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

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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. Using station-level prices for E85 (a high-ethanol blend fuel) from over 450 retail fuel stations, we show that pass-through of the ethanol subsidy is, on average, near complete. However, we find that full pass-through takes four to six weeks and that station-level pass-through rates exhibit substantial heterogeneity, with local market structure of stations influencing both the speed and overall level of pass-through.

JEL Codes: Q42, Q58, H23

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

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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 seek to decrease emissions by regulating upstream firms. The policies leverage the microeconomic principle that when markets are competitive, economic incidence is independent of statutory incidence. This insight allows policies 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 either explicitly or implicitly tax upstream fossil fuel emissions and subsidize upstream renewable energy production. Despite the success of these policies crucially hinging on pass-through to downstream users, little empirical work has studied their impacts on consumer prices to date.

This paper studies pass-through of tradeable compliance credits prices under the U.S. Renewable Fuel Standard (RFS) to retail E85 prices, a high-ethanol blend fuel. The RFS has been in place for over a decade and seeks to displace a quarter of the U.S. fuel supply with biofuels by 2022, making it among the largest and most ambitious renewable energy policies in the world. The RFS is administered using a tradeable credit system whereby upstream biofuel producers generate credits (known as RINs) in proportion to their production. RINs must either be produced or purchased by obligated parties, mainly oil refiners and fuel importers, to comply with the policy. Thus, a binding mandate subsidizes biofuels and taxes gasoline and diesel in proportion to RIN prices.

While compliance with the RFS in early years was relatively easy, meeting current and future targets is difficult due to the saturation of ethanol in conventional fuel blends. Regulated parties must sell increasing amounts of high-blend biofuels like E85 that require both adapted vehicles and dedicated distribution networks. Thus, the RFS 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). The primary mechanism to achieve this is through pass-through of the upstream RIN subsidy to retail prices of fuels blended with biofuels. 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 that fuel.

When markets are competitive, pass-through depends on relative supply and demand elasticities (Jenkin, 1872). Most work studying the RFS to date implicitly assumes complete or near complete pass-through of the upstream subsidies for biofuels to consumers by modeling fuel markets as competitive with inelastic (elastic) demand (supply) for fuel. However, both the overall incidence and the statutory and economic independence of taxes and subsidies change if markets deviate from perfect competition (Buchanan, 1969; Weyl and Fabinger, 2013). Imperfect competition may be a concern in our setting. For RIN subsidies and taxes to affect 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 historical 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, pass-through is, on average, near complete for all upstream costs and subsidies. Second, RIN and wholesale fuel cost pass-through take four to six weeks to be complete. Third, we find substantial heterogeneity in RIN pass-through rates across stations. In particular, we find that stations that have a local monopoly in E85 exhibit lower and slower pass-through than stations that have nearby competitors, even after controlling for fixed characteristics of the stations.

The first finding is significant as previous work has found that pass-through of the RIN subsidy to retail E85 prices is incomplete (Knittel et al., 2015). In addition, critics of the RFS cite incomplete pass-through of RINs to wholesale and retail fuel prices as a key policy failure.[1] The Environmental Protection Agency (EPA) - the enforcing agency - also cites incomplete pass-through as a barrier to expanding ethanol use in the United States. For example, the Agency included the following language in its proposed rule for the 2017 biofuel standards:

> *"RIN prices can continue to provide additional subsidies that help to reduce the price of E85 relative to E10 at retail, but the propensity for retail station owners and wholesalers to retain a substantial portion of the RIN value substantially reduces the effectiveness of this aspect of the RIN mechanism."*

If RIN pass-through is incomplete, sales of large volumes of E85 may be infeasible and future compliance costs with the RFS will likely to be higher than currently anticipated. In addition, both the estimated greenhouse gas benefits and distributional impacts of the policy would be misstated. While we only consider pass-through to retail E85 prices, our work along with the findings of complete RIN pass-through to wholesale fuel prices by Knittel et al. (2015) suggests that the market mechanism underlying the RFS is largely operating as intended, particularly in markets with sufficient retail and wholesale E85 competition.

Our second and third findings are broadly consistent with previous literature. Delayed pass-through of upstream costs is a common finding in retail fuel markets. Previous work has found that complete pass-through of upstream oil and wholesale price shocks typically takes four to six weeks, a similar time profile

[1] For example, Valero, a large oil refiner and ethanol producer, recently petitioned the Environmental Protection Agency to redefine the obligated parties under the RFS further downstream at wholesale fuel terminals. The company 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 pass-through of RINs to consumers. Others, including large investors in oil companies, have predicted RIN markets will cause refinery bankruptcies and further consolidation in refining capacity due to the burden associated with the RFS falling on refiners (Krauss, 2016).

to our findings (Borenstein et al., 1997; Lewis and Noel, 2011; Lewis, 2011). While we find complete pass-through on average, we also find significant heterogeneity in pass-through rates across stations consistent with certain stations exercising market power. In particular, we find that stations that are far from competitors that offer E85 exhibit slower and around 25% lower pass-through of the RIN subsidy than stations in more contested retail markets. In addition, we find that stations that are affiliated with large, vertically integrated refining companies exhibit lower pass-through; however, their pass-through rates are statistically indistinguishable from non-branded stations.

Our work contributes first to the literature studying market impacts of the RFS. Previous work has estimated demand for E85 and the role of policy in driving diffusion new alternative fuels (Corts, 2010; Anderson, 2012; Langer and McRae, 2014; Pouliot and Babcock, 2017). More recent empirical work has studied RIN cost drivers, as well as the effect of RIN prices on refiners' markups and profitability (Lade et al., 2016; Burkhardt, 2016). Knittel et al. (2015) build on work by Burkholder (2015), studying pass-through of the RIN tax and subsidy to bulk wholesale and retail fuel prices. The authors find that while the implicit tax on gasoline and diesel are fully and immediately passed through to bulk wholesale prices, little to none of the E85 subsidy is passed through to retail prices. The finding calls into question whether taxes and subsidies from similar policies are borne by consumers, a near universally assumption in work studying the distributional and efficiency properties of carbon taxes, new vehicle standards, and gasoline taxes (Bovenberg and Goulder, 2001; Hassett et al., 2009; Bento et al., 2009; Fullerton and Heutel, 2010; Grainger and Kolstad, 2010).

The paper is most related to independent work by Li and Stock (2017). The authors study RIN pass-through to E85 prices using data from 274 E85 stations in Minnesota from 2007 to March 2015. While Li and Stock (2017) use monthly data from only one state in our sample, the authors' have the advantage of having access to wholesale terminal E85 prices in addition to their retail E85 prices. In contrast, our study uses upstream bulk prices to control for E85 wholesale fuel costs, preventing us from being able to disentangle pass-through at wholesale terminals versus the retail station level. Nonetheless, our work largely conforms with the findings in Li and Stock (2017). While the authors find lower average pass-through than our paper, the results are driven by a larger number of observations in rural locations that we show have systematically lower pass-through than stations in urban, more competitive settings.[2]

More recent work by Pouliot et al. (2017) study RIN pass-through to regional wholesale fuel terminals. The authors primarily study pass-through of RIN costs to E10 blends, or gasoline with 10% ethanol. However, the authors also study RIN pass-through to some high ethanol blend fuels at wholesale terminals. While we are unable to disentangle low pass-through at retail stations versus at wholesale fuel terminals, our finding of near complete pass-through on average is only possible if wholesale terminals in the Midwest pass-through the

[2] In addition, as we show in Section 3.3, rural stations in Minnesota appear to have lower pass-through than rural stations in Iowa and Illinois.

RIN subsidy. Consistent with this, Pouliot et al. (2017) find that pass-through is complete or near complete at most wholesale terminals in the Midwest. However, the authors find significant regional heterogeneity in RIN pass-through to both E10 and E85, with systematically lower pass-through in East Coast markets.

Our paper also builds on previous work studying cost pass-through and industry pricing in energy intensive sectors. Previous work has studied whether supply conditions affect fuel tax incidence (Muehlegger and Marion, 2011), the incidence of taxation when firms can avoid taxes (Muehlegger et al., 2016), as well as the distributional impacts of taxes and its interaction retail market structure (Alm et al., 2009; Stolper, 2015). In general, the literature has found that in fossil fuel markets, market power of refineries, wholesale markets, and retail markets has important interactions with gasoline price dynamics (Borenstein et al., 1997; Borenstein and Shepard, 2002; Borenstein et al., 2004; Hastings, 2004; Houde, 2012). Less work has examined the direct impact of upstream compliance credit costs on downstream prices. Fabra and Reguant (2014) and Hintermann (2016) study pass-through of allowance prices under the European Union's Emissions Trading System (EU-ETS) to wholesale electricity prices. Others have used historical variation in upstream energy costs while taking advantage of cross-sectional and temporal variation in the competitiveness of industries to study the relationship between pass-through and market structure (Ganapati et al., 2016; Bushnell and Humber, 2015; Miller et al., 2017). While these studies are useful in understanding potential impacts of a carbon tax, they are unlikely to fully explain the downstream effects of cap and trade programs, intensity standards, and fuel mandates due to the historic volatility of compliance credit prices. Compliance credit markets are affected by political, regulatory, and economic uncertainty, and these sources have had substantial effects on compliance credit markets to date.[3] As we show, short-run dynamics are important in assessing impacts of upstream cost shocks on downstream consumers: an increase in the subsidy for E85 is not fully reflected in retail prices for four to six weeks, and firms that have local market power may not fully pass through the subsidy.

