.30	0.31**
	(0.17)	(0.93)	(0.15)
ΔX_{t-1}^k	0.36**	0.80	0.38**
	(0.17)	(0.75)	(0.16)
ΔX_{t-2}^k	0.33*	0.92	0.37**
	(0.19)	(0.80)	(0.16)
ΔX_{t-3}^k	0.37**	0.31	0.37**
	(0.18)	(0.80)	(0.16)
ΔX_{t-4}^k	0.40***	1.20	0.44***
	(0.14)	(0.73)	(0.12)
ΔX_{t-5}^k	0.43**	0.77	0.44**
	(0.20)	(0.73)	(0.18)
ΔX_{t-6}^k	0.43***	1.45*	0.51***
	(0.16)	(0.77)	(0.15)
ΔX_{t-7}^k	0.43**	1.31*	0.47**
	(0.20)	(0.77)	(0.19)
ΔX_{t-8}^k	0.53***	1.01	0.54***
	(0.14)	(0.70)	(0.12)
ΔX_{t-9}^k	0.35**	0.45	0.38***
	(0.15)	(0.62)	(0.14)
$\boldsymbol{X_{t-10}^k}$	0.62***	0.19	0.66***
	(0.11)	(0.35)	(0.10)
Constant	0.14	0.14	0.40
	(0.62)	(0.62)	(0.59)
Observations	3,358	3,358	3,358
R-squared	0.94	0.94	0.93

Notes: Columns 1 and 2 are estimated from the same regression model. All Oregon cities and blends are included, see Table A-2. The dependent variable is the rack margin. Standard errors are clustered at the month-year level. * Statistically significant at the 10% level, ** Statistically significant at the 5% level, *** Statistically significant at the 1% level.

Also, like California, pass-through is spatially heterogeneous in Oregon. Table 8 presents long-run estimates from (11) and (12) for Portland and Eugene separately. It shows that pass-through of the RIN, CFP, and combined subsidies is higher in Eugene on average. Although imprecise, the results here suggest a similar pattern to California and the LCFS, complete pass-through of the CFP in the smaller city, on average, relative to the urban center. Meaningful analysis in Oregon is also hindered by data availability and price volatility.

Table 8. Long-Run Pass-Through of Implicit Subsidies in Oregon

	Portland		Eugene	
	(1)	(2)	(3)	(4)
R_t^k	0.61***		0.75***	
	(0.10)		(0.19)	
L_t^k	0.13		1.02*	
	(0.37)		(0.57)	
$R_t^k + L_t^k$		0.65***		0.75***
		(0.10)		(0.19)
Constant	-0.17	0.11	0.65	0.98
	(0.64)	(0.62)	(0.79)	(0.60)
Observations	2,239	2,239	1,119	1,119
R-squared	0.96	0.96	0.82	0.82

Notes: The dependent variable is the rack margin. Standard errors are clustered at the month-year level.
* Statistically significant at the 10% level, ** Statistically significant at the 5% level, *** Significant at the 1% level.

6. Conclusion

This paper implements a framework to estimate pass-through of implicit taxes and subsidies created by the U.S. RFS, California's LCFS, and Oregon's CFP to various diesel prices. In California and Oregon, these implicit taxes and subsidies stack with those of the RFS and the federal tax credit for blending biodiesel. In all three policies, tradeable credits can be sold after biodiesel is blended into the diesel fuel supply. Biodiesel producers generate credits. Blenders are willing to pay the higher price of biodiesel since the associated credits can be sold. Obligated parties under each policy, generally oil refiners and petroleum importers, purchase credits from blenders to demonstrate compliance. For these market-based mechanisms to be efficient, the implicit taxes and subsidies must be passed through the supply chain of finished diesel fuel. This paper provides evidence that implicit RFS and LCFS taxes are fully passed through to downstream entities. The results of this paper present mixed findings in terms of pass-through of the implicit subsidies.

