Fuel Subsidy Pass-Through and Market Structure: Evidence from the Renewable Fuel Standard

Gabriel E. Lade* and James Bushnell†

*Corresponding author: gelade@iastate.edu

†Gabriel E. Lade is an assistant professor in the Department of Economics and the Center for Agricultural and Rural Development at Iowa State University. James Bushnell is a professor in the Department Economics at the University of California, Davis and a Research Associate of the National Bureau of Economic Research. We gratefully acknowledge financial support for this research from USDA NIFA Hatch Project Number IOW-03909, the Biobased Industry Center at Iowa State University, the Chevron Energy Fellowship at the Institute of Transportation Studies, University of California, Davis, NSF EPSCoR Seed Funding, and Resources for the Future's Regulatory Policy Initiative. We thank James Stock, Aaron Smith, Bruce Babcock, Ivan Rudik, Ben Meiselman, Kathy Segerson, Derek Wolfson, two anonymous referees, and seminar participants at UC Davis, University of Minnesota APEC, the 2016 AERE Summer Conference, and the 2017 TE3 Conference for valuable comments. Erix Ruiz Mondaca provided excellent research assistance. All errors are our own.

Abstract

The Renewable Fuel Standard (RFS) is among the largest renewable energy mandates in the world. The policy is enforced using tradeable credits that implicitly subsidize biofuels and tax fossil fuels. The RFS relies on these taxes and subsidies to be passed through to consumers to stimulate demand for biofuels and decrease demand for gasoline and diesel. We study pass-through of the RFS subsidy for E85, a high-ethanol blend fuel, to retail fuel prices using weekly prices from over 450 fuel stations in the U.S. We find that, on average, half to three-quarters of the E85 subsidy is passed-through to consumers. However, pass-through takes six to eight weeks, and station-level pass-through rates exhibit substantial heterogeneity, with the retailers' market structure influencing both the speed and level of pass-through.

JEL Codes: Q42, Q58, H23

Keywords: retail fuel markets, E85, renewable fuel standard, subsidy pass-through

1 Introduction

Cost pass-through and related studies of tax incidence have gained renewed interest among policymakers and economists with the increasing prevalence of environmental and energy policies that regulate upstream firms. The policies leverage the microeconomic principle that when markets are competitive, economic and statutory incidence are independent. This insight allows policymakers to specify a handful of firms as obligated parties rather than regulate thousands of downstream producers or millions of consumers. In the context of climate change policies, many current and proposed regulations explicitly or implicitly tax upstream fossil fuel emissions and subsidize renewable energy production. Despite the success of these policies critically relying on pass-through of these costs and subsidies to downstream users, rigorous empirical studies of their downstream impacts have just recently emerged.

This paper studies pass-through of tradeable compliance credits prices under the U.S. Renewable Fuel Standard (RFS) to retail prices of a high-ethanol blend fuel, E85. The RFS is a long-standing program that seeks to transform the transportation fuel sector. The policy was passed in its current form in 2007 and aims to displace a substantial portion of the U.S. fuel supply with biofuels by 2022. The program is administered using a tradeable credit system whereby upstream biofuel producers generate credits (known as RINs) in proportion to their biofuel production. RINs must either be produced or purchased by obligated parties, oil refiners and fuel importers, to meet their compliance obligations. Thus, a binding mandate subsidizes biofuels and taxes gasoline and diesel in proportion to RIN prices.

Regulated parties met their compliance obligations in the early years of the RFS with relative ease. However, meeting current and future targets is costly due to the saturation of ethanol in conventional fuel blends. Since 2013, regulated parties have relied on increased sales of high-blend fuels like E85 to meet the RFS mandates. These fuels typically require both adapted vehicles and dedicated distribution networks. Thus, the policy must stimulate demand for fuels like E85 by making them sufficiently price competitive to overcome the network barriers currently inhibiting their adoption (Pouliot and Babcock, 2014). Put simply, for the RFS to work as intended, the subsidy value reflected in RINS needs to lower E85 prices sufficiently to spur widespread adoption of the fuel.

When markets are competitive, pass-through depends on relative supply and demand elasticities (Jenkin, 1872). Both the incidence as well as the statutory and economic independence of taxes and subsidies change if markets are imperfectly competitive (Buchanan, 1969; Weyl and Fabinger, 2013). Imperfect competition may be a concern in our setting. For the RIN taxes and subsidy to impact retail prices, they must be passed through from oil refiners and biofuel producers to regional blending terminals, and finally to retail fuel stations. Each of these layers of the fuel supply chain has been the subject of both academic and regulatory inquiries for anti-competitive behavior (Borenstein and Shepard, 2002; Borenstein et al., 2004; Hastings, 2004).

In this paper, we take advantage of policy-induced variation in historical RIN prices and fluctuations in energy prices to estimate pass-through of the E85 subsidy and wholesale fuel costs to retail E85 prices using data from over 450 fueling stations in Iowa, Illinois, and Minnesota between 2013 and 2016. The paper has three main findings. First, on average half to three-quarters of the E85 subsidy is passed through to retail fuel prices, while wholesale fuel costs are fully passed-through. However, pass-through has increased over time, and we cannot reject the hypothesis that pass-through is, on average, complete since 2015. Second, subsidy pass-through takes six to eight weeks, while wholesale cost pass-through occurs more quickly. Third, we find substantial heterogeneity in pass-through rates across stations. Branded stations and stations in more isolated E85 markets have lower and slower subsidy pass-through, even after controlling for fixed characteristics of the stations.

The first finding is important because other work using aggregate price data and a more limited geographic sample finds low RIN pass-through to E85 prices (Knittel et al., 2017; Li and Stock, 2017). Critics of the RFS point to low RIN pass-through as a significant

[1] Valero, a large oil refiner and ethanol producer, along with other refining companies petitioned the Environmental Protection Agency to move the obligated parties under the RFS to wholesale fuel terminal owners. While the petition was primarily motivated by concerns that RIN costs were not fully passed-through to wholesale gasoline prices (Krauss, 2016), the company also argued that refiners should not be obligated parties as they are unable to "affect the amount of renewable fuels blended and sold to consumers" (Voegele, 2016). The company cites that among the most significant barriers to increasing renewable fuels is limited RIN pass-through.

policy failure.[1] The Environmental Protection Agency (EPA) – the enforcing agency – also cites incomplete pass-through as a key barrier to expanding ethanol use in the United States (Environmental Protection Agency, 2016). If RIN pass-through is low, future compliance costs will be higher than currently anticipated, sales of large volumes of E85 may be infeasible, and previous estimates of the distributional impacts of the policy would be misstated. Our work suggests that, in markets with sufficient retail E85 competition, the market mechanism underlying the RFS operates largely as intended, particularly since 2015. However, spurring demand for E85 through the RIN mechanism may be more costly in less contested markets as a portion of the RIN subsidy is likely captured by parties upstream of consumers.

Our second and third findings are broadly consistent with previous literature. Delayed cost pass-through is a common finding in retail fuel markets. Previous work has found that complete pass-through of upstream oil and wholesale costs takes four to six weeks, a similar time profile to our findings (Borenstein et al., 1997; Lewis and Noel, 2011; Lewis, 2011). We also document significant heterogeneity in pass-through rates across stations, consistent with some stations exercising market power. In particular, we find that stations that are far from competitors that offer E85 exhibit slower and 10% to 20% lower subsidy pass-through than stations in more contested markets. In addition, stations affiliated with large, vertically integrated refiners have lower subsidy pass-through than unbranded stations, while major gasoline retailers have higher subsidy pass-through rates.

Our work contributes first to the literature studying market impacts of the RFS. Previous work has estimated demand for E85 and the role of government in increasing demand for alternative fuels, as well as alternative fuel vehicles and fueling infrastructure (Corts, 2010; Anderson, 2012; Langer and McRae, 2014; Liu and Greene, 2015; Pouliot and Babcock, 2017). More recent empirical work has studied RIN cost drivers, and the impact of RIN prices on refiners' markups and profitability (Lade et al., 2016; Burkhardt, 2016). Knittel et al. (2017), building on Burkholder (2015), study RIN pass-through to bulk wholesale and retail prices. The authors find that while the RIN gasoline and diesel tax are fully and immediately passed through to bulk wholesale prices, little of the RIN subsidy is passed through to retail E85 prices. Our paper is also closely related to work by Li and Stock (2017). The authors study

RIN pass-through to retail E85 prices using monthly, station level data from Minnesota. The authors find 35% RIN subsidy pass-through, on average, with higher pass-through rates at stations in more contested markets. Our study is both distinct from and complements this work. While our data include fewer stations in Minnesota, our broader geographic coverage allows us to confirm that E85 subsidy pass-through is systematically higher in more contested markets in two additional states. We also have access to weekly, compared to monthly, data. The higher-frequency allows us to trace the responsiveness of retail E85 prices to changes in upstream costs over time. Methodologically, we highlight the importance of allowing for differential dynamic retail price adjustment to upstream wholesale and RIN cost shocks. We also complement work by Pouliot et al. (2017). The authors study RIN pass-through at wholesale fuel terminals. While we are unable to definitively disentangle the source of low pass-through in our study, our finding that pass-through is high in contested markets implies that RIN pass-through at wholesale terminals is also high in these markets. Consistent with this, Pouliot et al. (2017) find that RIN pass-through to wholesale E85 is largely complete in the Midwest.

Last, our work contributes to a large literature studying cost pass-through in energy-intensive industries. Previous work has studied whether supply conditions affect fuel tax incidence (Muehlegger and Marion, 2011) and the distributional impacts of taxes and their interaction with local market structure (Alm et al., 2009; Stolper, 2017). Less work has examined the impact of compliance credit costs on energy prices. Exceptions include Fabra and Reguant (2014) and Hintermann (2016), who study allowance cost pass-through to wholesale electricity prices under the European Union's Emissions Trading System (EU-ETS). Others have used historical variation in upstream energy costs, taking advantage of cross-sectional and temporal variation in the competitiveness of industries to study the relationship between cost pass-through and market structure in energy-intensive industries (Ganapati et al., 2016; Bushnell and Humber, 2017; Miller et al., 2017). While these studies are useful in understanding potential impacts of a carbon tax, they likely cannot explain the full downstream effects of cap and trade programs, intensity standards, and fuel mandates due to the historical volatility of compliance credit prices. Compliance credit markets are impacted by political, regulatory, and economic uncertainty, and these sources have important impacts on compliance credit prices.[2] We show that short-run dynamics are important. An increase in the E85 subsidy is not fully reflected in retail prices for six to eight weeks.

The paper proceeds as follows. Section 2 provides a background on the Renewable Fuel Standard. We describe key policy developments since 2013, their impacts on RIN markets, and their corresponding impact on the value of the E85 subsidy. The section also describes the data used in our analysis. Section 3 describes our empirical strategy and presents our results. We also explore the impacts of market structure on pass-through, study the evolution of pass-through over time, compare our results to those of similar studies, and discuss extensions and the robustness of our results. We conclude in Section 4 with a discussion of our findings, limitations of the current analysis, and directions for future research.