The paper proceeds as follows. Section 2 provides a background on the Renewable Fuel Standard. We describe key developments in the policy since 2013 and their impacts on RIN markets and the corresponding value of the subsidy for E85. The section also describes the data used in the subsequent analysis. Section 3 discusses our empirical strategy and presents our results. We also explore the impacts of market structure on pass-through and discuss some extensions as well as 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.

[3]Examples of volatility in compliance credit markets following political and economic events include: a sharp run-up and subsequent collapse in SO_2 allowance prices following the initial 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 prices in California's market for tradeable credits under its Low Carbon Fuel Standard following court decisions halting the regulation (Yeh et al., 2016); and volatility in the RFS RINs market following the EPA's decisions to relax the standards (Lade et al., 2016).

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 for U.S. refiners and fuel importers. The program was expanded in 2007 under the Energy Independence and Security Act (EISA). EISA significantly increased the 2005 mandates and established sub-mandates for advanced biofuels,[4] biomass-based diesel, and cellulosic ethanol.[5] While EISA sets volumetric biofuel targets, the EPA enforces the policy by setting fractional standards for each biofuel category. Each year, the EPA divides the final volumetric mandates by projected U.S. gasoline and diesel sales from the Energy Information Administration. To determine their compliance obligations, refiners and fuel importers multiply their gasoline and diesel sales by the fractional mandates. Thus, the RFS is a form of an intensity standard, requiring a minimum fraction of U.S. fuel sales be derived from biofuel.

The RFS is enforced using a tradeable compliance credit (RIN) mechanism. Figure 1 presents a stylized depiction of U.S. fuel markets for gasoline and ethanol production and illustrates the operation of RIN markets. Upstream firms produce gasoline and ethanol. They sell fuel to regional blending terminals before it is blended and sold to retail stations. Under the RFS, every gallon of qualifying biofuel generates a RIN that can be sold after the fuel has been blended and sold to consumers. 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.[6]

The point of obligation for the RFS currently lies with upstream oil refiners and fuel importers. To comply with the RFS, refiners must either produce biofuels or purchase RINs in proportion to their gasoline and diesel sales. At the end of each compliance period, refiners are obligated to the EPA for their prorated portion of the mandate. 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 sold, refiners must produce or 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. Thus, the policy subsidizes biofuels and taxes gasoline and diesel, where the total value of the subsidy to the biofuel industry equals refiners' total tax obligation (Lapan and Moschini, 2012).

[4]Biofuels qualify as 'advanced' if their life-cycle greenhouse gas emissions are at least 50% below a threshold set by the EPA.

[5]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. Advanced biofuel that does not qualify as cellulosic biofuel or biomass-based diesel, primarily sugarcane ethanol imported from Brazil, counts towards the advanced biofuel mandate as well as the total biofuel mandate. All non-advanced biofuels, mainly corn ethanol, counts only towards the total biofuel mandate.

[6]Firms also generate D3 RINs by producing cellulosic ethanol. Because little cellulosic ethanol has been produced to date, the D3 RIN market is relatively illiquid and therefore is not considered in this paper.

Due to technical and regulatory restrictions, ethanol is not blended into gasoline in continuous intervals. The primary ethanol-gasoline blends sold in the U.S. are E10 (fuel with a 10% ethanol-gasoline blend) and E85 (fuel with a 51%-83% ethanol-gasoline blend).[7] Before 2013 the fuel industry was able to comply cheaply with the RFS by switching gasoline sold in most markets from E0 (pure gasoline) to E10. By 2013, little E0 was still sold in the U.S. (Energy Information Agency, 2016a).

The 2014 statutory mandates began to require greater volumes of ethanol than could be consumed with a national E10 blend. This barrier is often referred to as the 'blend wall.' The fuel industry has two primary compliance options to meet the mandates beyond the blend wall. First, the industry can increase consumption of E85. However, widespread adoption of E85 is hampered by network and coordination issues. E85 requires both consumers to own special vehicles, known as flex fuel vehicles (FFVs), as well as for gasoline stations to invest in fueling infrastructure. A second compliance option is to increase blending of biomass-based diesel, where blending constraints are less binding. Both options are costly and require high RIN prices. The latter option is expensive due to high feedstock and production costs, while the former requires E85 prices to be low relative to E10 prices to spur demand, increase investments in FFVs, and increase the number of stations offering E85. Babcock and Pouliot (2015) argue that E85 could breach the blend wall and meet the original RFS mandates. However, doing so would require sustained high RIN prices being passed-through to E85 prices to stimulate demand for the fuel.

2.1 2014-2016 RFS Mandates and RIN Markets

RINs traded below \$0.10/gal before 2013, reflecting the fuel industry's ability to easily comply with the mandates by phasing in E10 across the country. In early 2013, as it became apparent that the volumetric mandates would exceed the blend wall, RIN prices rose rapidly. The EPA responded to concerns about the potentially harmful impacts of high RIN prices in its 2013 final rule by stating that it would likely set the 2014 mandates below statutory levels. The announcement caused RIN prices to collapse. A subsequent Reuters article leaked an early version of the 2014 mandates, revealing that the proposed 2014 mandate level would not only be below statutory levels but below the 2013 mandates. This caused RIN prices to fall further. The subsequently proposed rule was released in November 2013, at which point RIN markets bottomed out.[8]

The 2014 proposed rule set off a prolonged period of stakeholder feedback and regulatory delay. A final rule was not released until May 2015, when the EPA issued a joint proposal for the 2014, 2015, and 2016

[7] Fuel containing 10.5% to 15% ethanol-gasoline blends (E15) is approved by the EPA for use in vehicles produced after 2001; however, stations selling the fuel must meet a number of requirements including implementing mis-fueling mitigation plans to prevent older vehicles from using the fuel. Likely due to liability concerns, few stations offer E15 to date, and E15 sales constituted less than 0.5% of all fuel sales in 2015 and 2016 (Energy Information Agency, 2016a).

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

mandates. In the rule, the EPA increased the mandates relative to the proposed rule published in 2013; however, the levels were 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 to the rule 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 at the end of our observation period.

2.2 RIN Prices and the E85 Subsidy

We construct our measure of the net E85 subsidy using RIN prices reported by the Oil Price Information Service (OPIS). We assume that every gallon of ethanol generates a D6 RIN, i.e., is corn ethanol.[9] The net tax for each gallon of ethanol, therefore, equals:

$$\tau_{E100} = -P_{D6}.$$

Our estimate of the subsidy for E85 depends on: (i) the relative blend rates of ethanol and gasoline in the fuel; and (ii) whether we assume RINs are passed-through to wholesale fuel prices. Despite its name, E85 seldom contains as much as 85% ethanol. Blending rates for E85 change seasonally and depend on the region of the U.S. in which the fuel is sold. The Energy Information Administration estimates that E85 contains anywhere between 51% and 83% ethanol by volume (Energy Information Agency, 2016a). We use blending standards set by ASTM International to designate the E85 blend rates. ASTM publishes ethanol content requirements for Summer, Spring/Fall, and Winter blends.[10]

In our main specification, we include as control variables the wholesale prices of gasoline and ethanol. Burkholder (2015) argues that wholesale ethanol prices include RINs, i.e. when a party purchases ethanol using a CME contract they buy both the physical ethanol as well as the RIN credit associated with the fuel that can be sold once it has been blended and sold to retail stations. Thus, every gallon of E85 generates a RIN subsidy equal to the blend rate of ethanol in E85 times the RIN price. Knittel et al. (2015) show that RIN costs are fully and immediately passed through to wholesale gas prices. Thus, we assume that the costs attributable to the RFS to gasoline are already reflected in wholesale gasoline prices. We, therefore, do not

[9]The value does not change much if we assume a certain portion of ethanol is advanced ethanol as D5 RINs and D6 RINs traded closely to one another over the sample period.