An important contribution of this paper is utilizing institutional details and context to build an understanding of how the stacked costs and incentives from overlapping market-based renewable fuel policies propagate through the supply chain of diesel fuels. This paper focuses on the diesel sector because it is understudied and complex relative to the gasoline sector, due to the intermittent nature of the Blender's Tax Credit (BTC), and relative diversity of feedstocks used in biodiesel, which can impact policy incentive magnitude in the state policies.

Although a similar tax-subsidy scheme is used in the LCFS and CFP as the RFS, pass-through of the policies' taxes and subsidies can't be evaluated in the same way, due to differences in the regulations. Section 4 showed that applying the same framework used in the RFS to the LCFS can lead to the wrong conclusion about tax pass-through. Estimating pass-through of the LCFS tax at the wholesale level, as done for the RFS tax, will fail to capture the fact that, in some cases, the deficit obligation itself is held downstream by the blender. We find that the implicit LCFS tax has been fully passed through to rack diesel prices in California prior to the COVID-19 pandemic. This finding also informs the analysis on LCFS subsidy pass-through for biodiesel, as it suggests that our sample reflects blenders that hold both credits and deficits, creating a net rather than gross subsidy. Not accounting for the downstream deficit obligation will overstate the magnitude of the net subsidy realized by the blender.

Pass-through of the RIN tax on ULSD is found to be complete in all major spot markets on average, except for San Francisco. Pass-through of the RIN subsidy for biodiesel (focusing on SME due to data availability) is complete in the Midwest, and incomplete in the East Coast, West Coast, and Gulf Coast. The findings of incomplete RIN subsidy pass-through in our sample, which includes data from the last six years, over regimes of high and low RIN prices, aren't consistent with rack buyers lacking salience in terms of how the RIN subsidy affects the margins of rack sellers. Additionally, incomplete pass-through of the RIN subsidy in the Gulf Coast differs from previous findings of complete pass-through of RIN subsidies for ethanol (Pouliot et al., 2020).

In California, RIN taxes and LCFS taxes are fully passed through to wholesale prices and rack prices, respectively, except for the RIN tax in the San Francisco spot market. Pass-through of both the RIN subsidy and LCFS subsidy is incomplete in California. We find that 68 percent of the combined subsidy is passed through to rack prices in California in the long-run on average. Blenders passed through less of the RIN and LCFS subsidies when selling blends with higher biodiesel content by volume, which is consistent with blenders having market power in higher blends. We can rule out lack of salience as the cause of incomplete pass-through of both subsidies in California because that would require that all costs be passed through at the same rate (Pouliot et al., 2020), which is inconsistent with results from the unrestricted models shown in Figure A-3.

CFP tax pass-through is not studied here due to lack of data. Spot prices for diesel are especially volatile in the Pacific Northwest, creating significant noise in Oregon rack margins. At the same time, CFP credit prices, and therefore biodiesel subsidies, lack variation, resulting in imprecise estimates of subsidy pass-through. On average, however, the full value of the subsidy wasn't passed through to rack prices.

Together, the results presented in this paper point to some inefficiencies in the RFS, LCFS, and CFP. Our results suggest that blenders may have captured rents from RIN and LCFS credit subsidies by not lowering the price of blended fuel by the full amount of the subsidy when selling to downstream buyers. Explanations for their ability to capture rents from LCFS credits are unclear and requires further research and better data. However, some explanations are ruled out, such as buyers not fully understanding how the subsidies affect the margins of rack sellers.

This study was bounded by significant data limitations, especially in California and Oregon. Our sample of rack prices purchased from OPIS had no associated volumes, meaning it is unclear to what extent our results can be generalized to the United States or any region considered in this study. Additionally, rack sellers didn't always disclose how LCFS/CFP credits were accounted for in their reported prices. An important limitation of this study was a lack of California- and Oregon-specific spot prices for biodiesel, which meant we were unable to calculate accurate rack margins. Data on the cost of biodiesel in California and Oregon would greatly assist researchers study policy incentive pass-through in the diesel sector. There were also no feedstock-specific biodiesel spot prices in California or Oregon available to us. Feedstock-specific costs would allow for more accurate calculations of implicit subsidies and rack margins, and for estimating pass-through for diesel blended with biodiesel produced from feedstocks with much larger market shares in California and Oregon, such as tallow and used cooking oil.