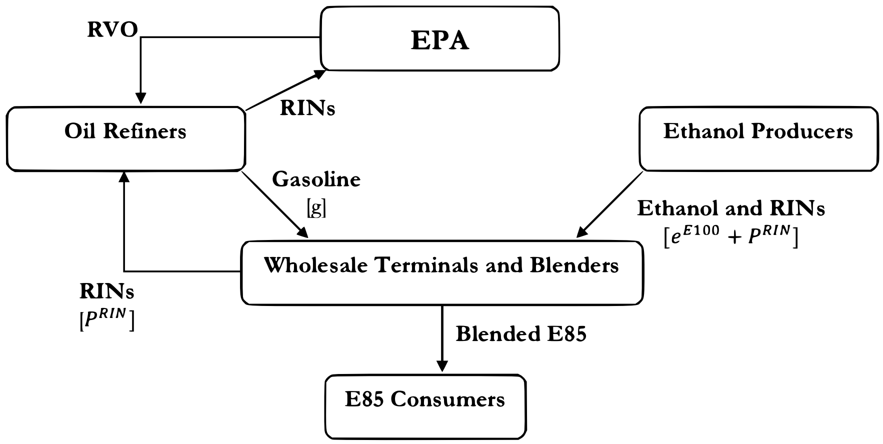
2 Policy Background and Data Sources

The Renewable Fuel Standard was established by the Energy Policy Act of 2005, which set modest biofuel blending mandates. Congress significantly expanded the program in 2007 with the Energy Independence and Security Act (EISA), both increasing the original mandates and establishing sub-mandates for advanced biofuels, biomass-based diesel, and

[2]Examples of compliance credit volatility due to political and regulatory events include: a sharp run-up and subsequent collapse in SO_2 allowance prices following the passage and eventual vacation of new standards for the pollutant (Hitaj and Stocking, 2016); the fall of EU-ETS allowance prices after regulated parties discovered that permits were over-allocated in the first phase of the program (Hintermann, 2010; Bushnell et al., 2013); the fall of tradeable credit prices for California's Low Carbon Fuel Standard after a court decision to delay implementation of the regulation (Yeh et al., 2016); and volatility in the RFS RINs market following the EPAs decision to relax the mandates on several occasions (Lade et al., 2016).

[3]Biofuels are 'advanced' if their life-cycle greenhouse gas emissions are at least 50% below a threshold set by the EPA. The biomass-based diesel and cellulosic ethanol mandates are nested within the advanced biofuel mandate, and the advanced biofuel mandate is nested within the total biofuel mandate. Thus, every gallon of qualifying cellulosic or biomass-based diesel fuel counts towards its own mandate, the advanced biofuel mandate, and the total biofuel mandate. Other advanced biofuels, primarily Brazilian sugarcane ethanol, count towards the advanced biofuel mandate and the total biofuel mandate. Non-advanced biofuels, mainly corn ethanol, count only towards the total biofuel mandate.

Figure 1: E85 Market and RIN Payments



cellulosic ethanol.[3] While EISA specifies volumetric blending targets, the EPA enforces the law by setting fractional standards for each biofuel category. Each year, the EPA divides the volumetric mandates by projected U.S. gasoline and diesel sales from the Energy Information Administration. Regulated parties determine their compliance obligations by multiplying their gasoline and diesel sales by the fractional standards.

The RFS is enforced using tradeable compliance credits (RINs). Figure 1 presents a stylized depiction of the market for gasoline, ethanol, and E85 in the U.S. and illustrates the operation of RIN markets. Upstream firms produce gasoline and ethanol at cost g and e^{E100}, respectively. They sell the fuels to regional terminals where they are blended into E85 and sold to retail stations. Under the RFS, every gallon of qualifying biofuel also generates a RIN with value P^{RIN}.[4] RINs are separated and sold after ethanol has been blended for final consumption by fuel terminals. To comply with the RFS, oil refiners must either blend biofuels or purchase RINs in proportion to their gasoline and diesel sales. At the end of each compliance period, refiners must turn into the EPA RINS equivalent to their prorated

[4]While not depicted here for simplicity, RINs are differentiated by biofuel type to enforce each sub-mandate. The RINs categories are (i) D6 RINs, generated mainly by corn ethanol; (ii) D5 RINs, generated by advanced biofuels; and (iii) D4 RINs, generated by biomass-based diesel. Firms also generate D3 RINs by producing cellulosic ethanol. Because little cellulosic ethanol has been produced to date, the D3 RIN market is illiquid and therefore is not considered in this paper.

[5]For example, suppose the EPA sets a 10% total biofuel mandate with a 2% sub-mandate for advanced biofuel. For every one hundred gallons of gasoline and diesel sales, refiners must purchase ten RINs, of which at least two RINs must be D5 or D4 RINs. The remaining eight RINs are allowed to be D6 RINs.

portion of the mandate, known as their renewable volume obligation (RVO).[5] Thus, the policy subsidizes biofuels and taxes gasoline and diesel (Lapan and Moschini, 2012).

Due to technical and regulatory restrictions, fuel providers cannot blend ethanol into gasoline in continuous intervals. The most common ethanol-gasoline blends are E10 (10% ethanol-gasoline blend) and E85 (51%-83% ethanol-gasoline blend).[6] Before 2013 the fuel industry was able to comply with the RFS by switching gasoline sold in most markets from E0 (pure gasoline) to E10. By 2013, little E0 was sold in the U.S. (Energy Information Agency, 2016). In 2014, the EISA mandates began to require greater volumes of ethanol than could be consumed with a national E10 blend. This barrier, referred to as the 'blend wall,' leaves the industry with two main compliance options. First, the industry can increase E85 sales. Second, the industry can increase biomass-based diesel sales, which faces less restrictive blending constraints. Both options are costly and require high RIN prices. The latter is expensive due to high feedstock and production costs, while the former requires E85 prices to be low relative to E10 prices to spur its demand, increase investments in FFVs, and increase the number of stations offering the fuel (Babcock and Pouliot, 2017).

2.1 2014-2016 RFS Mandates and RIN Markets

Before 2013, RINs traded below $0.10/gal, reflecting the fuel industry's ability to easily comply with the mandates by phasing in E10 across the country. Low RIN prices and mandate volumes ensured compliance obligations represented a small cost to refiners. This changed in early 2013 as it became apparent that the mandates would exceed the blend wall. RIN prices rose rapidly, and industry pressure rose in tandem as RFS compliance costs increased. The EPA responded to concerns of potentially harmful impacts of high RIN prices in its 2013 final rule, stating that it would likely set the 2014 mandates below statutory levels. The announcement caused RIN prices to collapse. A subsequent Reuters

[6]The EPA also allows E15 sales (10.5% to 15% ethanol-gasoline blend). However, E15 is only approved for use in vehicles produced after 2001, and cannot be sold in the summertime in many states due to Reid Vapor Pressure requirements. As such, E15 sales constituted less than 0.5% of all fuel sales in 2015 and 2016 (Energy Information Agency, 2016).

article revealed that the proposed 2014 levels would not only be below statutory levels but below 2013 levels. This caused RIN prices to fall further. The subsequently proposed rule was released in November 2013, at which point RIN markets bottomed out.[7]

The 2014 proposed rule set off a prolonged period of stakeholder feedback and regulatory delay. EPA did not release a final rule until May 2015, when it issued a joint proposal for 2014, 2015, and 2016. In the rule, the EPA increased the mandates relative to the 2013 proposed rule; however, the levels remained lower than the industry expected as evidenced by the sharp decrease in RIN prices following its release (Irwin and Good, 2015). Subsequently, in November 2015 the EPA finalized the 2014, 2015, and 2016 mandates, increasing the total biofuel requirements slightly from the levels proposed in May 2015. The increases were meaningful, placing the mandates above the blend wall. RIN prices responded and increased rapidly. In May 2016, the EPA released its proposed rule for 2017, further increasing the mandates beyond the blend wall. This again caused RIN prices to rise rapidly, and prices continued to climb until the end of our observation period in June 2016.

2.2 RIN Prices and the E85 Subsidy

We construct our measure of the E85 subsidy, defined as the value of the separated RIN from wholesale ethanol upon blending, using RIN prices reported by the Oil Price Information Service (OPIS). We assume that every blended gallon of ethanol generates a D6 RIN, i.e., is corn ethanol.[8] For ease of exposition, we write the subsidy as a negative tax such that:

$$\tau^{E100} = -P_{D6}.$$

Despite its name, E85 seldom contains as much as 85% ethanol. E85 contains between 51% and 83% ethanol by volume, and blending rates vary geographically and by season (Energy Information Agency, 2016). We use season- and state-specific blend rates published

[7]See Lade et al. (2016) for a more detailed account of the EPA announcements over this period and their impacts on RIN prices, commodity markets, and stock prices of publicly traded biofuels firms.

[8]The value does not change substantively if we assume a portion of ethanol is advanced since D5 and D6 RIN prices were close to one another over our sample period.

by ASTM International, an organization that sets fuel quality specifications in the U.S.[9] Letting B_j^{E85} denote ethanol's E85 blend rate in season j, our measure of the E85 RIN subsidy is:

$$\tau^{E85} = B_j^{E85}\tau^{E100}. \tag{1}$$

For example, if the RIN price is $1.00 and the ethanol blend rate is 75%, the RIN subsidy is $0.75/gal.[10]

2.3 Retail E85 and Wholesale Price Data

Publicly available retail E85 price data are sparse. Knittel et al. (2017) use a national average retail E85 price reported by AAA. The Department of Energy's (DOE) Alternative Fuels Data Center (AFDC) publishes regional average E85 prices through its Clean Cities Alternative Fuel Price Report; however, the reports are only published three to four times per year. Other crowd-sourced websites such as E85Prices.com report price data; however, station-level time series are difficult to construct, the quality of the data are difficult to verify, and coverage of stations in many states is limited (Jessen, 2015).