[10]Summer blends (Class 1) are classified by ASTM standards and must contain a minimum 79% ethanol blend. Spring and Fall (Class 2) blends must contain a minimum 74% ethanol blend. Winter blends (Class 3/4) must contain a minimum 70% ethanol blend. See Alleman (2011) for more information regarding minimum blending requirements. Volatility class by month for Iowa, Minnesota, and Illinois are designated using Table E.1 from Department of Energy (2016). Independent testing has shown that actual blending follows relatively closely to these standards (Alleman, 2011).

adjust the subsidy for ethanol in E85 downward by the value of the RIN tax on gasoline in E85, and specify the net RIN tax for E85 in season j as:

$$\tau_{E85} = B_{E85,j}\tau_{E100}, \tag{1}$$

where $B_{E85,j}$ is the ASTM blending standard for E85 in season j.[11] For example, if the RIN price is \$1.00 and the ethanol blend rate is 75%, the net RIN tax equals -\$0.75/gal.

Figure 3c graphs the subsidy for E85, equal to $-\tau_{E85}$, from 2013 to 2016, as well as the timing of the policy developments discussed in Section 2.1. While the subsidy averaged \$0.44/gal, it varied considerably, ranging from \$0.05/gal to over \$1.00/gal. The subsidy was especially volatile in the weeks following policy developments described above. In general, the subsidy decreased following news that moved the expected mandates below the blend wall and increased following news that moved the expected mandates above it. Thus, the primary source of variation in the RIN subsidy that we exploit is that induced by the policy announcements, the timing of which are largely determined by the enacting legislation and requirements for the EPA to address stakeholder feedback and legal challenges. To the extent that regulatory and legal considerations determined the timing of the announcements, the historical variation is plausibly exogenous to local E85 market conditions.

2.3 Retail E85 and Wholesale Price Data

Publicly available prices for retail E85 are sparse and mostly available in aggregated series. Knittel et al. (2015) 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.[12] 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 station-level E85 prices from Iowa, Illinois, and Minnesota from OPIS for January 2013 through June 2016. OPIS records daily gasoline prices from over 140,000 stations in the U.S.[13] While OPIS

[11] We test the sensitivity of our constructed E85 net tax in three ways. First, we assumed that all E85 contains 74% ethanol as in Knittel et al. (2015). Second, we estimate specifications in which we assume zero pass-through of RINs to wholesale gasoline. In this case, the constructed net RIN subsidy equals:

$$\tau_{E85} = (1 - B_{E85,j})\tau_{E0} + B_{E85,j}\tau_{E100}.$$

Last, in Appendix A.2 we use an instrumental variables strategy to explore potential endogeneity concerns. The IV strategies would also correct for classical measurement error in the construction of the E85 subsidy measure. Our pass-through estimates are similar in all instances.

[12] Reports are available at http://www.afdc.energy.gov/fuels/prices.html.

[13] Prices are recorded using fleet credit card transactions, direct feeds from stations, and phone surveys.

has detailed prices for regular, mid-grade, and premium gasoline, its coverage of retail E85 prices is relatively sparse. The three states were chosen primarily because coverage of station-level E85 prices is best in the Midwest. Despite the relatively higher coverage of E85 prices in the region, the data have several limitations. First, while OPIS reports daily prices, many stations report prices in less frequent intervals. As a result, we collapse the data to average weekly prices, where stations have less reporting gaps.

In addition, OPIS reports prices for only a subset of E85 stations in the states. The AFDC maintains a list of E85 stations in the United States.[14] As of July 2016, AFDC reported that 2,797 stations offered E85, of which 735 (over 25%) were in Iowa, Illinois, or Minnesota.[15] After restricting the sample to stations that report prices for more than 16 weeks, our data contain 451 stations, representing over half of the stations that sell E85 in the region.[16] Figure 2 maps the location of the stations included in our analysis in orange and green along with the locations of all other stations reported as selling E85 by the AFDC. As can be seen, OPIS' coverage is relatively balanced geographically. While most of the stations are located in major metropolitan areas, we also observe many stations in rural locations.

We include as control variables wholesale ethanol and gasoline costs. We use prompt-month ethanol futures prices from the Chicago Mercantile Exchange (CME) downloaded from Quandl to control for spot wholesale ethanol costs. To control for wholesale spot gasoline prices, we use prompt-month New York Harbor RBOB gasoline futures from the Intercontinental Exchange (ICE). The series are included in our analysis for three reasons. First, the wholesale prices help to better explain variation in E85 prices over the sample period. Both gasoline and ethanol markets were volatile between 2013 and 2016, with wholesale gas prices falling from \$3.00/gal in 2013 to below \$1.50/gal in late 2014 (Figure 3a). In mid-2014, the ethanol marked experienced a dramatic run-up in price from below \$2.00/gal to above \$3.00/gal before falling sharply again by the end of 2014.[17] Second, previous work has found important dynamic responses of retail fuel prices to changes in upstream wholesale fuel prices (Borenstein et al., 1997). Last, the wholesale prices should theoretically affect RIN values themselves (Lade et al., 2016), and are therefore correlated with the E85 subsidy.

We use two types of measures to proxy for imperfect competition in retail fuel markets. First, we study whether pass-through varies by stations' ownership structures. In particular, we test whether stations

[14] See http://www.afdc.energy.gov/fuels/ethanol_locations.html.

[15] Some groups have raised concerns that the DOE's coverage of E85 stations is incomplete (Jessen, 2015). This is evidenced in our data by the presence of 36 of the 451 stations that report E85 prices to OPIS that do not appear in the AFDC list. The omission of some stations may inhibit our identification of the impact of market structure on pass-through as we use the reported location of stations from OPIS and AFDC to construct our measures of E85 station density. To our knowledge, the OPIS and AFDC datasets represent the most complete list of E85 stations.

[16] In the restricted sample, stations report prices on average for 94 weeks, and 68 stations report prices for more than 130 weeks.

[17] The ethanol price spike was largely driven by rail supply constraints caused by the 'polar vortex' that hit the Midwestern United States in 2014.

that are either affiliated with a vertically integrated oil company or stations that are affiliated with major, independent retail fuel chains exhibit differential pass-through than other stations in our sample. These types of ownership measures are commonly used in the literature studying market power in retail gasoline markets (Hastings, 2004; Stolper, 2015). The literature on retail gasoline competition has also found 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. In addition, we also include indicators for whether a station is affiliated with a large retail chain. These chains are not affiliated with upstream refiners, however, their operations are typically more advanced than a typical independent gasoline station.

Table 1 and Figure 3 summarize and graph the data used in our analysis. On average, E85 prices were \$2.21/gal. E85 prices exhibit both substantial spatial and temporal variation, with an average minimum price of \$1.08/gal and a high of \$4.17/gal. Prices at major branded stations are \$0.12/gal higher than average, while prices at major retailers are \$0.06/gal lower than average. Stations are on average less than 7 miles away from a competitor that offers E85. However, the distance between competitors ranges between 0.02 miles to over 100 miles.[18]

3 Pass-Through to Retail E85 Prices

In this section, we discuss our identification strategy to study pass-through of the E85 subsidy and wholesale fuel costs to retail E85 prices (Section 3.1). Given inconclusive results from stationarity and cointegration tests (see Appendix A.1), we use multiple empirical strategies to ensure that our conclusions are not sensitive to whether the series exhibit a stationary, long-run relationship. Section 3.2 presents our main pass-through results. We discuss both long-run pass-through and short-run dynamics. Section 3.3 tests whether local market structure impacts pass-through of the subsidy and wholesale fuel costs and Section 3.5 discusses the implications of our findings.

3.1 Empirical Strategy

The objective of our empirical analysis is to estimate the long-run relationship between retail E85 prices, the upstream subsidy for E85, and its component wholesale costs. The simplest model of this relationship that we could estimate would be a linear OLS regression of the form:

$$Y_{it} = \alpha_i + \beta_{\text{eth}}[B_{E85}e_{it}] + \beta_{\text{gas}}[(1 - B_{E85})g_{it}] + \beta_\tau[\tau_{E85,t}] + \epsilon_{it} \quad (2)$$

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

where Y_{it} is the retail E85 price at station i in week t, α_i is a station-specific markup, e_{it} is the station's wholesale ethanol cost, g_{it} is the station's wholesale gasoline cost, B_{E85} is the ethanol blend rate in E85, $\tau_{E85,t}$ is the E85 net tax, and β_i are the pass-through coefficients for each upstream cost.[19]

Estimating equation (2) is infeasible and potentially undesirable for a number of reasons. Because we do not observe station-specific wholesale costs, we proxy for stations' wholesale costs using exchange-traded bulk wholesale prices for gasoline and ethanol such that $[e_{it}; g_{it}] = [e_t; g_t]$ for all i. In addition, equation (2) imposes a number of restrictions on stations' equilibrium price functions. First, it assumes that prices are additively separable, and that pass-through is constant for each cost. While additive separability seems natural in our setting as fuel distributors can either purchase pre-blended E85 or purchase and blend ethanol and gasoline themselves at or above the rack, non-linearities in the data generating process would bias our estimates. Constant pass-through is a common assumption in the literature estimating pass-through, though the assumption relies on a particular class of demand systems (Bulow and Pfleiderer, 1983; Miller et al., 2017). Equation (2) also assumes that OLS consistently estimates the long-run relationship between the upstream costs and retail fuel prices, i.e., that the series are cointegrated. If the series exhibit high degrees of serial correlation, the OLS coefficients may not consistently estimate the long-run relationship between upstream costs and downstream prices. In addition, equation (2) is unable to account for lagged adjustment in retail prices that have been shown to be an important feature of retail fuel markets.[20]

To account for potential lagged adjustment of retail prices to changes in upstream costs in our main specification, we estimate a cumulative dynamic multiplier (CDM) model given by:

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

where $\mathbf{X}_t = [e_t; g_t; \tau_{E85,t}]$ and γ_τ are month fixed effects to control for seasonality in stations' average mark-ups. The coefficients β_j are cumulative pass-through rates from $\mathbf{X}$ to retail fuel prices after $j \in [0, L]$ periods.[21] Note that we do not adjust the wholesale ethanol and gasoline costs by their relative blend rates. Thus, the estimated coefficients should reflect both the pass-through rates of wholesale fuel costs to retail prices as well as the relatively blend rates of ethanol and gasoline in E85.