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Data Summary

Products of Research

Daily pricing data was acquired from the Oil Price Information Service (OPIS) and Bloomberg on rack prices and spot prices of diesel, biodiesel, RINs, and LCFS and CFP credits to calculate daily profit margins for blenders. Specifically, the following were obtained:

(i) RIN prices from the Bloomberg terminal.

(ii) Daily average spot prices of LCFS and CFP credits purchased from the OPIS.

(iii) Daily spot prices for ULSD, jet fuel, and biodiesel (B100) in the major U.S. spot markets purchased from OPIS.

(iv) Supplier-level, daily prices paid for blended diesel fuels at rack terminals purchased from OPIS. Acquired data for six cities: Los Angeles, CA; San Francisco, CA; Bakersfield, CA; Stockton, CA; Portland, OR; Eugene, OR; Wood River, IL; Trenton, NJ; Dallas, TX; St. Louis, MO. Rack prices are differentiated by the blend level and feedstock type. Biodiesel is assigned one of three feedstock types in the OPIS data: soy methyl ester (SME), yellow grease methyl ester (YGME), and a mix of multiple feedstocks (MULT).

Data Format and Content

The data are stored in CSV files on a secure drive. Each file contains a column for the data and separate columns for each price series.

Data Access, Sharing, Reuse, and Redistribution

The data were purchased from Bloomberg and OPIS and cannot be made publicly available.

A. Appendix

Supplemental Figures

Figure A-1. Spot Price of CA LCFS and OR CFP Credits.