We purchased daily, station-level E85 prices from Iowa, Illinois, and Minnesota from OPIS for January 2013 through June 2016.[11] Figure 2 maps the location of stations included in our analysis in orange diamonds and green circles along with the locations of all other stations reported as selling E85 by the AFDC in hollow diamonds. While OPIS has relatively extensive regular, mid-grade, and premium coverage, its E85 price reporting is less reliable, particularly in markets where the fuel is new. We chose the three states because E85 price

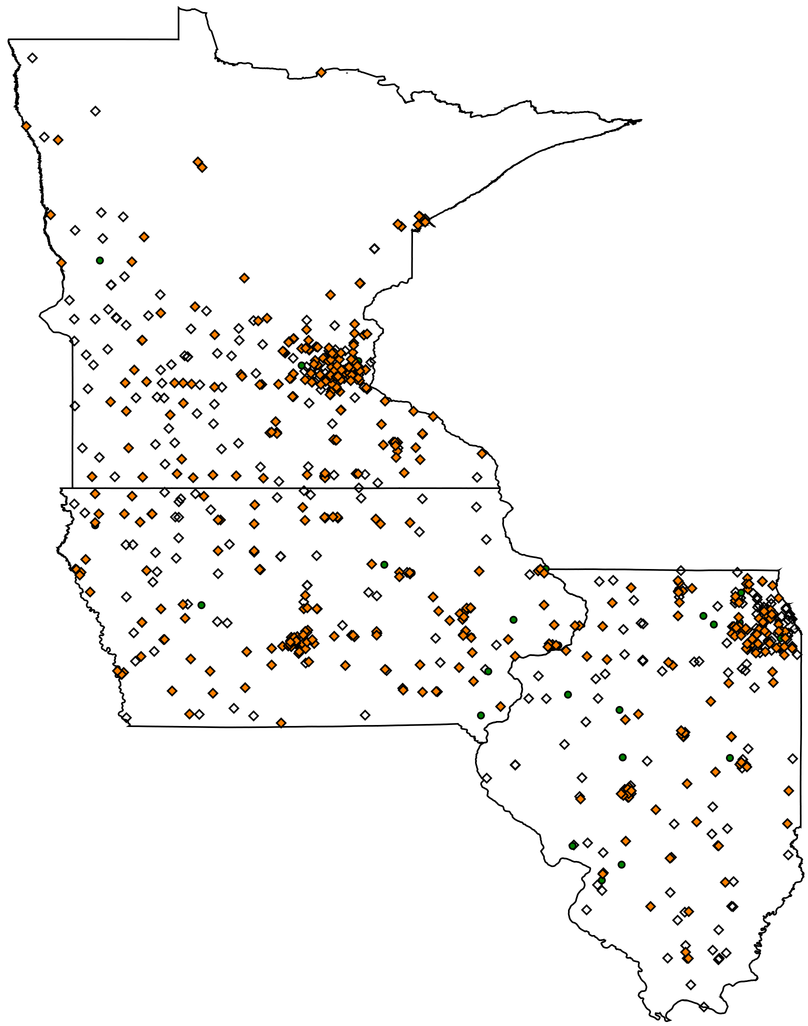
[9]ASTM ethanol content requirements for Summer, Spring/Fall, and Winter blends for Iowa, Minnesota, and Illinois are largely uniform. Summer blends must contain a minimum of 79% ethanol, Spring and Fall blends 74%, and winter blends 70%. See Alleman (2011) for a more detailed discussion of E85 blending in the U.S., and evidence that actual blending follows relatively close to ASTM standards.

[10]We tested the sensitivity of our results using two other specifications for B_j^{E85}. First, we assumed that all E85 contains 74% ethanol as in Knittel et al. (2017). Second, we use average blend rates reported by Iowa Renewable Fuel Association. Results do not change appreciably to either robustness check.

[11]OPIS records gasoline prices from over 140,000 stations in the U.S. OPIS records prices through fleet credit card transactions, direct feeds from stations, and phone surveys.

coverage is most reliable in the Midwest.

Figure 2: E85 Stations in Iowa, Illinois, and Minnesota



Notes: The figure graphs the location of all E85 stations reported by DOE's AFDC and OPIS from 2013-2016. Black hollow diamonds are stations in the AFDC data only; orange diamonds are stations in both the OPIS and AFDC databases; and green circles are stations in the OPIS but not the AFDC database.

The data have several limitations. First, many stations report prices infrequently. As such, we collapse the data to average weekly prices, where stations have fewer reporting gaps. Second, OPIS reports prices for only a subset of E85 stations. The DOE claims to

[12]As of July 2016, AFDC reported that 2,797 stations offered E85, of which 735 (over 25%) were in Iowa, Illinois, or Minnesota.

maintain a comprehensive list of alternative fueling stations through its Alternative Fuels Data Center.[12] After restricting our sample to stations that report prices for more than 16 weeks, our data contain 451 stations, just over half of the E85 stations that the AFDC reports are in the region.[13,14] Third, stations that report prices to OPIS may be different from those that do not. While we have relatively broad coverage in metropolitan areas (Minneapolis, Des Moines, and Chicago), our coverage in rural areas is more sparse.[15]

We merge the retail price data with state-average, weekly wholesale ethanol and gasoline prices, also purchased from OPIS. OPIS records wholesale prices from all major wholesale fuel distributors in the U.S. Discussions with industry groups and a major terminal operator in the Midwest revealed that most E85 is splash blended at terminals. That is, instead of purchasing E85 from wholesale terminals, fuel tanker trucks buy pure ethanol and sub-octane gasoline and blend them in their trucks before distributing the fuel to retail stations.[16] As such, we use the OPIS series for 'pure ethanol with RIN' and 'conventional sub-octane regular gasoline' to construct our state average wholesale E85 costs as:

$$\bar{e}^{E85}_{s,t} = B^{E85}_j \bar{e}^{E100}_{s,t} + (1 - B^{E85}_j)\bar{g}_{s,t},$$

[13]In our final sample, stations report prices on average for 94 weeks, and 68 stations report prices for more than 130 weeks.

[14]Some industry groups have raised concerns over DOE's coverage of E85 stations (Jessen, 2015). In our data, 36 of our 451 stations do not appear in the AFDC database. Incomplete coverage is important as we use the AFDC and OPIS station list to construct our measures of E85 station density. To our knowledge, the OPIS and AFDC datasets represent the most complete list of E85 stations available.

[15]We test the sensitivity of our results in Appendix B to using different subsets of the data, ensuring that differential rural-urban pricing strategies do not drive our results. Nonetheless, the selection remains a concern in interpreting our results.

[16]'Sub-octane' gasoline refers to the octane rating being below the limit required for use in vehicles. Because ethanol has a high octane level, many refiners now produce 84 octane gasoline. After the fuel is blended as E10 or higher, the blended fuel meets octane standards for vehicles (mostly 87 octane).

[17]Figure 1 over-simplifies several aspects of E85 markets. Not all E85 sales occur through wholesale terminals. Some ethanol plants purchase gasoline and blend E85 for direct sale to retailers. This, along with using state-average wholesale prices, induces measurement error in our wholesale prices. Our E85 subsidy may also be measured with error if OPIS RIN prices do not reflect the value fuel individual providers and blenders receive for RINs. While we do not explicitly account for this in our main empirical results, we use an instrumental variables strategy that would correct for classical measurement error in Appendix B.

where $\bar{e}^{E100}_{s,t}$ is the state-average pure ethanol price for state s in week t, $\bar{g}_{s,t}$ is the state-average sub-octane gasoline price, and B^{E85}_{j} is the ASTM E85 blending standard.[17]

We use two measures of retail markets structure. First, we study whether pass-through varies by stations' ownership type, testing whether stations affiliated with vertically integrated oil companies (branded majors) or major independent retail chains (major retailers) exhibit differential pass-through. These ownership measures are commonly used in the literature studying retail gasoline market power (Hastings, 2004; Stolper, 2017). The literature on retail gasoline competition also finds that stations compete in highly localized markets (Houde, 2012; Langer and McRae, 2014). To capture this, our second measure of market structure is the distance to the nearest competitor station offering E85.

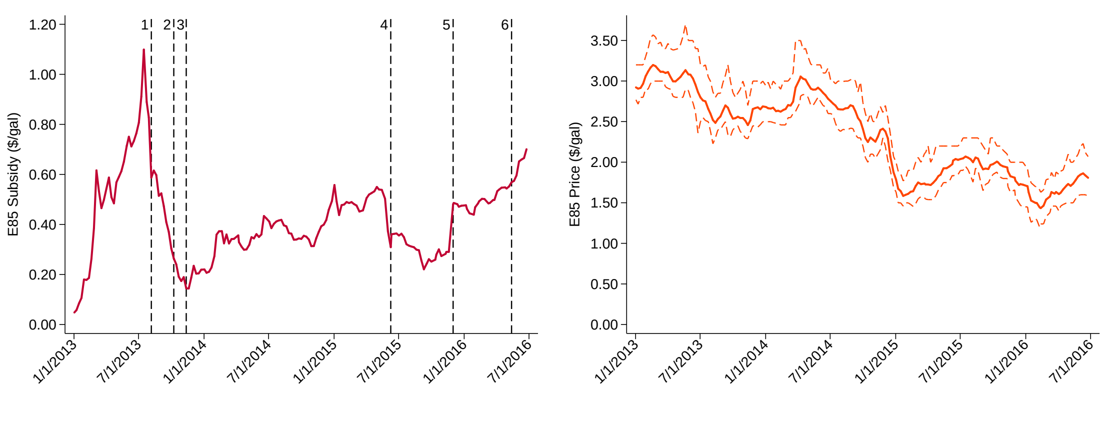
Table 1 and Figure 3 summarize our data. On average, E85 prices were \$2.21/gal. E85 prices exhibit substantial spatial and temporal variation, ranging from \$1.08/gal to \$4.17/gal. Prices at branded major stations, representing a quarter of our sample, are \$0.12/gal higher on average than at other stations. Almost 60% of our sample are from major retail stations, who have lower than average E85 prices. We also observe a broad range of distances to stations' nearest competitor. Stations are on average less than 7 miles away from a competitor, but the distance varies from 0.02 miles to over 100 miles.[18] Prices are somewhat higher at stations >10 miles from a competitor. The average E85 subsidy was \$0.44/gal, but ranged from \$0.05 to \$1.10/gal. This highlights a key difference between our setting and fuel tax pass-through studies. Tax changes occur infrequently and are typically small and discrete. In contrast, the E85 subsidy exhibits substantial volatility, especially around key policy developments.

[18]Only one station located in north central Minnesota is 100 miles from its nearest competitor. The next furthest distance is 35 miles. All results are similar if we drop the outlier.

Table 1: Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
E85 ($/gal):	2.21	0.56	1.08	4.17	29,938
Branded Major ($/gal)	2.33	0.61	1.2	4.17	6,919
Major Retailer ($/gal)	2.15	0.52	1.08	3.76	17,246
> 10 Miles to Competitor ($/gal)	2.25	0.57	1.20	3.70	6,994
E85 Subsidy ($/gal)	-0.44	0.16	-1.10	-0.05	29,938
Wholesale E85 ($/gal)	2.00	0.52	1.25	3.43	29,938
Wholesale Sub-Octane Gasoline ($/gal)	2.08	0.71	0.80	3.64	29,938
Wholesale Ethanol ($/gal)	1.97	0.46	1.40	3.67	29,938
Branded Major (Indicator)	0.23	0.42	0	1	29,938
Major Retailer (Indicator)	0.58	0.49	0	1	29,938
Minimum Distance to Competitor (miles)	6.86	8.68	0.02	103.23	29,938

Figure 3: E85 Subsidy and E85 Prices



(a) E85 Subsidy

(b) Average E85 Prices (IA, IL, MN)

Notes: Figure 3a graphs the E85 subsidy and the timing of key RFS policy developments. The events are: (1) 2013 Final Rule; (2) Leaked 2014 Proposed Rule; (3) 2014 Proposed Rule; (4) 2014-2016 Proposed Rule; (5) 2014-2016 Final Rule; and (6) 2017 Proposed Rule. Figure 3b graphs the mean, 5th percentile, and 95th percentile of the E85 prices in our sample of stations.