[19]Recall that the subsidy is constructed in equation (1) so that negative values represent a subsidy. Thus, a \$1.00/gal increase in τ_{E85} corresponds to a \$1.00/gal decrease in the subsidy. .

[20]An additional concern may be the degree of collinearity, particularly between wholesale ethanol and gasoline prices. To test for this, we computed the variance inflation factor (VIF) for each variable after estimating equation (2). The VIFs for ethanol and RBOB are around 5 and the VIF for the ethanol subsidy is around 1. While the VIFs on the wholesale fuel costs are relatively high, they are well below conventional levels that warrant concern.

[21]We could alternatively estimate a model of the form:

$$Y_{it} = \alpha_i + \sum_{j=0}^{L} \delta_j \mathbf{X}_{t-j} + \gamma_\tau + \epsilon_{it}.$$

In this case, the cumulative pass-through after K periods equals $\sum_{j=0}^{K} \delta_j$. Model (3) represents a more convenient, but functionally equivalent, method to estimate cumulative pass-through.

We also include first-differenced specifications with no station or month-by-year fixed effects given by:

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

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

Equations (2)-(4) assume that stations' pricing decisions are not a function of other stations' prices. However, if stations have market power in E85, both the overall 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 structure. Specifically, we interact $\mathbf{X}_t$ with indicators for whether a station is affiliated with a major, vertically integrated refining company or a large independent gasoline retailer.[22] Stations owned by branded major oil companies often have centralized pricing, and have been the subject of previous studies of market power in retail fuel markets (Borenstein et al., 2004; Hastings, 2004). Major independent gasoline retailers typically purchase ethanol and gasoline 'above the rack' (e.g., from refiners directly) rather than from wholesale fuel terminals. As a result, many of these chains separate and market RINs themselves, and several market participants have accused these retailers of realizing 'windfall' profits from RINs.[23]

Second, we interact $\mathbf{X}_t$ with indicators for the distance between stations and their nearest competitor offering E85. Specifically, we create indicator variables for whether a station is greater than 5 or 10 miles from its nearest competitor. The model is consistent with a Bertrand-Nash equilibrium where stations compete in localized geographic markets (Pinkse et al., 2002), and similar empirical strategies have been used in recent studies of cost pass-through in other industries (e.g., Miller et al. (2017)). Because we control for fixed characteristics of stations, identification of differential pass-through at stations that may have market power comes from temporal variation in RIN and fuel prices as well as from the entry of new E85 stations. Thus, we control for any time-invariant correlation between the location of stations and prices such as stations locating in places where unobserved demand is high or costs are low. Despite this, our estimates may be biased if there is unobserved, time-varying correlation between our measures of market structure and firm's pricing residual.

Note that while Y_{it} are station-level prices, all variables in $\mathbf{X}_t$ are national prices. Thus, if stations respond similarly to changes in national average values of $\mathbf{X}_t$, panel-robust standard errors clustered at the station would overstate our inference. Heteroskedasticity is especially important in our setting because some large retail chains appear to use centralized pricing strategies. As such, we estimate two-way clustered

[22]Stations are designated as 'branded majors' if their gasoline brand is BP, Valero, ExxonMobil, Citgo, Marathon, Cenex, Tesoro, or Phillips 66. All companies are obligated parties under the RFS. In total, we observe 118 branded major stations in our sample. Stations are designated as 'major retailers' if their store brand is Caseys, Fast Stop, Holiday, Kum and Go, Kwik Trip, Murphy USA, or Speedway. In total, we observe 235 major retail stations in our sample.

[23]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).

standard errors at the station and year-month to allow for both autocorrelation and heteroskedasticity in the residuals.[24]

The specifications above assume that contemporaneous and lagged RIN and wholesale market prices are exogenous to E85 prices, conditional on our control variables. 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 and trends in the levels specification, or when using the first differences specification, the primary source of variation in RIN prices are policy developments changing industry expectations of whether the mandates will be above or below the blend wall. Wholesale gasoline prices are largely determined by upstream oil prices that are set on the world market. National and international markets largely determine wholesale ethanol prices, which are principally governed by feedstock supply conditions. Given that E85 constitutes a small share of both the ethanol and gasoline market (<1%), local demand conditions for E85 are unlikely to affect either national price series. Appendix A.2 presents results using an instrumental variables strategy, and results are similar – though noisier – to the specifications shown here.

3.2 Results: Subsidy, Ethanol, and Gasoline Cost Pass-Through

Table 2 provides our pass-through estimates of the E85 subsidy, wholesale ethanol, and wholesale gasoline to retail E85 prices. The CDM models present pass-through estimates after six and eight weeks. To be included in the analysis, a station must report price data for $L+1$ consecutive weeks. Thus, our sample size varies depending on the number of lags included in each specification.

Column (1) presents estimates from the OLS model using the level of contemporaneous prices with station fixed effects. The wholesale ethanol and gasoline costs are unadjusted in the regression. Therefore, if wholesale fuel costs are fully passed-through to retail prices, the coefficients on the fuel prices should reflect the relative blend-rates of ethanol and gasoline in E85, respectively. The estimates suggest that just over half of the RIN subsidy is passed through to retail prices, while a \$1/gal increase in wholesale ethanol (gasoline) costs increase E85 prices by \$0.58/gal (\$0.42/gal). While the wholesale cost coefficients are consistent with ethanol having a larger impact on E85 prices than gasoline, they do not reflect the relative blending ratio of each fuel.

Columns (2)-(5) present pass-through estimates from our CDM model that explicitly allows for lagged adjustment in retail fuel prices to upstream cost shocks. Columns (2) and (3) present the estimated pass-through rates after six and eight weeks, respectively, for the levels specification with month-of-year and station fixed effects, and columns (4) and (5) present similar results for the first-differences model. Estimates for the subsidy pass-through range between 79% and 94% and in no specification can the null hypothesis of

[24] We also explored clustering at the corporation and year-month. Our results are not sensitive to the change.

complete pass-through be rejected. The results suggest that, on average, pass-through is near complete to complete at the stations in our sample.

In all CDM specifications, the estimated coefficients on wholesale ethanol and gasoline costs generally reflect their relative blend rates in E85. The point estimates correspond to a \$1.00/gal increase in wholesale ethanol costs increasing retail E85 prices between \$0.73/gal and \$0.82/gal after eight weeks, while a \$1.00/gal increase in wholesale gasoline increases E85 prices between \$0.29/gal and \$0.38/gal. All specifications reject the null hypothesis of no pass-through, and a test of the hypothesis that the coefficients on ethanol and gasoline sum to unity cannot be rejected.

Estimated pass-through rates for all variables are lower after six weeks than after eight weeks, suggesting that prices may be slow to react to upstream cost changes. To explore this further, Figure 4 graphs the cumulative pass-through rates of each series for both CDM specifications. Week 0 corresponds to the week in which a one-time, \$1.00/gal cost shock occurs. For the E85 subsidy, this corresponds to a \$1.00/gal decrease in the E85 subsidy.

E85 prices do not respond to the initial shock for any of the three variables, and we cannot reject the null hypothesis of zero pass-through for many specifications in week 0. Retail prices begin to increase on average within one week following each cost shock; however, the E85 subsidy and ethanol costs are not entirely passed through until four to six weeks after the shock occurs. In contrast, pass-through of a wholesale gasoline cost shock is relatively quick, taking only one to two weeks.