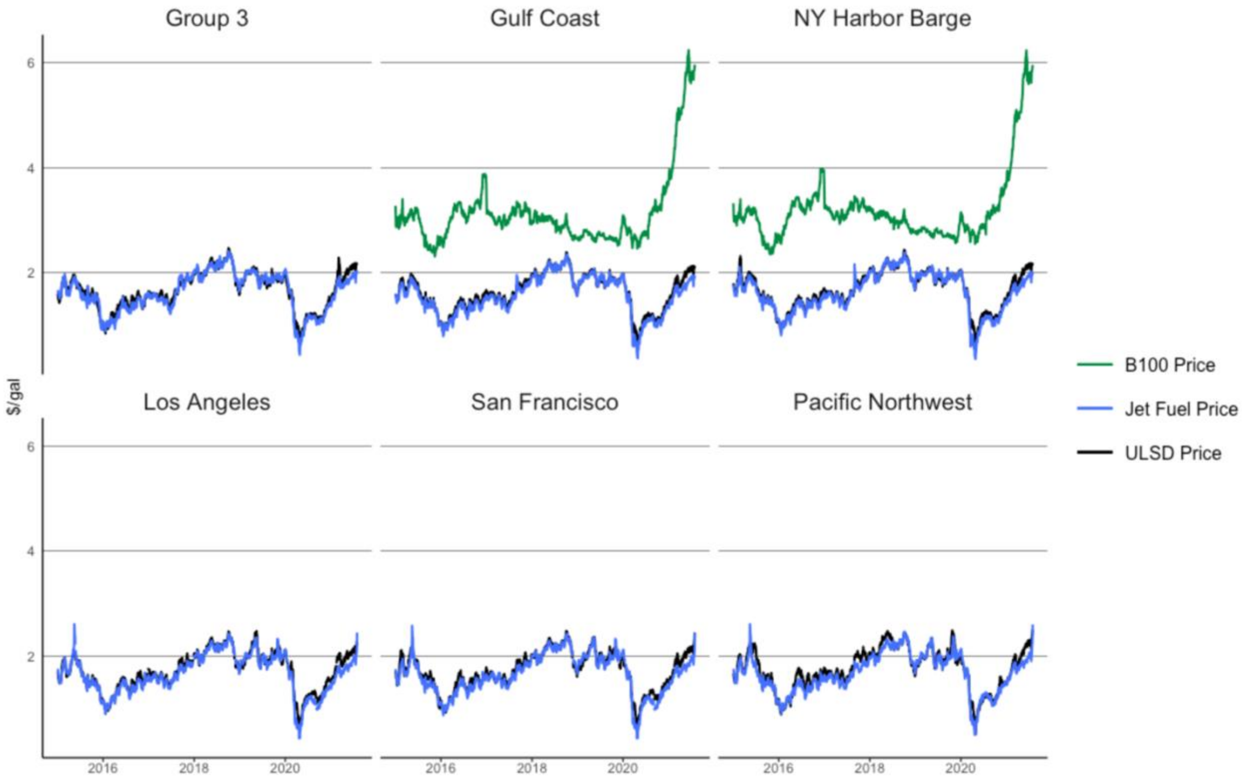

Figure A-2. Spot Prices

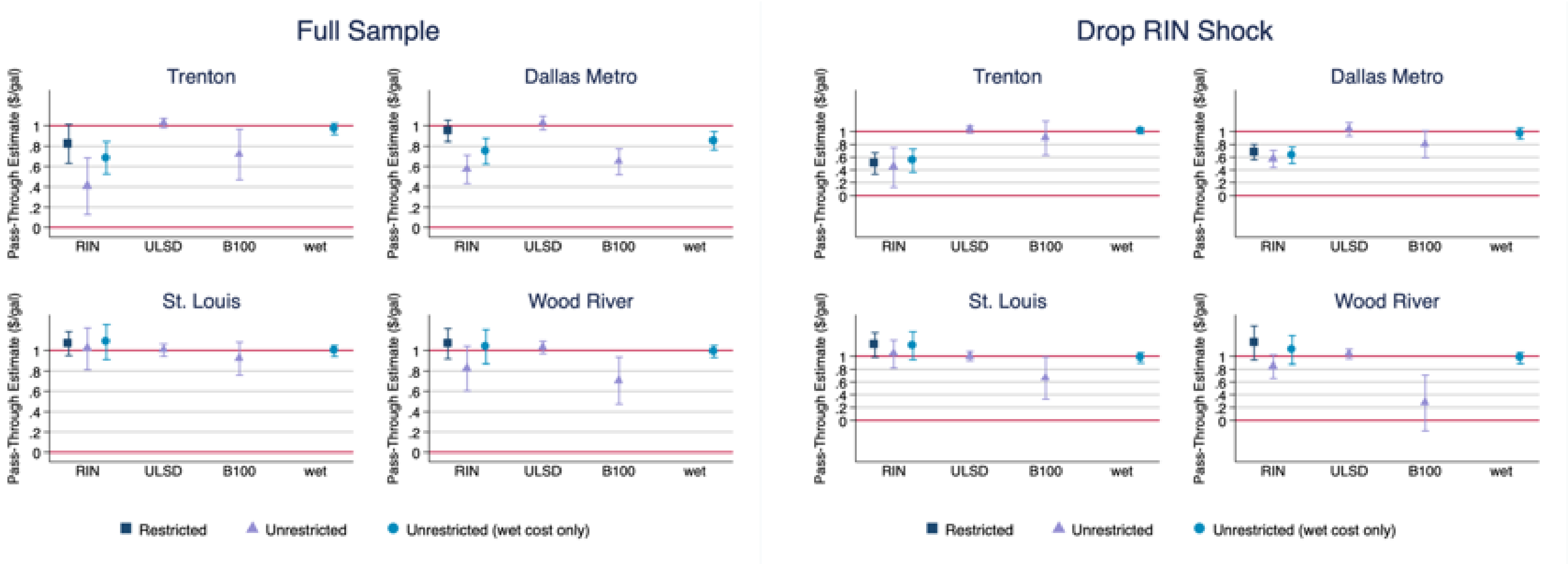

Figure A-3. Input Cost and Subsidy Pass-Through

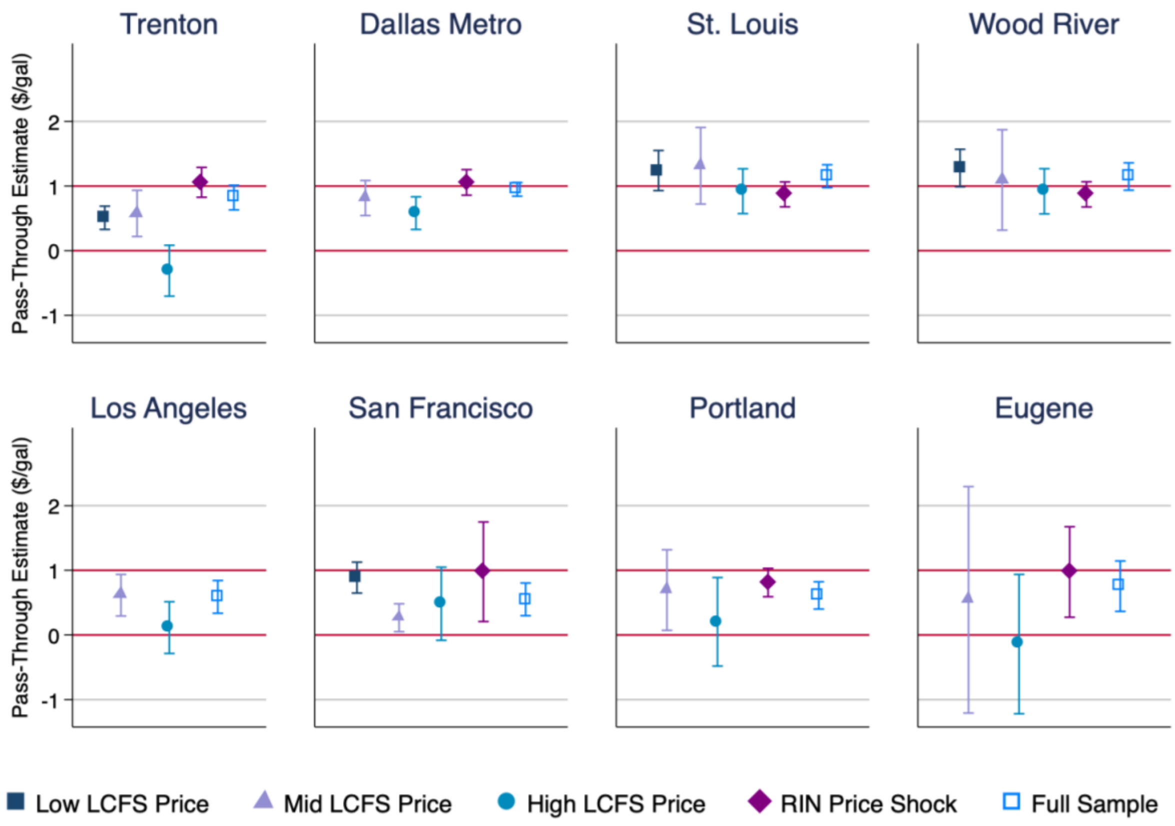

Figure A-4. Long-Run Pass-Through of RIN Subsidies by Subsample and City.

Supplemental Tables

Table A-1. List of Rack Cities and Nearby Spot Markets

Rack City	State	Region	ULSD Spot Market	B100 Spot Market
Trenton	NJ	East Coast	NY Harbor Barge	NY Harbor Barge
Dallas Metro	TX	Gulf	Gulf Coast	Gulf Coast
Wood River	IL	Midwest	Chicago	Chicago
St. Louis	MO	Midwest	Group 3	Chicago
Eugene	OR	Pacific Northwest	Pacific Northwest	NY Harbor Barge
Portland	OR	Pacific Northwest	Pacific Northwest	NY Harbor Barge
Bakersfield	CA	West Coast	Los Angeles	NY Harbor Barge
Los Angeles	CA	West Coast	Los Angeles	NY Harbor Barge
San Francisco	CA	West Coast	San Francisco	NY Harbor Barge
Stockton	CA	West Coast	San Francisco	NY Harbor Barge