3 Pass-Through to Retail E85 Prices

In this section, we discuss our identification strategy (Section 3.1). Given inconclusive results from stationarity and cointegration tests (Appendix A), we use multiple strategies to ensure that our conclusions are not sensitive to whether the series do or do not exhibit a stationary, long-run relationship. Section 3.2 presents our main results, discussing both long-run and short-run pass-through. Section 3.3 tests whether local market structure impacts pass-through, Section 3.4 tests for differential pass-through in the first- versus second-half of our sample, Section 3.5 discusses the robustness of our results, and Section 3.6 seeks to reconcile our findings with other work.

3.1 Empirical Strategy

Our objective is to estimate the long-run relationship and short-run dynamics between retail E85 prices, wholesale costs, and the upstream RIN subsidy for the fuel. We are particularly interested in whether, upon being detached from ethanol at the wholesale terminal, the RIN subsidy value is reflected in retail prices. The simplest model is a linear OLS regression:[19]

$$Y_{it} = \alpha_i + \beta^e[e_{i,t}^{E85}] + \beta^\tau[\tau_t^{E85}] + \epsilon_{it}, \tag{2}$$

where Y_{it} is the retail E85 price at station i in week t; α_i is a station-specific markup; e_{it}^{85} is the station's wholesale E85 cost; $\tau_{E85,t}$ is the E85 subsidy; and β are the pass-through coefficients of interest. Estimating equation (2) is infeasible and potentially undesirable for a number of reasons. First, we do not observe stations' wholesale costs. Instead, we use state-average wholesale prices such that $e_{i,t}^{85} = \bar{e}_{s,t}^{85}$ for all stations i in state s. Equation (2) also imposes restrictions on stations' equilibrium price functions. Second, equation (2) does not allow for lagged adjustment of retail prices to upstream cost shocks. For this, we

[19]The ethanol wholesale price index includes the RIN. Identifying the extent to which the RIN value from ethanol is reflected in retail prices requires having sufficient independent variation in both wholesale E85 costs and the RIN subsidy. Variance inflation factors for wholesale E85 and the RIN subsidy are typically around 5, well below conventional levels that warrant concern.

estimate a cumulative dynamic multiplier (CDM) model, given by:

$$Y_{it} = \alpha_i + \sum_{j=0}^{L-1} \beta_j \Delta \mathbf{X}_{t-j} + \beta_L \mathbf{X}_{t-L} + \gamma_m + \epsilon_{it}. \tag{3}$$

where $\mathbf{X}_t = [\bar{e}^{E85}_{s,t}; \tau^{E85}_t]$ and γ_m are month-of-year fixed effects that account for seasonality in station mark-ups. The coefficients β_j are cumulative pass-through rates from $\mathbf{X}$ to retail fuel prices after $j \in [0, L]$ periods. So long as L is sufficiently large, β_L represent long-run, cumulative pass-through rates.

We also estimate a first-differences CDM model to ensure that our results are not sensitive to whether the variables are non-stationarity. The specification is:

$$\Delta Y_{it} = \alpha + \sum_{j=0}^{L-1} \beta_j \Delta^2 \mathbf{X}_{t-j} + \beta_L \Delta \mathbf{X}_{t-L} + \gamma_m + \epsilon_{it}. \tag{4}$$

As before, the coefficients β_j are cumulative pass-through rates after j periods.

Equations (2)-(4) assume that stations' prices are not a function of other stations' prices. If stations have market power, both the level and speed of pass-through may be affected. We explore this using two strategies. First, we interact $\mathbf{X}_t$ with indicators of stations' ownership structures. Specifically, we interact $\mathbf{X}_t$ with indicators for whether a station is affiliated with a vertically integrated refining company or a large independent gasoline retailer.[20] Stations owned by branded majors often have centralized pricing strategies, and have been the subject of previous market power studies (Borenstein et al., 2004; Hastings, 2004). Major retailers may be of interest because many purchase ethanol and gasoline 'above the rack' (i.e., from refiners) and separate and market RINs themselves. Because of this, several market participants have accused them of realizing 'windfall' profits from RINs.[21]

Second, we interact $\mathbf{X}_t$ with indicators for whether a station is greater than 10 miles from its nearest competitor offering E85. The model is consistent with a Bertrand-Nash

[20] Stations are 'branded majors' if their gasoline brand is BP, Valero, ExxonMobil, Citgo, Marathon, Cenex, Tesoro, or Phillips 66. We observe 118 branded major stations. Stations are 'major retailers' if their store brand is Caseys, Fast Stop, Holiday, Kum and Go, Kwik Trip, Murphy USA, or Speedway. We observe 235 major retail stations.

[21] For example, see the letter from the Small Retailers Coalition to Janet McCabe, the Acting Assistant Administrator of the Office of Air and Radiation at EPA (Bill Douglas, 2016).

equilibrium where stations compete in localized geographic markets (Pinkse et al., 2002), and similar empirical strategies have been used in studies of cost pass-through in other industries (e.g., Miller et al. (2017)). Because we include station fixed effects, identification of differential pass-through comes from temporal variation in RIN and fuel prices as well as the entry of new E85 stations. Importantly, our identification strategy does not rely on time-invariant correlation between stations' location decisions and local market conditions. Despite this, our estimates may be biased if there exists unobserved, time-varying correlation between our market structure measures and firms' pricing residuals.[22]

The specifications above assume that contemporaneous and lagged RIN and wholesale market prices, conditional on our control variables, are exogenous. The estimates are biased if $\mathbf{X}_t$ are correlated with the error term ϵ_{it}. We believe this is not a significant concern. After controlling for seasonality or when using our first differences specification, the primary source of variation in RIN prices is policy developments. Wholesale gasoline prices are largely determined by upstream oil costs that are set on the world market, and wholesale ethanol prices are principally governed by feedstock supply conditions and E10 blending demand. Because E85 constitutes a small share of the fuel market (<1%), local demand conditions for E85 are unlikely to affect state-average ethanol prices. Nonetheless, Appendix B presents results using an instrumental variables strategy that uses plausibly exogenous instruments for wholesale fuel and RIN costs, and results are similar to our main findings.

While Y_{it} are station-level prices, RIN prices are national and our wholesale cost estimates are state averages. If stations respond similarly to changes in national or state average changes in $\mathbf{X}_t$, panel-robust standard errors clustered at the station will be too small. Heteroskedasticity is of particular importance in our setting because some large chains use centralized pricing. To account for this, we estimate two-way clustered standard errors at the station and year-month to flexibly allow for autocorrelation and heteroskedasticity in the residuals.[23]

[22] Another source of potential bias is our implicit assumption that pass-through is constant for each cost. While constant pass-through is a common assumption in the literature, it holds only for a particular class of demand systems (Bulow and Pfleiderer, 1983; Miller et al., 2017).

[23] Our inference is not sensitive to clustering at the corporation and year-month.

Table 2: Long-Run E85 Cost Pass-Through

	(1)	(2)	(3)	(4)	(5)
E85 Subsidy ($/gal)	0.478***	0.521***	0.785***	0.623***	0.770***
	(0.103)	(0.082)	(0.063)	(0.119)	(0.110)
E85 Wholesale ($/gal)	0.973***	0.997***	0.969***	0.805***	0.709***
	(0.047)	(0.025)	(0.019)	(0.089)	(0.054)
H_0: $\beta_L^\tau = 1$	0.000	0.000	0.002	0.003	0.044
H_0: $\beta_L^e = 1$	0.569	0.916	0.110	0.034	0.000
Observations	29,938	16,772	16,772	15,913	15,913
N (Stations)	451	412	412	411	411
Model	OLS	CDM	CDM	CDM	CDM
Specification	Level	Level	Level	FD	FD
Lags (Weeks)	N/A	8	8	8	8
Station FE	Yes	Yes	Yes	No	No
Month FE	Yes	No	Yes	No	Yes

Notes: The dependent variable is the retail E85 price ($/gal). The CDM columns present the cumulative dynamic multipliers for each variable after eight weeks. H_0: $\beta_L^\tau = 1$ and H_0: $\beta_L^e = 1$ present p-values from a test of complete pass-through of the RIN subsidy and E85 wholesale costs after eight weeks, respectively. Standard errors are two-way clustered at the station and year-by-month. *, **, *** denotes significance at the 10%, 5%, and 1% level.

3.2 Results: Subsidy and Wholesale Cost Pass-Through

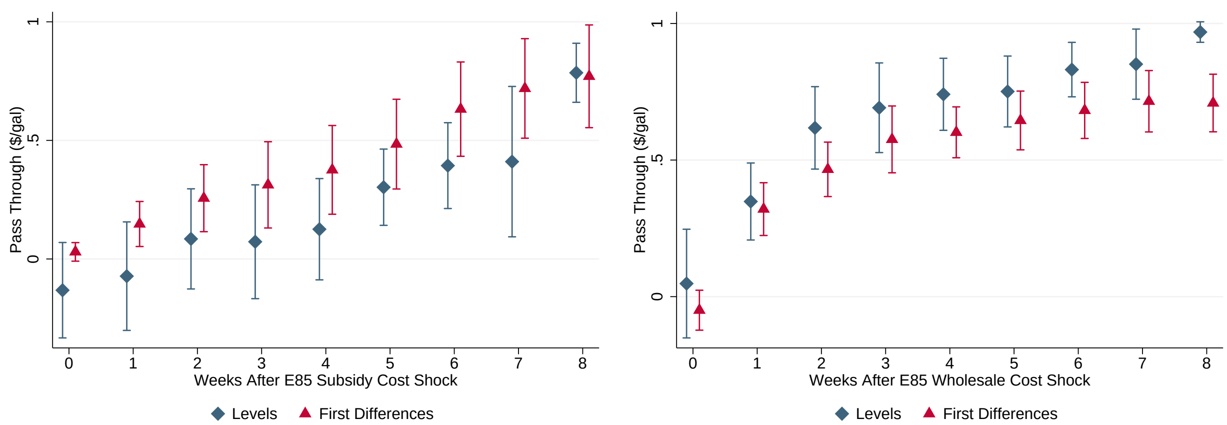
Table 2 presents our long-run pass-through estimates. We present estimates from our OLS model in column (1), and columns (2) to (5) present estimates of cumulative pass-through after eight weeks from the CDM models. In all specifications, complete pass-through corresponds to a point estimate of one, and we include the p-values from the hypothesis test that the long-run pass-through rates equal one in the second panel. While all models are estimated in levels ($/gal), we interpret the estimates as pass-through rates or the percent of the cost shock reflected in retail prices since complete pass-through corresponds to a long-run coefficient of one.