The delayed pass-through of the subsidy and wholesale ethanol costs conforms with previous studies of retail fuel price responses to oil and wholesale gasoline price shocks. For example, Borenstein et al. (1997) find that oil price increases take three to four weeks to pass-through to retail fuel prices, with oil price decreases taking longer to be pass-through than oil price increases.[25] Lewis and Noel (2011) and Lewis (2011) find that retail prices take between four and eight weeks to adjust to wholesale gasoline cost shocks depending on the competitiveness of the wholesale markets.

Our findings suggest that E85 sold at stations in our sample, on average, reflects its component upstream wholesale fuel costs and the E85 subsidy. The finding supports the notion that price impacts from energy and environmental regulations on upstream firms affect consumer prices. However, the long delays in pass-through rates may be indicative of firms exercising market power in the face of costly supply adjustments (Borenstein and Shepard, 2002), a feature that may have important impacts on the efficiency and cost of market-based regulations. While full pass-through may be reflective of competitive retail and wholesale markets, unit pass-through may also occur if markets are imperfectly competitive. To explore this futher, we estimate pass-through of each variable as a function of our measures of local market structure.

[25] In Appendix A.2 we explore potential asymmetric pass-through and find that asymmetries do not play a major role in our setting.

3.3 Results: Pass-Through and Local Market Structure

Table 3 presents our estimates of the interaction between pass-through and market structure. We present results here for the CDM model in first differences only; however, results are similar for the levels specification with month fixed effects. Column (1) presents results comparing pass-through at branded major versus unbranded stations. Average pass-through estimates for unbranded stations are similar to our previous findings, with complete pass-through of the E85 subsidy as well as ethanol and gasoline wholesale costs being passed through at their approximate blend rates. Branded majors have a \$0.13/gal lower estimated pass-through rate of the E85 subsidy after eight weeks. However, we cannot reject the hypothesis that the stations exhibit the same pass-through as all other stations. We also find that branded majors have higher pass-through of wholesale ethanol costs, and lower pass-through of gasoline costs.

Column (2) presents our results for major independent retailers. The baseline pass-through estimate is 81%, and we estimate the major retailers have \$0.21/gal higher pass-through of the E85 subsidy after eight weeks. The findings suggest that, contrary to suggestions by many market participants, large independent retailers exhibit systematically higher pass-through on average than smaller retailers and branded major stations.

Columns (3)-(4) present results for stations that are further than 5 and 10 miles from other stations offering E85. Consider first pass-through of the E85 subsidy. Stations that are farther from other E85 stations have large and statistically significantly lower estimated E85 subsidy pass-through after eight weeks. The subsidy pass-through rate differences are greater for stations that are more than 10 miles from other stations (\$0.23/gal lower) than for stations that are greater than 5 miles from another station (\$0.10/gal). Stations farther from competitors do not exhibit differential pass-through of wholesale gasoline costs, however, they have lower estimated pass-through of ethanol costs. Thus, E85 prices at stations in rural locations on average have lower estimated pass-through rates of both the E85 subsidy and wholesale ethanol costs. In all cases, the differential pass-through of wholesale ethanol costs is lower than the decreased pass-through rate of the E85 subsidy. Thus, on average, stations that are farther from competitors have higher estimated E85 prices even after controlling for fixed characteristics of the station such as the distance to a wholesale fuel terminal.

Figures 5a - 5f graph the estimated pass-through rates over time for each variable for unbranded versus branded stations in the left column, as well as for stations that are less than and greater than 10 miles from their nearest competitor in the right column. Stations that are branded and have higher local market power in E85 exhibit slower pass-through of the E85 subsidy and ethanol wholesale costs than stations in more contested markets. In contrast, gasoline cost shocks are largely similar across the different stations. The differences in pass-through rates for the E85 subsidy and wholesale ethanol costs at branded versus unbranded stations largely dissipates after two to three weeks, while the difference in pass-through between stations in more isolated vs. more contested markets largely remains even after eight weeks.

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

$$Y_t = \alpha + \sum_{j=0}^{L-1} \beta_j \Delta \mathbf{X}_{t-j} + \beta_L \mathbf{X}_{t-L} + \gamma_\tau + \epsilon_{it}, \qquad \forall i.$$

Given sample size limitations, particularly for stations with less frequent price reports, we are only able to reliable estimate pass-through rates for a subset of stations. In particular, we estimate pass-through for stations that we observe for more than 25 weeks, and that report prices for at least seven consecutive weeks. After dropping all stations that do not satisfy this criterion as well as stations for which the estimated standard errors are very large, we are left with 163 station-specific pass-through estimates.[26] For ease of exposition, we truncate the few negative estimated pass-through rates at zero and the few high pass-through rates at 1. Thus, pass-through rates equal to 1 represent full to overfull pass-through.

Given the focus of the paper, we present pass-through results for the E85 subsidy only here. Figures 6a-6c graph the station-level pass-through rates after six weeks and provide histograms of the pass-through rates for each state. In all three states, the distribution of the subsidy pass-through is bi-modal, with most stations exhibiting either little to negative pass-through or full to overfull pass-through. Consistent with our market-power results, stations in rural areas tend to exhibit lower pass-through rates while stations in metropolitan areas exhibit higher pass-through rates. The majority of stations in Iowa and Illinois exhibit complete pass-through. Full pass-through occurs even for many rural stations in Iowa. In Minnesota, station pass-through rates are bi-modal, consistent with Li and Stock (2017), with stations in the Minneapolis metropolitan area exhibiting near full to full pass-through while rural stations all appear to exhibit low pass-through.

In addition, we graph stations' estimated subsidy pass-through rates as a function of characteristics of the local fuel market. Figure 7 graphs the estimated subsidy pass-through rate after six weeks as a function of: (i) whether the station is branded or unbranded; (ii) the distance between stations and their nearest competitor;[27] (iii) the population density of the county in which the station is located; and (iv) the median home value of the county in which the station is located. The figures graph raw correlations between the subsidy pass-through and the market measures as well as best-fit lines.

In general, the pass-through rates are consistent with a model in which retailers with markets power exhibit lower pass through. Stations that are farther from competitors have lower pass through. Stations that are branded and affiliated with a large, vertically integrated refinery have lower average pass-through rates. Similar to Stolper (2015), we estimate that subsidy pass-through is higher in areas in which proxies

[26] Note that our main results are not driven by the stations with less reliable reporting as evidenced by results in Table B.4. The restricted sample of stations that report greater than two years are the same stations we can reliably estimate station-level pass-through rates for.

[27] Because the distance between stations changes over time with the entrance of new stations offering E85, we present the pass-through rates as a function of the average distance between the stations.

for local customer wealth are higher. Specifically, pass-through is higher in counties that are more densely populated and in counties with higher median home values.

3.4 Resolving Differences with Knittel et al. (2015)

Knittel et al. (2015) (KMS) find full and immediate RIN pass-through to wholesale fuel prices; however, the authors find little to no pass-through of the E85 subsidy retail E85 prices. In contrast, we find complete pass-through on average. Here, we explore the reasons for the divergence in our findings.

KMS study the relationship between the spread between daily E85 and E10 prices reported by the American Automobile Association (AAA) and RIN prices that they adjust to account for the net E10 tax ($\tau_{E85} - \tau_{E10}$). They argue that by studying the spread between E85 and E10 prices, they implicitly control for wholesale price movements in each series. For comparison, we construct a similar dependent variable by averaging the daily E85 prices reported by all stations in our data.[28] We then use the difference between our daily average E85 prices and AAA's daily average U.S. gasoline price obtained from Bloomberg as our dependent variable. Thus, any differences in our empirical results should be driven only by differences in the stations used to construct the daily average E85 price.

We explore four reasons for the difference in our findings with KMS: (i) the specification of the dependent variable; (ii) the lag specification; (iii) the regional sample selection; and (iv) the period over which the study is conducted. We first estimate a CDM model similar to the one estimated in KMS using the E85-E10 price spread as the dependent variable and over the same period that the authors consider. Second, we expand the sample to include the more recent data included in our analysis. Last, we explore specifications with the level of E85 prices with ethanol and gasoline wholesale price controls to demonstrate the importance of controlling for dynamic adjustment of retail prices to upstream wholesale costs and vary the number of lagged RIN and wholesale price series.[29] In all cases, we vary the number of lags included in the model between 15 and 35 days. The former roughly correspond to the number of lags that KMS allow for in their main specification, and the latter is roughly the time that we estimate it takes for retail E85 prices to adjust fully to changes in the RIN subsidy. All specifications include the same seasonality controls used by KMS.[30]

Table 4 presents the results for our estimated cumulative pass-through rates after the specified number of days. Column (1) presents estimates using the same sample as was used by KMS with 15 lags. Column (2) uses the same period but includes 35 lags. Columns (3) and (4) estimate the same two models but include data through 2016. Columns (5) and (6) present the estimates most similar to our specification, allowing for

[28] Some days involve taking the average of only a few prices. Despite this, the series is relatively smooth and follows very closely with the average weekly price series in Figure 3d.