Table A-2. Rack Suppliers and Available Blends

		Available Blends	
Rack City	**# of Suppliers**	**Unbranded**	**Branded**
Trenton	4	B2, B5, B10, B20, B99	B2, B5, B10, B20, B99
Dallas Metro	15	B5, B20, B99	B5
Wood River	4	B2, B5, B20, B50	B5
St. Louis	3	B2, B5, B11, B20, B50	B5
Eugene	13	B5, B20	B5
Portland	15	B5, B10, B20, B50	B5
Bakersfield	3	B20	B20
Los Angeles	5	B100	N/A
San Francisco	7	B1, B5, B20, B50, B100	N/A
Stockton	8	B5, B10, B20, B100	B100

Table A-3. RIN Tax Pass-Through Dynamics

	Full Sample			Drop RIN Shock (6/20-7/21)		
	CA (1)	PNW (2)	ROUS (3)	CA (4)	PNW (5)	ROUS (6)
ΔR_t^u	0.80*	-1.11*	1.44***	-0.02	-0.66	1.09**
	(0.46)	(0.66)	(0.36)	(0.52)	(1.04)	(0.44)
ΔR_{t-1}^u	0.90**	-0.83	1.32***	0.04	-0.94	1.05***
	(0.36)	(0.52)	(0.28)	(0.46)	(0.91)	(0.35)
ΔR_{t-2}^u	0.70*	-1.15	1.22***	-0.21	-1.64	0.89***
	(0.40)	(0.69)	(0.25)	(0.45)	(1.07)	(0.32)
ΔR_{t-3}^u	0.69*	-1.50**	1.04***	-0.40	-2.06*	0.54
	(0.39)	(0.73)	(0.24)	(0.43)	(1.06)	(0.34)
ΔR_{t-4}^u	0.68	-1.45**	1.03***	-0.42	-2.09**	0.51
	(0.45)	(0.70)	(0.25)	(0.53)	(0.85)	(0.39)
ΔR_{t-5}^u	0.73	-1.36*	1.08***	-0.48	-2.24**	0.60*
	(0.50)	(0.68)	(0.22)	(0.56)	(1.00)	(0.33)
ΔR_{t-6}^u	0.86*	-1.44**	1.10***	-0.34	-2.30**	0.46
	(0.48)	(0.65)	(0.25)	(0.59)	(1.03)	(0.39)
ΔR_{t-7}^u	0.65	-1.16*	1.01***	-0.57	-2.26**	0.38
	(0.45)	(0.65)	(0.26)	(0.62)	(0.96)	(0.48)
ΔR_{t-8}^u	0.76	-1.19	0.88***	-0.67	-2.53**	0.29
	(0.55)	(0.76)	(0.27)	(0.69)	(1.00)	(0.47)
ΔR_{t-9}^u	0.95*	-1.59**	0.96***	-0.35	-2.44***	0.41
	(0.57)	(0.68)	(0.25)	(0.66)	(0.89)	(0.38)
$\boldsymbol{R_{t-10}^u}$	**1.23*** **	**1.35*** **	**1.12*** **	**0.72*** **	**1.65*** **	**0.94*** **
	(0.11)	**(0.16)**	**(0.07)**	**(0.17)**	**(0.28)**	**(0.12)**
Constant	-0.02**	-0.01	-0.04***	-0.01	-0.02	-0.03***
	(0.01)	(0.01)	(0.01)	(0.01)	(0.02)	(0.01)
Observations	3,260	1,630	4,890	2,674	1,337	4,011
R-squared	0.42	0.39	0.59	0.32	0.39	0.48

Notes: The dependent variable is the ULSD-Jet wholesale spread. Standard errors are clustered at the month-year level. * Statistically significant at the 10% level, ** Statistically significant at the 5% level, *** Significant at the 1% level.