We reject the null hypotheses of both zero or complete subsidy pass-through in all specifications and generally find complete wholesale cost pass-through. The OLS model, which includes station and month fixed effects, suggests that E85 wholesale costs are entirely passed through to retail prices while just under half of the E85 subsidy is passed-through. In the CDM models, subsidy pass-through estimates are sensitive to the inclusion of month fixed effects. Point estimates are similar to the OLS model when we do not include them, ranging from 50% and 60% (columns (2) and (4)). When we include them, the value increases to just under 80% (columns (3) and (5)). As discussed in Knittel et al. (2017), fuel market spreads exhibit strong seasonality, supporting their inclusion. Another important distinction arises in our wholesale cost pass-through estimates in the levels versus first-differences CDM models. In the former, we estimate full wholesale cost pass-through while in the latter we can reject full pass-through. While we can partly resolve this by including more lags, the finding arises in almost all variants of the first-differences model. Because wholesale costs are estimated to be less than fully passed through and the models are estimated with less precision, we are hesitant to rely too greatly on the first-differences results.

Figure 4 graphs pass-through over time using the specifications from columns (3) and (5) of Table 2. Week 0 corresponds to the week in which a one-time, \$1.00/gal increase in the E85 wholesale price or \$1.00/gal decrease in the E85 subsidy occurs. Each subsequent point graphs the cumulative average retail price response up to eight weeks after the cost shock. E85 prices do not respond immediately to either a change in the E85 subsidy or the wholesale fuel costs. E85 prices begin to respond to RIN subsidy changes within one to two weeks. However, the adjustment is gradual, and we do not observe RIN pass-through rates greater than 50% until five to six weeks after the initial shock. In contrast, retail prices respond relatively quickly to wholesale cost changes. Around one-third of the wholesale fuel cost shock is passed through within a week, and half to three-quarters of the cost shock is reflected in retail prices within three weeks. The delayed responses are consistent with previous studies of retail and wholesale gasoline price dynamics. Borenstein et al. (1997) find that oil price increases take three to four weeks to pass-through to retail fuel prices.

Lewis and Noel (2011) and Lewis (2011) find that retail prices take between four and eight weeks to adjust to wholesale gasoline cost shocks. We depart from this literature in that we observe differential time profiles in our pass-through rates. Wholesale costs are passed through more quickly than RINs. The discrepancy may be driven by RINs being generated further upstream than wholesale prices.[24]

Figure 4: Pass-Through of Upstream Costs to Retail E85 Prices



(a) E85 Subsidy

(b) Wholesale E85 Costs

Notes: The figure graphs cumulative retail price pass-through after a \$1.00/gal decrease in the E85 subsidy (4a) and a \$1.00/gal increase in E85 wholesale costs (4b). Estimates are presented for both the levels CDM model with station and month fixed effects (blue diamonds) and the first-differences CDM model with month fixed effects (red triangles). Cost shocks occur in week 0.

Our findings support the notion that price impacts from upstream energy and environmental regulations affect consumer prices. However, both the lack of complete subsidy

[24]A previous version of this paper used bulk wholesale ethanol and gasoline prices to control for wholesale costs (Lade and Bushnell, 2016). We found similar time profiles for the subsidy and wholesale cost pass-through, consistent with the hypothesis that the differential pass-through rates are driven by differences in the distance of upstream generation.

[25]Observing less than perfect pass-through is also consistent with a model of perfect competition with a large supply relative to demand elasticity. Conventional wisdom is that fuel demand is inelastic. However, Babcock and Pouliot (2017) find that E85 demand is inelastic above E10 price parity and highly elastic below E10 price parity.

pass-through and the delays in its pass-through suggest that firms may exercise market when pricing E85 (Borenstein and Shepard, 2002).[25] Retailer market power would have important implications for both the efficiency and cost of the RFS. Our next section explores this hypothesis further, estimating heterogeneity in pass-through rates using our measures of local retail market structure.

3.3 Results: Pass-Through and Local Market Structure

Table 3 presents our market structure results for the levels and first-differences CDM models. The comparable specifications from before are from columns (3) and (5) of Table 2. Columns (1) and (2) compare pass-through at branded major versus unbranded stations. Average subsidy pass-through at branded stations is, on average, 14% to 18% lower than at unbranded stations, and the difference is statistically significant in the levels model. In contrast, major independent retailers have around 14% higher subsidy pass-through.[26] The findings suggest that, contrary to suggestions by some market participants, large independent fuel retailers have higher RIN pass-through than smaller retailers and branded major stations. Columns (5)-(6) compare pass-through at stations with competitors within 10 miles versus those whose nearest competitor offering E85 is more than 10 miles away. In both specifications, stations whose nearest competitor is more than 10 miles away have between 10% and 20% lower subsidy pass-through.[27]

Differences in wholesale cost pass-through are smaller and sensitive to model specification. For example, in the levels model we find that branded stations have 7% higher wholesale cost pass-through. However, the point estimate changes to -0.03% in the first differences model. In all specifications, the differential subsidy pass-through estimate is larger than the corresponding wholesale cost term. For example, in column (3) we find that major retailers have 14% higher subsidy pass-through but 8% lower wholesale cost pass-through.

[26]Results are similar if we exclude branded major stations from the regressions in columns (3) and (4) and compare pass-through rates at small versus large fuel retailers.

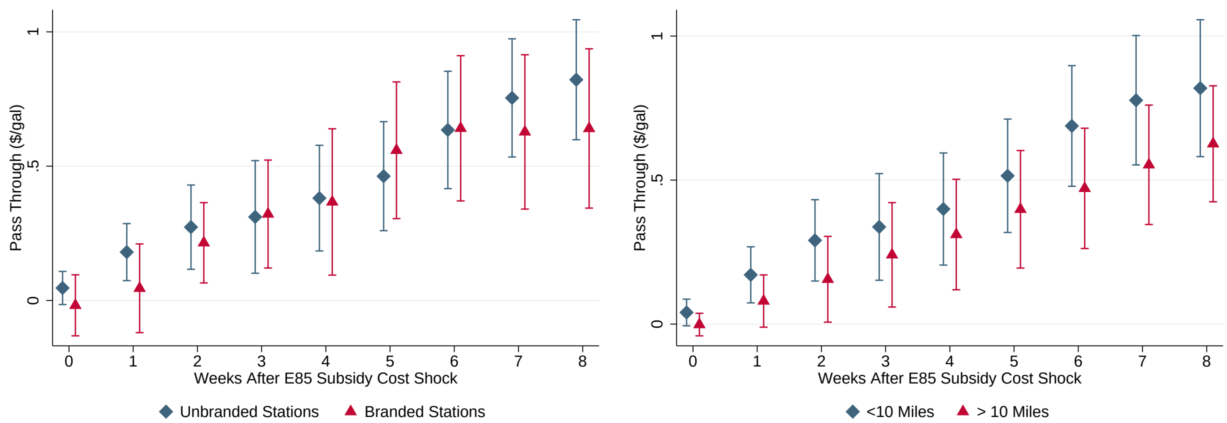
[27]The coefficient (s.e.) on the distance indicator when we use a 2, 5, and 15 mile radius is -0.028 (0.047), -0.020 (0.045), and -0.107 (0.085) for the levels model and -0.125 (0.043), -0.094 (0.098), and -0.252 (0.077) for the first-differences model.

Table 3: Long-Run E85 Cost Pass-Through and Market Structure

	(1)	(2)	(3)	(4)	(5)	(6)
E85 Subsidy (\$/gal):	0.827***	0.822***	0.693***	0.688***	0.807***	0.819***
	(0.062)	(0.114)	(0.075)	(0.101)	(0.063)	(0.121)
× Branded Major	-0.138**	-0.182				
	(0.065)	(0.130)				
× Major Retailer			0.142**	0.139		
			(0.059)	(0.141)		
× > 10 mi. to Competitor					-0.089	-0.193**
					(0.056)	(0.093)
E85 Wholesale (\$/gal):	0.963***	0.723***	1.024***	0.635***	0.954***	0.733***
	(0.019)	(0.065)	(0.024)	(0.067)	(0.020)	(0.053)
× Branded Major	0.071***	-0.030				
	(0.023)	(0.081)				
× Major Retailer			-0.083***	0.115*		
			(0.025)	(0.064)		
× > 10 mi. to Competitor					0.069***	-0.101**
					(0.019)	(0.040)
Observations	16,772	15,913	16,772	15,913	16,772	15,913
N (Stations)	412	411	412	411	412	411
Model	CDM	CDM	CDM	CDM	CDM	CDM
Specification	Level	FD	Level	FD	FD	FD
Lags (Weeks)	8	8	8	8	8	8
Station FE	Yes	No	Yes	No	Yes	No
Month FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The dependent variable is the retail E85 price (\$/gal). "× Branded Major" is an indicator variable for whether a station is affiliated with a large, vertically integrated oil company. "× Major Retailer" is an indicator for whether the station is affiliated with a large, independent gasoline retail company. "× > 10 mi. to Competitor" is an indicator for whether the closest competitor selling E85 is more than 10 miles away. Standard errors are robust to heteroskedasticity and clustering at the station and month-by-year level. *, **, *** denotes significance at the 10%, 5%, and 1% level.

Figure 5: E85 Subsidy Pass-Through to Retail E85 Prices and Local Market Structure



(a) Branded vs. Non-Branded

(b) Distance to Rival

Notes: The figure graphs the cumulative retail price pass-through over eight weeks after a $1.00/gal decrease in the E85 subsidy. Estimates are presented for the first-differences CDM model with month fixed effects. Cost shocks occur in week 0.

Figure 5 graphs cumulative subsidy pass-through estimates for branded versus unbranded stations and stations that are less than versus greater than ten miles from their nearest competitor.[28] Subsidy pass-through looks mostly similar across unbranded and branded stations until seven weeks after the cost shock. At week seven, the two estimates diverge, and branded stations have lower subsidy pass-through rates. A different story emerges when we consider stations close versus far from their nearest competitor. Subsidy pass-through is systematically lower at stations greater than ten miles from their nearest competitor in all weeks, and the difference increases over time.

In addition to our panel data estimator, we estimate station-level pass-through rates for a subset of our sample. Specifically, for each station we estimate the following regression:

$$Y_{i,t} = \alpha_i + \sum_{j=0}^{L-1} \beta_j \Delta \mathbf{X}_{t-j} + \beta_L \mathbf{X}_{t-L} + \gamma_s + \epsilon_{it} \quad \forall i. \tag{5}$$

[28]Wholesale cost pass-through looks similar over time at branded versus unbranded stations, while pass-through takes longer at stations farther from competitors. As before, we find that the E85 subsidy is passed through more slowly than wholesale fuel costs.