[29] In all specifications where we use the spread between E85 and E10 prices, we use an adjusted RIN subsidy equal to $\tau_{E85} - \tau_{E10}$. When we use the level of E85 prices as the dependent variable, we use the level of the daily RIN subsidy τ_{E85}.

[30] Specifically, seasonal controls are sines and cosines evaluated at the first four seasonal frequencies.

15 and 35 lags, respectively. Column (1) corresponds most closely with the specification reported in Table 7 of KMS. We find that stations pass-through around 9% of the RIN subsidy on average, and we cannot reject the null hypothesis of no pass-through. For comparison, KMS find approximately 18% pass-through. Thus, the average E85 prices from our stations do not systematically exhibit higher pass-through than those reported by AAA, i.e., our findings are not driven by sample selection in using only Midwest E85 stations.

The estimated subsidy pass-through rate increased to 43% when 35 lags are included; however, standard errors are large, and we cannot reject zero pass-through at conventional confidence levels. Columns (3) and (4) include data through 2016 with 15 and 35 lags, respectively. Both point estimates are higher than those from the previous columns, suggesting that the longer sample and more recent data exhibit higher pass-through. When all data is included, we estimate a statistically significant 54% pass-through rate when the longer adjustment period is considered, and cannot reject the null hypothesis of full pass-through at a 10% confidence level (p-value=0.07). Columns (5) and (6) present the estimates using the level of E85 prices as the dependent variable with controls for contemporaneous and lagged upstream ethanol and gasoline wholesale costs. Estimated pass-through rates from all three series are small but statistically significant after 15 days. When 35 lags are included, however, we find similar results as in our main specification with 88% pass-through of the E85 subsidy.

Overall the results suggest that the primary reasons for the differences in our results are the number of lags considered, the extended sample period used in this study, and the empirical specification. In particular, the results suggest that controlling for lagged adjustment, both for upstream wholesale costs as well as upstream RIN values, is important when studying pass-through in the current setting.

3.5 Discussion and Robustness

Figure 8 summarizes our findings graphically. The figure graphs the average retail taxes for E85 along with our estimated wholesale gasoline (blue) and ethanol (orange) cost components of E85. The black line is the average retail E85 price for all stations in our data, and the red line adjusts the average retail prices upward by the value of the RIN subsidy. When we do not account for the subsidy, average retail margins over the sample are -\$0.09/gal, with sustained losses from selling E85 from 2015-2016. Once we account for the value of the RIN subsidy, however, average retail margins increase to \$0.33/gal, in line with conventional retail margin estimates from selling other fuels. Thus, we can rationalize historical E85 prices only if we allow for pass-through of the E85 subsidy. Also apparent in the figure is the lagged adjustment of the retail price series to sharp changes in wholesale costs, with our estimated margins shrinking towards zero following cost shocks and increasing slowly after.

We explore the robustness of our regression results in Appendix A.2 in a number of ways. First, we consider whether pass-through rates have changed over time. RIN markets and E85 fuel are relatively new additions to the transportation fuel sector. In contrast to fuel tax changes that are discrete and known in advance of when they are enacted, upstream subsidies and taxes from the RFS have been volatile since 2013. This feature of RIN markets increases the complexity of marketing arrangements between firms and may cause pass-through rates in early years to differ from more recent years. However, we find little evidence that pass-through rates differ in the first versus the second half of our sample. Our results are robust to a number of other specifications, including limiting our attention to stations that report prices more reliably and using a variety of instrumental variables strategies.

4 Conclusions

Through the Renewable Fuel Standard (RFS), the U.S. Government has set aggressive goals for the expansion of alternative fuels in the U.S. transportation sector. Because of technical limits on the blending of ethanol with conventional fuel, meeting these RFS requirements will require an increase in the consumption of both E85 and biodiesel. Increasing demand for E85 has therefore become a major policy objective of both the EPA and the U.S. Department of Agriculture. Both Agencies have primarily focused on improving E85 fueling infrastructure.[31] Given current limits in the number of pumps and vehicles capable of consuming E85, along with its lower energy content, increasing demand for the fuel almost certainly require a persistently high RIN value *and* a coincident reduction in the relative cost of E85 to E10 (Babcock and Pouliot, 2013, 2015). However, policy-makers and industry have raised concerns that the value of RIN subsidies is not being reflected in retail prices, thereby threatening the price-based mechanism through which ethanol consumption was to be expanded by the RFS.

Using detailed, station-level data, we find that, contrary to this perception, retail E85 prices do in fact, on average, reflect upstream subsidies and wholesale fuel costs. As with previous studies of the effects of wholesale gasoline and oil cost shocks, however, we find important deviations from competitive pricing at some stations. In particular, we find that the long-run subsidy pass through to E85 is lower at stations that likely have market power in selling the fuel. In addition, pass-through of both the E85 subsidy and wholesale fuel costs is delayed significantly, taking on average four to six weeks to be complete.

Despite the storability of fuel, delayed pass-through of upstream wholesale costs is a common finding in the literature. The literature has proposed a number of explanations for the presence of such delays. Borenstein and Shepard (2002) find that delayed pass-through is consistent with a model with costly supply adjustment and market power. If refiners and biofuel plants are unable to change their production schedules immediately in response to changes in RIN or wholesale price changes, prices will respond slowly over time as production adjusts to reach a new equilibrium. Other authors have presented competing theories to explain

[31] In 2015 the USDA announcing a $130 million Biofuel Infrastructure Partnership program with the explicit goal of expanding high-ethanol blending pumps.

delayed adjustment including costly consumer search (Johnson, 2002) and the presence of menu costs (Davis and Hamilton, 2004).

While we are unable to distinguish between competing explanations for lagged adjustment of E85 prices, all carry equity implications. Given the large fluctuations in RIN values, even short delays in pass-through leave room for upstream firms to capture significant rents. In addition, the lower pass-through estimates after eight weeks among firms that are greater than 10 miles from their nearest competitor suggests that some stations can charge persistently higher E85 prices. Thus, more research is necessary to determine both the reasons for and the sources of market power as it relates to the RFS.

While complete pass-through does not alone imply that E85 meet the future RFS obligations, our work along with the work by Pouliot and Babcock (2017) that shows that demand for E85 is highly elastic when it is priced to be less expensive than E10 on an energy equivalence basis implies that the market mechanism underlying the RFS is operating as intended in the enacting legislation. However, market power does appear to play a role in RIN pass-through, which may limit the effectiveness of such policies, particularly as E85 pumps expand to areas where the technology is relatively new and few stations offer the fuel. As such, more work is needed to improve data collection of alternative fuel prices and sales to gain a better understanding of pricing dynamics as well as public demand for these new fuels. In addition, further studies of pass-through from environmental and energy policies are necessary to understand the efficiency and distributional impacts of such policies more completely.

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5 Tables and Figures

Table 1: Summary Statistics

Variable	Mean	Std. Dev.	Min.	Max.	N
E85 ($/gal)	2.21	0.56	1.08	4.17	29,938
Branded Major	2.33	0.61	1.2	4.17	6,919
Major Retailer	2.15	0.52	1.08	3.76	17,246
E85 Subsidy ($/gal)	-0.44	0.16	-1.10	-0.05	29,938
RBOB ($/gal)	2.06	0.70	0.95	3.15	29,938
Ethanol ($/gal)	1.81	0.40	1.32	3.24	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 Rival (miles)	6.86	8.68	0.02	103.23	29,938

Table 2: E85 Subsidy Pass-Through

	(1)	(2)	(3)	(4)	(5)
E85 Subsidy ($/gal)	0.527***	0.790***	0.807***	0.844***	0.940***
	(0.119)	(0.060)	(0.062)	(0.115)	(0.119)
Ethanol ($/gal)	0.583***	0.811***	0.817***	0.633***	0.731***
	(0.156)	(0.060)	(0.059)	(0.070)	(0.077)
Gasoline ($/gal)	0.419***	0.294***	0.291***	0.367***	0.381***
	(0.073)	(0.029)	(0.031)	(0.089)	(0.097)
Observations	29,938	18,722	16,772	17,713	15,913
Model	OLS	CDM	CDM	CDM	CDM
Specification	Level	Level	Level	FD	FD
Lags (Weeks)	N/A	6	8	6	8
Station FE	Yes	Yes	Yes	No	No
Month FE	No	Yes	Yes	No	No

The dependent variable is the retail E85 price ($/gal). The CDM columns present estimates of the cumulative dynamic multipliers for each variable after the number of lagged periods specified in the bottom panel. Standard errors are robust to heteroskedasticity and are two-way clustered at the station and year-by-month. *, **, *** denotes significance at the 10%, 5%, and 1% level.