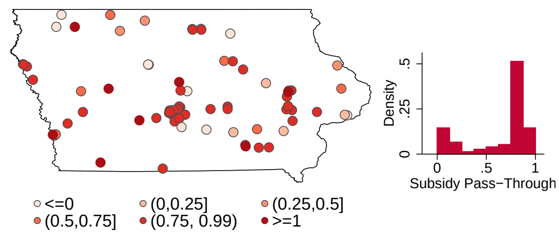
Estimating equation (5) for each station severely restricts our sample size. As a result, we aggregate our month indicator variables to quarterly indicators, γ_s. We also limit our sample to stations that we observe for at least 25 weeks and that report prices for at least eight consecutive weeks. After this initial restriction, we also drop stations whose estimated pass-through rates have unrealistically large standard errors or pass-through estimates. After these exclusions, we are left with 173 station-specific pass-through estimates.

Given the focus of the paper, we present pass-through results for the E85 subsidy only. Figure 6 graphs the station-level pass-through rates after eight weeks and corresponding histograms for each state. We truncate the estimates at zero (negative or zero subsidy pass-through) and one (full to overfull subsidy pass-through). In all three states, the pass-through distribution is bi-modal. Most stations exhibit either little to negative pass-through or full to overfull pass-through. Consistent with our market-power results, isolated stations tend to have lower pass-through than stations with nearby competitors. However, there are notable exceptions. For example, several stations in Chicago have pass-through rates less than 50% while some stations in rural Iowa have pass-through rates exceeding 90%.

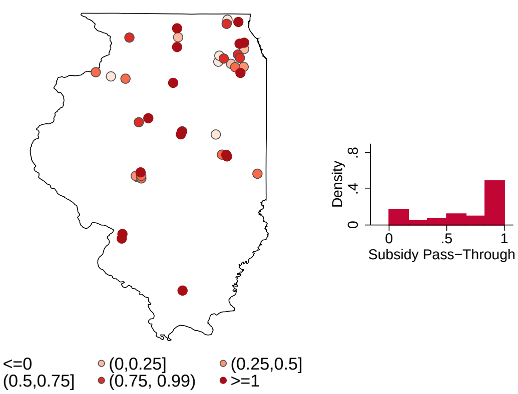
Figure 7 graphs the subsidy pass-through as a function of (i) the average distance between stations; (ii) whether the station is branded; (iii) the population density for each station's zip code; and (iv) the median home value for each stations' zip code.[29] We overlay the scatter plots with a line of best fit to illustrate the correlation between the pass-through estimates and market characteristics. In all cases, the pass-through estimates are consistent with a model where retailers with local market power exhibit lower subsidy pass-through. Pass-through is greater when stations are closer to competitors or unbranded. Similar to Stolper (2017), we find that subsidy pass-through is higher in more densely populated areas and areas with higher median home values.

[29]Zip code population and home values are from the 2010 Census (Ruggles et al., 2015).

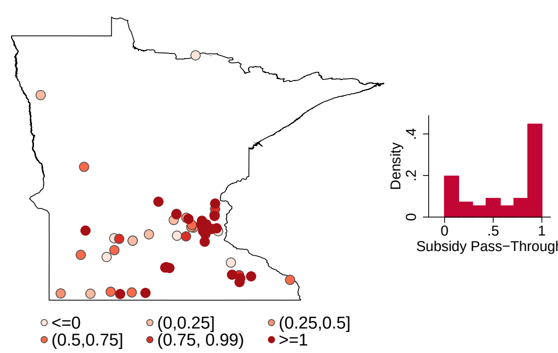
Figure 6: Station-Level E85 Subsidy Pass-Through



(a) Iowa



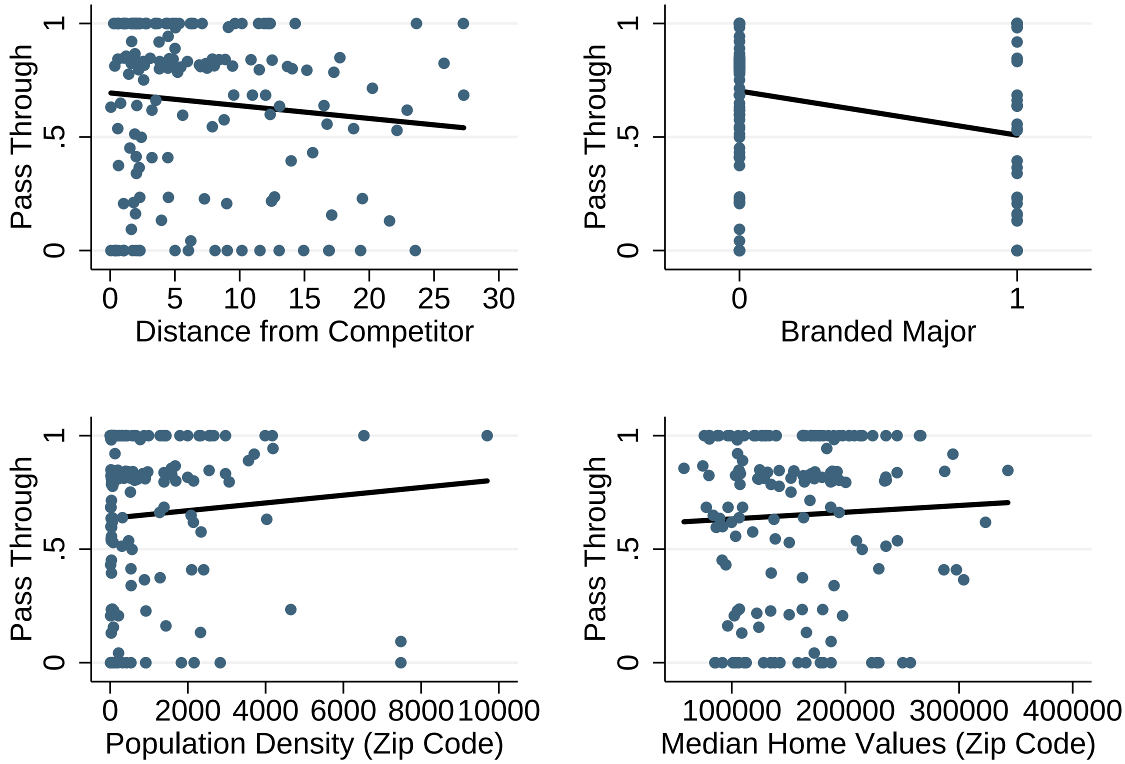
(b) Illinois



(c) Minnesota

Notes: The figures graph station-level pass-through estimates after eight weeks for the E85 subsidy as well as histograms of the station pass-through rates. Pass-through rates are truncated at zero and one.

Figure 7: Station-Level E85 Subsidy Pass-Through and Local Market Structure



Notes: The figure graphs correlations and best fit lines for station-level pass-through rates and measures of local market structure.

3.4 Results: Evolution of Pass-Through over Time

RINs and E85 are relatively new additions to fuel markets. Unlike taxes, the RIN subsidy for E85 is variable. Thus, we may expect pass-through rates to change over time as parties learn to incorporate volatile RIN values into their marketing arrangements better. To test for this, we re-estimate our levels and first differences CDM models splitting our samples into early (2013-2014) and later (2015-2016) periods.

Table 4 presents the results. Consistent with the hypothesis above, we find that E85 subsidy pass-through is higher in all specifications for 2015-2016 compared to 2013-2014. In

Table 4: Long-Run E85 Cost Pass-Through:

Evolution over Time

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
E85 Subsidy ($/gal)	0.480***	0.821***	0.723***	1.033***	0.562***	0.658***	0.730***	1.187***
	(0.135)	(0.098)	(0.109)	(0.197)	(0.143)	(0.192)	(0.140)	(0.230)
E85 Wholesale ($/gal)	0.994***	1.105***	0.886***	0.652***	0.720***	1.143***	0.681***	0.958 ***
	(0.102)	(0.041)	(0.076)	(0.079)	(0.085)	(0.092)	(0.083)	(0.153)
H_0: $\beta_L^\tau = 1$	0.001	0.086	0.019	0.867	0.006	0.092	0.067	0.426
H_0: $\beta_L^e = 1$	0.953	0.020	0.147	0.000	0.003	0.140	0.001	0.789
Observations	8,417	8,350	8,417	8,350	8,118	7,795	8,118	7,795
N (Stations)	162	393	162	393	162	393	162	393
Sample	'13-'14	'15-'16	'13-'14	'15-'16	'13-'14	'15-'16	'13-'14	'15-'16
Model	CDM	CDM	CDM	CDM	CDM	CDM	CDM	CDM
Specification	Level	Level	Level	Level	FD	FD	FD	FD
Lags (Weeks)	8	8	8	8	8	8	8	8
Station FE	Yes	Yes	Yes	Yes	No	No	No	No
Month FE	No	No	Yes	Yes	No	No	Yes	Yes

Notes: The dependent variable is the retail E85 price ($/gal). The CDM columns present the cumulative dynamic multipliers for each variable after eight weeks. H_0: $\beta_L^\tau = 1$ and H_0: $\beta_L^e = 1$ present p-values from a test of complete pass-through of the RIN subsidy and E85 wholesale costs after eight weeks, respectively. Standard errors are two-way clustered at the station and year-by-month. *, **, *** denotes significance at the 10%, 5%, and 1% level.

all levels and one first differences specification, we can reject the null hypothesis that pass-through is zero and cannot reject the hypothesis that pass-through is complete. As with our main results, wholesale cost pass-through is relatively stable, with full pass-through across the specifications. However, in some CDM specifications, we find low wholesale and subsidy pass-through.

3.5 Robustness and Discussion

Appendix B explores the sensitivity of our results. First, we separately estimate pass-through for stations that report less than versus more than two years of price data. Similar to concerns over which stations report prices to OPIS, stations that report prices more frequently may be systematically different from those that report less. We find that stations with higher reporting rates tend to have higher subsidy pass-through, suggesting that selection in our sample may bias our results upward. However, pass-through at stations that report less frequently is still estimated to be between 40% and 65%, we can reject zero pass-through in all specifications, and the market structure results are largely the same across the two samples. A second concern is whether a rural-urban distinction drives our results. To test this, we divide our sample into zip codes classified by the U.S. Department of Agriculture (USDA) as metropolitan versus micropolitan, small town, and rural.[30] Average pass-through rates are higher in metropolitan areas in most specifications. However, the market structure results are mostly the same across the two sub-samples – stations in smaller communities and rural areas have higher subsidy pass-through rates when a competitor selling E85 is nearby.[31]

Figure 8: Average E85 Margins

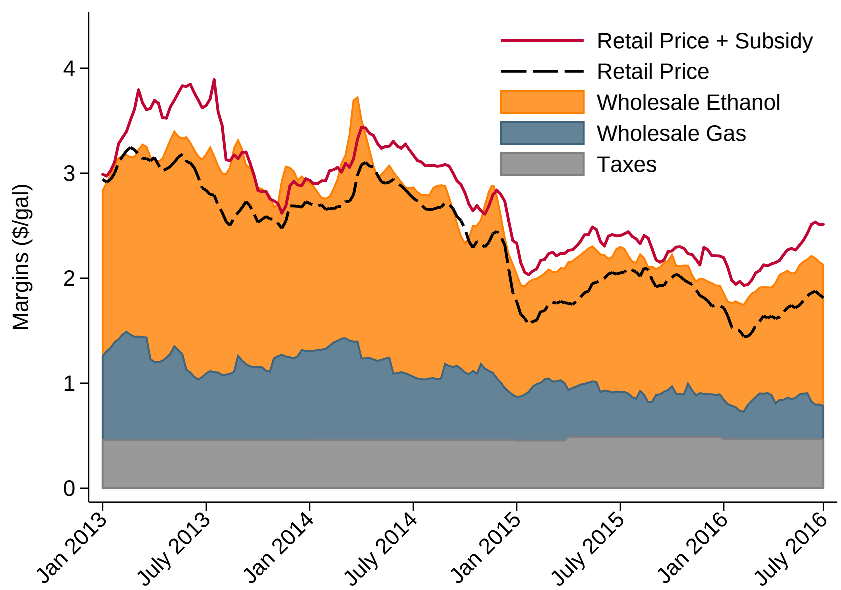


Figure 8 provides a succinct summary of our findings. We graph the average E85 retail tax rate in gray and the component average wholesale gasoline and ethanol costs in blue and orange, respectively. The sum of the three areas is a lower bound estimate of the average cost

[30]USDA uses population density and commuting patterns from the 2010 Census to classify areas as metropolitan, micropolitan, small town, and rural areas.

[31]We also explore two instrumental variables strategies and test for asymmetric retail price responses to cost shocks in Appendix B.

of purchasing E85 for retail sale in the three states.[32] We overlay the cost estimate with the average retail E85 price in black. A simple comparison of the retail price and cost estimate would conclude that average retail E85 margins were -\$0.23/gal since 2013. However, when we adjust the retail prices by the full RIN subsidy, graphed in red, average retail margins increase to \$0.19/gal. If we assume 50% and 75% subsidy pass-through, the average margin is -\$0.02/gal and \$0.08/gal, respectively. Thus, we can only rationalize historic E85 prices if we allow for RIN pass-through of at least 50%. The figure also illustrates how margins have changed over time. From 2013 to 2014, margins were volatile, with retailers experiencing periods of high average margins and period of negative margins. However, average margins have become much steadier and have averaged \$0.18/gal since 2015.

3.6 Reconciling Differences with Existing Literature

The two most comparable studies to our own are Knittel et al. (2017) (KMS) and Li and Stock (2017) (LS). KMS find full and immediate RIN pass-through to bulk wholesale prices, but limited evidence of RIN pass-through to E85 retail prices. LS study RIN pass-through at E85 stations in Minnesota, finding an average pass-through rate of 35%. In contrast, we find higher average RIN subsidy pass-through. Given the importance of RIN pass-through to policymakers, we attempt to resolve these somewhat discordant findings here.

KMS study RIN pass-through to retail E85 prices using a weekly average national E85 price reported by American Automobile Association (AAA). Their empirical strategy only partially controls for contemporaneous wholesale fuel prices by specifying their dependent variable as the spread between E85 and a national average E10 price series, also from AAA. They find mixed evidence of long-run RIN pass-through to E85 prices, estimating rates between -0.08 to 0.24 (Table 1, KMS). Their dynamic pass-through estimates range between -0.05 and 0.213 using a VAR model, and 0.228 and 0.538 using a CDM model (Tables A2-1 and A5-1, KMS). In their preferred VAR and CDM specifications, they estimate pass-through rates of -0.05 and 0.228 after six weeks, respectively (Figure 10, KMS).

[32] The cost does not include transportation costs or other retailing costs.

We construct a similar weekly average E85 price series using all stations in our data and collect from Bloomberg the same AAA E10 prices used in KMS to explore reasons for our different findings. We consider four reasons (i) our sample; (ii) the extended period over which we estimate our regressions; (iii) the lag specification; and (iv) the specification of the dependent variable.

Table 5 reports our results. Columns (1) uses the same period and price spread as KMS. The only difference is that the E85 price series is from stations in our sample and not AAA's E85 price.[33] Our point estimate is 0.40, and we can reject neither zero nor complete pass-through. While the estimate is almost twice as large as the preferred specification in KMS, several CDM specifications from KMS produce similar point estimates. This suggests that our sample of stations in the Midwest may drive some, though not all of the differences in our findings. Column (2) extends the sample period. The point estimate increases to 0.50, the lower range of our estimates. We can also reject separate hypotheses of complete pass-through and no pass-through at a 10% confidence level. The increase in the point estimate and decrease in standard error point to the longer period as partly explaining both our higher pass-through estimate and our higher degree of statistical confidence. Column (3) extends the lag structure from six to eight weeks. The point estimate stays nearly the same as in column (2) and decreases our degree of statistical precision. Thus our extended lag structure does not alone drive the differences in our conclusions. Last, columns (4) and (5) present estimates from our preferred specification – a first-differences CDM model that controls for contemporaneous and lagged E85 wholesale costs. The estimated subsidy pass-through is 52% when we include only six weekly lags, but increases to just under 70%, near our preferred estimate, when we include eight weekly lags. Thus, the empirical specification plays an important role in explaining the difference with KMS. We argue that our specification is preferred given the importance of lagged retail price adjustment to upstream cost shocks. While the E85-E10 price spread controls to some extent for changes in contemporaneous wholesale E85 costs, it does not take into account lagged retail price adjustment. If his-

[33] As in KMS, we adjust the RIN subsidy by the implicit E10 RIN tax in all specifications where we use the E85-E10 price spread as our dependent variable. We also include seasonality controls (sines and cosines evaluated at the first four seasonal frequencies) in all specifications.

Table 5: Knittel et al. (2017) Comparison

	(1)	(2)	(3)	(4)	(5)
Dependent Variable	E85-E10	E85-E10	E85-E10	E85	E85
E85 Subsidy ($/gal)	0.402	0.496*	0.484	0.520***	0.685***
	(0.351)	(0.266)	(0.311)	(0.116)	(0.135)
E85 Wholesale ($/gal)				0.693***	0.716***
				(0.080)	(0.090)
H_0: $\beta^\tau_L = 1$	0.092	0.060	0.099	0.000	0.021
H_0: $\beta^e_L = 1$				0.000	0.002
Observations	107	173	171	175	173
Lags (Weeks)	6	6	8	6	8
Period	KMS	Full	Full	Full	Full

Notes: The dependent variable is either the E85-E10 price spread or the first difference E85 price. The table presents cumulative pass-through estimates from a CDM model after the specified number of weeks. The 'KMS' period is 1/1/2013-3/10/2015 and the 'Full' period is 1/1/2013-6/30/2016. H_0: $\beta^\tau_L = 1$ and H_0: $\beta^e_L = 1$ present p-values from a test of complete RIN and wholesale cost pass-through, respectively. Standard errors are Newey-West with 6 weekly lags. All specifications include seasonality controls as in KMS. *, **, and *** denotes significance at the 10%, 5%, and 1% level.

torical E85 wholesale prices and RINs are correlated, the omission of lagged costs excludes potentially important variables from the regression.

Last, we compare our results to those in Table 8 of LS. In their specifications, LS use monthly E85 prices from January 2012 to March 2015 and control for wholesale E10 and E85 costs. We collapse our data to monthly average station prices; however, we are unable to control for wholesale E10 and E85 costs due to data limitations.[34] We, therefore, focus on differences in our findings with LS due to (i) geography; and (ii) CDM lag structure.

[34]LS use nearby wholesale terminal prices for E10 and E85, where we have only state-average pure ethanol and sub-octane gasoline wholesale prices.

Table 6: Li and Stock (2017) Comparison

	(1)	(2)	(3)	(4)	(5)	(6)
E85 Subsidy ($/gal)	0.656***	0.822***	0.354***	0.647***	0.684***	0.839***
	(0.132)	(0.168)	(0.085)	(0.173)	(0.087)	(0.103)
E85 Wholesale ($/gal)	0.742***	0.775***	0.695***	0.666***	0.828***	0.716***
	(0.137)	(0.162)	(0.115)	(0.231)	(0.093)	(0.110)
H_0: $\beta_L^{\tau} = 1$	0.013	0.298	0.000	0.049	0.001	0.126
H_0: $\beta_L^{e} = 1$	0.067	0.171	0.011	0.156	0.071	0.014
Observations	2,255	1,417	838	2,019	4,358	3,869
N (Stations)	169	109	60	164	278	268
States	MN	MN	MN	MN	IA/IL	IA/IL
Sample	All	Metro	Micro/Rural	All	All	All
Model	CDM	CDM	CDM	CDM	CDM	CDM
Specification	FD	FD	FD	FD	FD	FD
Lags (Months)	1	1	1	2	1	2
Station FE	No	No	No	No	No	No
Month FE	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The dependent variable is the retail E85 price ($/gal). The table presents cumulative estimated pass-through rates after the specified number of months. H_0: $\beta_L^{\tau} = 1$ and H_0: $\beta_L^{e} = 1$ present p-values from a test of complete RIN and wholesale cost pass-through, respectively. Standard errors are two-way clustered at the station and year-by-month. *, **, *** denotes significance at the 10%, 5%, and 1% level.

Table 6 reports our results. Columns (1) to (3) present pass-through estimates using monthly station prices when we restrict the sample to Minnesota stations and allow for one month lag in the first differences CDM model. Similar to LS, we cannot reject the null hypothesis of complete pass-through of wholesale E85 costs. However, our average subsidy pass-through estimate is 66% compared to 35% in LS. LS report much higher pass-through estimates for metropolitan (80%) versus non-metropolitan areas (30%). Similarly, we find higher subsidy pass-through in metropolitan (82%) versus non-metropolitan (35%) areas. Also consistent with LS, our estimated average subsidy pass-through does not increase when we include two monthly lags in column (4). When we estimate the same regressions using only stations in Illinois and Iowa, the average subsidy pass-through estimate after one month increases slightly to 68%. However, when we extend the lag order for Illinois and Iowa, the subsidy pass-through estimate increases to 84%, and we cannot reject full pass-through. Thus, the discrepancy between our results and those in LS appear to be best explained by both the higher frequency of metropolitan stations in our Minnesota sample, and higher subsidy pass-through between weeks six and eight for stations in Iowa and Illinois.