Table 3: E85 Subsidy Pass-Through & Market Structure

	(1)	(2)	(3)	(4)
E85 Subsidy ($/gal)	0.978***	0.810***	0.992***	0.999***
	(0.141)	(0.130)	(0.118)	(0.121)
× Branded Major	-0.132			
	(0.121)			
× Major Retailer		0.213**		
		(0.088)		
× > 5 mi. to E85 Station			-0.101	
			(0.063)	
× > 10 mi. to E85 Station				-0.234***
				(0.059)
Ethanol ($/gal)	0.706***	0.665***	0.781	0.767
	(0.085)	(0.078)	(0.091)	(0.083)
× Branded Major	0.117			
	(0.115)			
× Major Retailer		0.104		
		(0.084)		
× > 5 mi. to E85 Station			-0.098**	
			(0.041)	
× > 10 mi. to E85 Station				-0.150**
				(0.062)
Gasoline ($/gal)	0.409***	0.371***	0.373	0.377
	(0.110)	(0.086)	(0.104)	(0.099)
× Branded Major	-0.142			
	(0.112)			
× Major Retailer		0.015		
		(0.058)		
× > 5 mi. to E85 Station			0.016	
			(0.039)	
× > 10 mi. to E85 Station				0.018
				(0.039)
Observations	15,913	15,913	15,913	15,913
Model	CDM	CDM	CDM	CDM
Specification	FD	FD	FD	FD
Lags (Weeks)	8	8	8	8

The dependent variable is the first difference of the retail E85 price ($/gal). **1**(Branded Major) is an indicator variable for whether a station is affiliated with a large, vertically integrated oil company. **1**(Major Retailer) is an indicator for whether the station is affiliated with a large, independent gasoline retail company. **1**(> 5 mi. to E85 Station) and **1**(> 10 mi. to E85 Station) are indicator variables that equal 1 the closest rival station selling E85 is more than 5 (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.

Table 4: E85 Subsidy Pass-Through: Daily CDM Model

	(1)	(2)	(3)	(4)	(5)	(6)
Dep. Variable	E85-E10	E85-E10	E85-E10	E85-E10	E85	E85
E85 Subsidy ($/gal)	0.093	0.429	0.123	0.537**	0.326***	0.884***
	(0.135)	(0.328)	(0.140)	(0.257)	(0.109)	(0.163)
Ethanol ($/gal)					0.406***	0.668***
					(0.068)	(0.078)
Gasoline ($/gal)					0.403***	0.347***
					(0.086)	(0.116)
Observations	524	504	843	824	853	833
Lags (Days)	15	35	15	35	15	35
Period	KMS	KMS	Full	Full	Full	Full

The table presents estimates of the cumulative dynamic multipliers for each variable after the number of lagged days specified in the bottom panel. Standard errors are Newey-West with 30 lags. All specifications include seasonality controls as in KMS. The 'KMS' period is 1/1/2013-3/10/2015 and the 'Full' period is 1/1/2013-6/30/2016. Differences in observations across specifications arise due to differences in lag structures and due to availability of AAA average gasoline price, which we have only through 6/1/2016. *, **, and *** denotes significance at the 10%, 5%, and 1% level.

Figure 1: Fuel Market Structure and RIN Markets

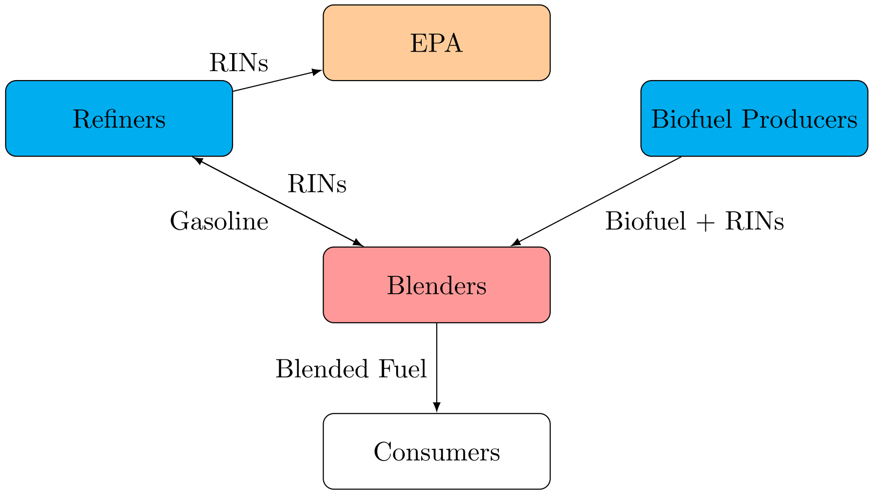
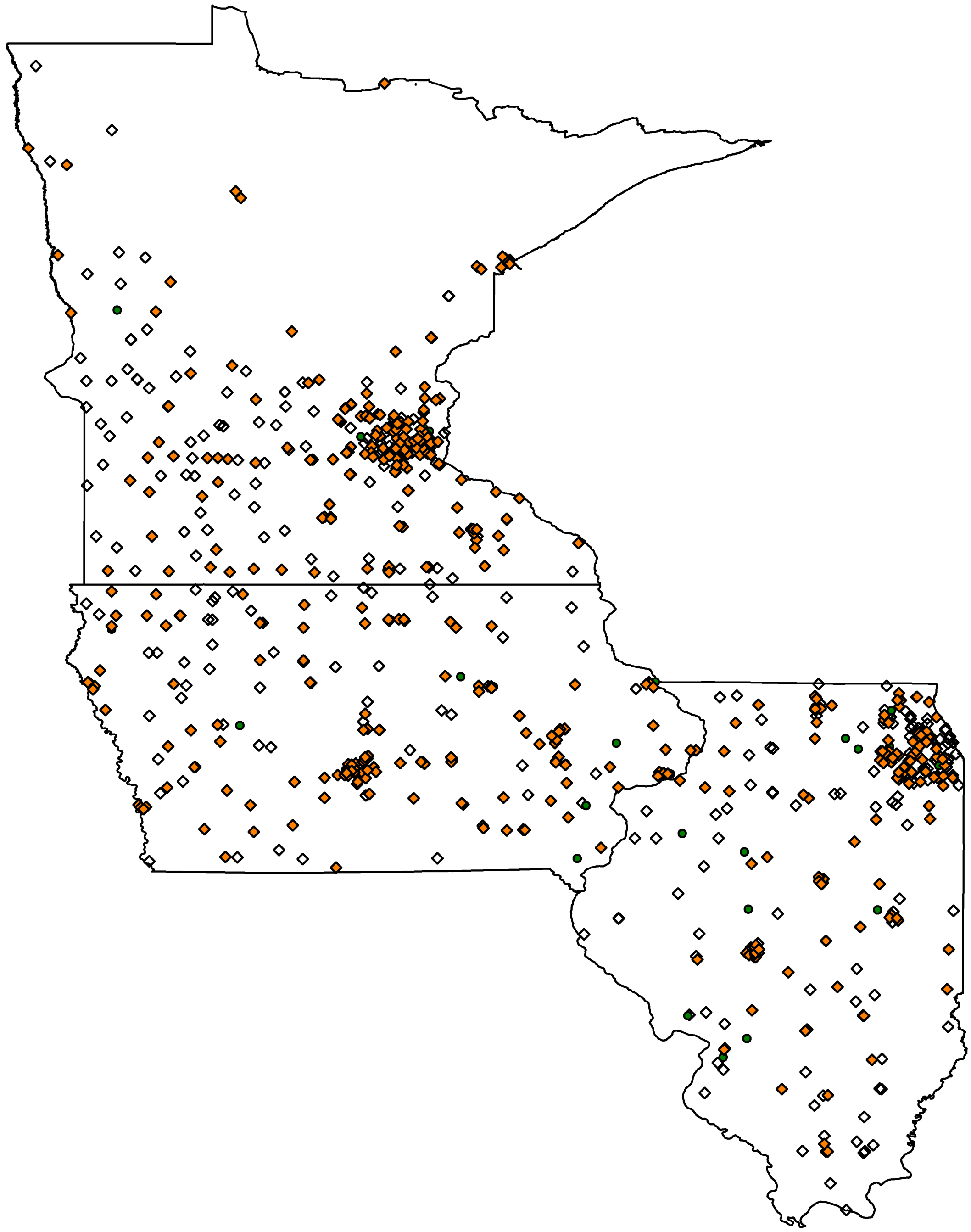
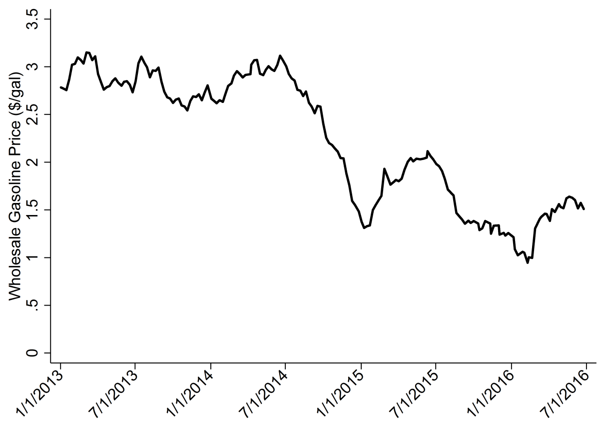