4 Conclusions

The U.S. Congress set aggressive biofuel blending mandates for the transportation sector in 2007. Because of technical limitations on ethanol blending, meeting these requirements will require an increase in the consumption of fuels like E85. Given current limits in the number of pumps and vehicles capable of using E85, increasing demand for the fuel will almost certainly require a persistent, high RIN value and a simultaneous reduction in the relative cost of E85 to E10 (Babcock and Pouliot, 2013, 2017). However, policy-makers and industry have raised concerns that the full value of the RIN subsidy is not reflected in retail prices, threatening the price mechanism through which the RFS can expand ethanol consumption. Using detailed, station-level data, we find that retail E85 prices do in fact reflect a significant portion of the upstream subsidy for the fuel. While we can reject that the subsidy was fully passed-through over our entire observation period, we find that subsidy pass-through is, on average, complete since 2015. However, we also find important deviations from competitive pricing in many markets – subsidy pass-through is lower at stations that have characteristics indicative of market power in every period and sub-sample of stations that we consider.

Our findings have several policy implications. First, the results confirm that retail fuel prices reflect upstream regulatory costs and subsidies. Second, our results highlight a potential strategic policy role in increasing demand for new fuels. State and federal governments often offer generous tax credits and grants for alternative fueling infrastructure. For example, in 2015 the U.S. Department of Agriculture dedicated around $130 million to expand retail ethanol blend pumps through its Biofuel Infrastructure Partnership program. Our findings suggest that targeting these programs to increase retail market competitiveness may increase pass-through of upstream fuel subsidies, and therefore increase demand for renewable fuels.

Our results are subject to several caveats. We chose the Midwest as our study region because of the relatively high penetration of E85 stations in those states and the high station coverage by OPIS. Both our comparison with other papers and recent work studying RIN pass-through to wholesale prices by Pouliot et al. (2017) highlight potentially important regional heterogeneity. Also, our finding that pass-through has increased substantively even over our relatively short sample suggests that many results in this literature may be sensitive to study period. As such, future work on RIN and other cost pass-through in different markets and years are important to better understand drivers of heterogeneity of cost pass-through under current and future environmental regulations.

References

Alleman, Teresa. 2011. National 2010-2011 Survey of E85. NREL Technical Report: NREL/TP-5400-52905.

Alm, James, Edward Sennoga, and Mark Skidmore. 2009. Perfect Competition, Urbanization, and Tax Incidence in the Retail Gasoline Market. *Economic Inquiry* 47 (1): 118–134.

Anderson, Soren. 2012. The Demand for Ethanol as a Gasoline Substitute. *Journal of Environmental Economics and Management* 63 (2): 151–168.

Babcock, Bruce and Sebastien Pouliot. 2013. Price It and They Will Buy: How E85 Can Break the Blend Wall. CARD Policy Brief 13-PB 11.

——— 2017. Feasibility of Meeting Increased Biofuel Mandates with E85. *Energy Policy* 101 (1): 194–200.

Bill Douglas. 2016. Letter from Small Retailers Coalition to EPA. July 28. http://static.politico.com/d3/c9/c42118b142d189cac65d4ef15663/small-retailer-letter-on-rfs-obligation.pdf.

Borenstein, Severin, James Bushnell, and Matthew Lewis. 2004. Market Power in California's Gasoline Market. Center for the Study of Energy Markets Working Paper 132.

Borenstein, Severin, Colin Cameron, and Richard Gilbert. 1997. Do Gasoline Prices Respond Anymmetrically to Crude Oil Price Changes?. *The Quarterly Journal of Economics* 112 (1): 305–339.

Borenstein, Severin and Andrea Shepard. 2002. Sticky Prices, Inventories, and Market Power in Wholesale Gasoline Markets. *RAND Journal of Economics* 33 (1): 116–139.

Buchanan, James. 1969. External Diseconomies, Corrective Taxes, and Market Structure. *American Economic Review* 59 (1): 174–177.

Bulow, Jeremy and Paul Pfleiderer. 1983. A Note on the Effect of Cost Changes on Prices. *Journal of Political Economy* 91 (1): 182–185.

Burkhardt, Jesse. 2016. Incomplete Regulation in an Imperfectly Competitive Market: The Impact of the Renewable Fuel Standard on U.S. Oil Refineries. Working Paper.

Burkholder, Dallas. 2015. A Preliminary Assessment of RIN Market Dynamics, RIN Prices, and Their Effects. Office of Transportation and Air Quality, U.S. Environmental Protection Agency.

Bushnell, James, Howard Chong, and Erin Mansur. 2013. Profiting from Regulation: An Event Study of the EU Carbon Market. *American Economic Journal: Economic Policy* 5 (4): 78–106.

Bushnell, James and Jacob Humber. 2017. Rethinking Trade Exposure: The Incidence of Environmental Charges in the Nitrogenous Fertilizer Industry. *Journal of the Association of Environmental and Resource Economists* 4 (3): 857–894.

Corts, Kenneth. 2010. Building out Alternative Fuel Retail Infrastructure: Government Fleet Spillovers in E85. *Journal of Environmental Economics and Management* 59 (3): 219–234.

Energy Information Agency. 2016. Almost all U.S. Gasoline is Blended with 10% Ethanol. *Energy Information Agency: Today in Energy*, May 4.

Environmental Protection Agency. 2016. Renewable Fuel Standard Program: Standards for 2017 and Biomass Based Diesel Volume for 2018; Proposed Rule. *Federal Register* 81 (104): 34778–34816.

Fabra, Natalia and Mar Reguant. 2014. Pass-Through of Emissions Costs in Electricity Markets. *American Economic Review* 104 (9): 2872–2899.

Ganapati, Sharat, Joseph Shapiro, and Reed Walker. 2016. Energy Prices, Pass-Through, and Incidence in U.S. Manufacturing. NBER Working Paper 22281.

Hastings, Justine. 2004. Vertical Relationships and Competition in Retail Gasoline Markets: Empirical Evidence from Contract Changes in Southern California. *American Economics Review* 94 (1): 317–328.

Hintermann, Beat. 2010. Allowance Price Drivers in the First Phase of the EU ETS. *Journal of Environmental Economics and Management* 59 (1): 43–56.

——— 2016. Pass-Through of CO_2 Emission Costs to Hourly Electricity Prices in Germany. *Journal of the Association of Environmental and Resource Economists* 3 (4): 857–891.

Hitaj, Claudia and Andrew Stocking. 2016. Market Efficiency and the U.S. Market for Sulfur Dioxide Allowances. *Energy Economics* 55 (1): 135–147.

Houde, Jean-Francois. 2012. Spatial Differentiation and Vertical Mergers in Retail Markets for Gasoline. *American Economic Review* 102 (5): 2147–2182.

Irwin, Scott and Darrel Good. 2015. The EPA's Proposed Ethanol Mandates for 2014, 2015, and 2016: Is There a 'Push' or Not?. *farmdoc daily* 5 (102): Department of Agricultural and Consumer Economics, University of Illinois.

Jenkin, Fleeming. 1872. On the Principles which Regulate the Incidence of Taxes. *Proceedings of the Royal Society of Edinburgh* 7 (1): 618–631.

Jessen, Holly. 2015. Go to E85prices.com and Get Involved. *Ethanol Producers Magazine* March 23.

Knittel, Christopher, Ben Meiselman, and James Stock. 2017. The Pass-Through of RIN Prices to Wholesale and Retail Fuels under the Renewable Fuel Standard. *Journal of the Association of Environmental and Resource Economists* 4 (4): 1081–1119.

Krauss, Clifford. 2016. High-Price Ethanol Credits Add to Refiners' Woes. *The New York Times*. August 22.

Lade, Gabriel E. and James Bushnell. 2016. Fuel Subsidy Pass-Through and Market Structure: Evidence from the Renewable Fuel Standard. CARD Working Paper 16-WP 570.

Lade, Gabriel E., C.-Y. Cynthia Lin Lawell, and Aaron Smith. 2016. Policy Shocks and Market-Based Regulations: Evidence from the Renewable Fuel Standard. CARD Working Paper 16-WP 565.

Langer, Ashley and Shaun McRae. 2014. Fueling Alternatives: Evidence form Real-World Driving Data. Working Paper.

Lapan, Harvey and GianCarlo Moschini. 2012. Second-Best Biofuels Policies and the Welfare Effects of Quantity Mandates and Subsidies. *Journal of Environmental Economics and Management* 63 (2): 224–241.

Lewis, Matthew. 2011. Asymmetric Price Adjustment and Consumer Search: An Examination of the Retail Gasoline Market. *Journal of Economics and Management Strategy* 20 (2): 409–449.

Lewis, Matthew and Michael Noel. 2011. The Speed of Gasoline Price Response in Markets with and without Edgeworth Cycles. *Review of Economics and Statistics* 93 (2): 672–682.

Li, Jing and James Stock. 2017. Cost Pass-Through to Higher Ethanol Blends at the Pump: Evidence from Minnesota Gas Station Data. Working Paper.

Liu, Changzheng and David L. Greene. 2015. Consumer Choice of E85: Price Sensitivity and Cost of Limited Fuel Availability. *Transportation Research Record* 2454 20–27.

Miller, Nathan, Matthew Osborne, and Gloria Sheu. 2017. Pass-Through in a Concentrated Industry: Empirical Evidence and Regulatory Implications. *RAND Journal of Economics* 48 (1): 69–93.

Muehlegger, Erich and Justin Marion. 2011. Tax Incidence and Supply Conditions. *Journal of Public Economics* 95 (9): 1202–1212.

Pinkse, Joris, Margaret Slade, and Craig Brett. 2002. Spatial Price Competition: A Semiparametric Approach. *Econometrica* 70 (3): 111–1153.

Pouliot, Sebastien and Bruce Babcock. 2014. The Demand for E85: Geographic Location and Retail Capacity Constraints. *Energy Economics* 45 (1): 134–143.

——— 2017. Feasibility of Meeting Increased Biofuel Mandates with E85. *Energy Policy* 101 (1): 194–200.

Pouliot, Sebastien, Aaron Smith, and James Stock. 2017. RIN Pass-Through at Gasoline Terminals. Working Paper.

Ruggles, Steven, Katie Genadek, Ronald Goeken, Josiah Grover, and Matthew Sobek. 2015. Integrated Public Use Microdata Series: Version 6.0 [dataset]. Minneapolis: University of Minnesota.

Stolper, Samuel. 2017. Local Pass-Through and the Regressivity of Taxes: Evidence from Automotive Fuel Markets. Working Paper.

Voegele, Erin. 2016. Valero Petitions EPA to Redefine RFS Obligated Party. *Biomass Magazine*. June 16.

Weyl, E. Glen and Michal Fabinger. 2013. Pass-Through as an Economic Tool: Principles of Incidence under Imperfect Competition. *Journal of Political Economy* 121 (3): 528–583.

Yeh, Sonia, Julie Witcover, Gabriel Lade, and Daniel Sperling. 2016. A Review of Low Carbon Fuel Policies: Principles, Program Status, and Future Directions. *Energy Policy* 97 (1): 220–234.