Figure 2: E85 Stations in Iowa, Illinois, and Minnesota

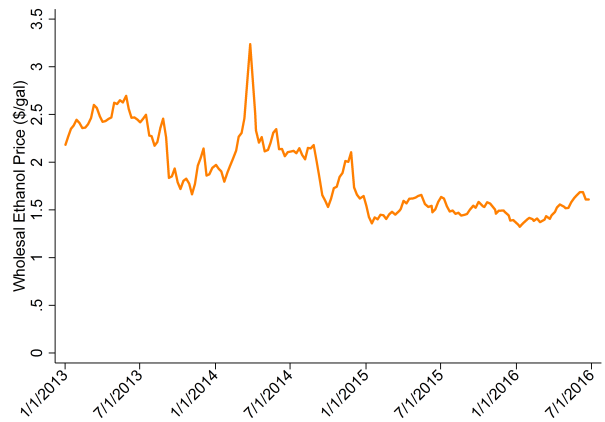


Note: The figure graphs the location of all E85 stations reported by the Department of Energy's Alternative Fuel Data Center (AFDC) and OPIS from 2013-2016. Black hollow diamonds represent stations reported as selling E85 by the AFDC, orange diamonds represent stations that report E85 prices to OPIS and are in the AFDC database, and green circles represent stations that report E85 prices to OPIS but are not in the AFDC database.

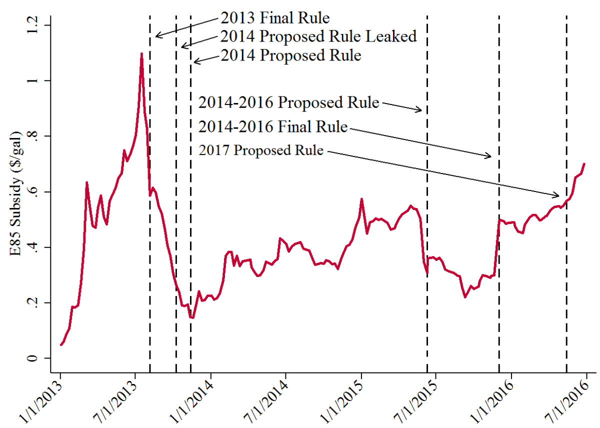
Figure 3: Wholesale Fuel Prices, E85 Prices and the E85 subsidy



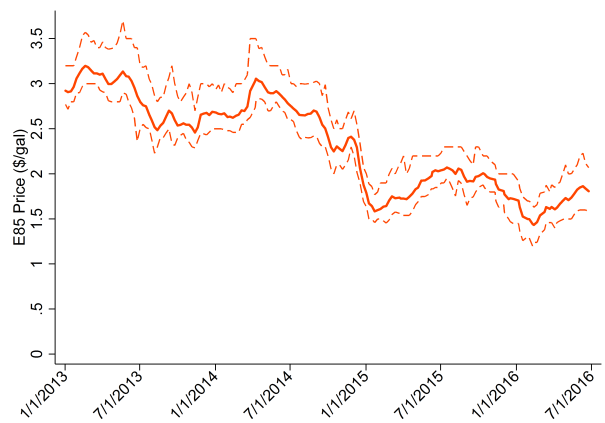
(a) Wholesale Gasoline Prices



(b) Wholesale Ethanol Prices



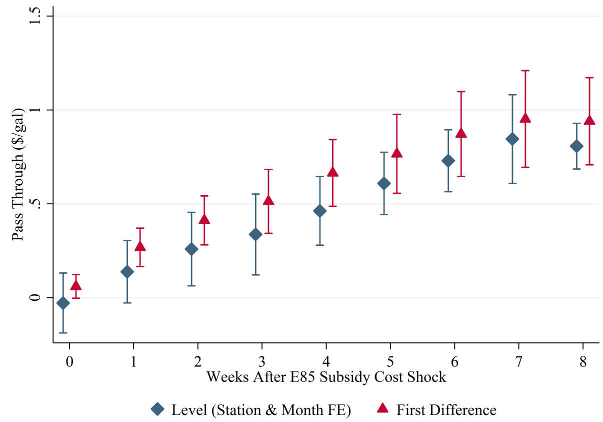
(c) E85 Implicit Subsidy and E0 Implicit Tax



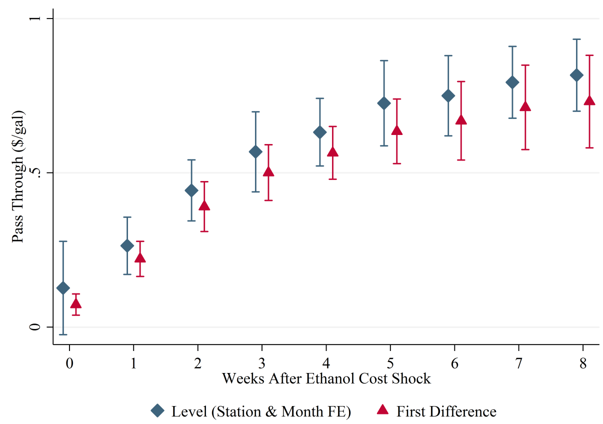
(d) Average E85 Prices (IA, IL, MN)

Note: Figures 3a and 3b graph wholesale gasoline prices and ethanol prices in the U.S. from 2013-2016. Figure 3c graphs the value of the E85 subsidy for E85 in red (solid line) and the timing of key RFS policy developments between 2013 and 2016. Figure 3d graphs the mean, 5th percentile, and 95th percentile of the E85 prices in our sample of stations.

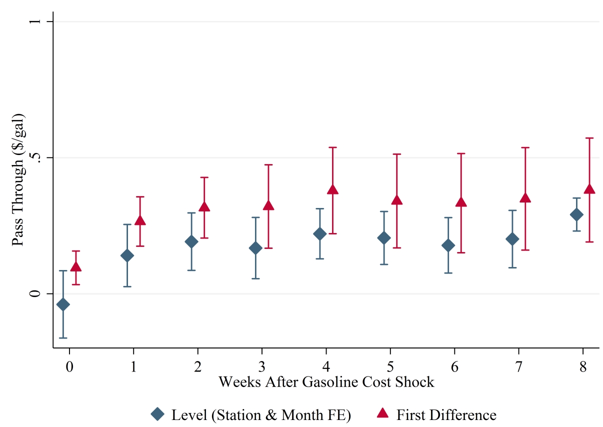
Figure 4: Pass-Through of Upstream Costs to Retail E85 Prices



(a) E85 Subsidy



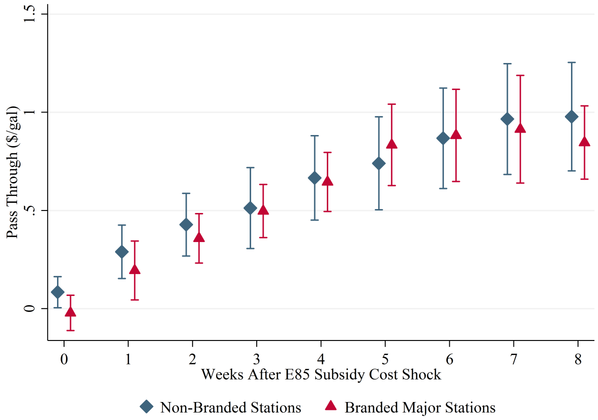
(b) Wholesale Ethanol



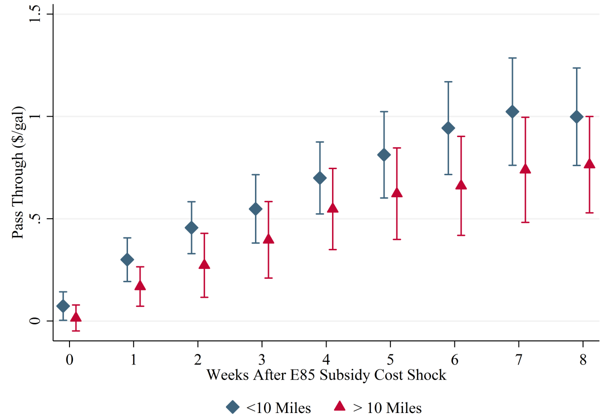
(c) Wholesale Gasoline

Note: The figure graphs the average speed with which a shock to the upstream E85 subsidy, wholesale ethanol price, and wholesale gasoline price are reflected in retail E85 prices. Estimates are presented using two empirical specifications: (i) a first-differenced CDM model and a CDM model with all variables specified in levels with month and station fixed effects. All cost shocks occur in week 0.

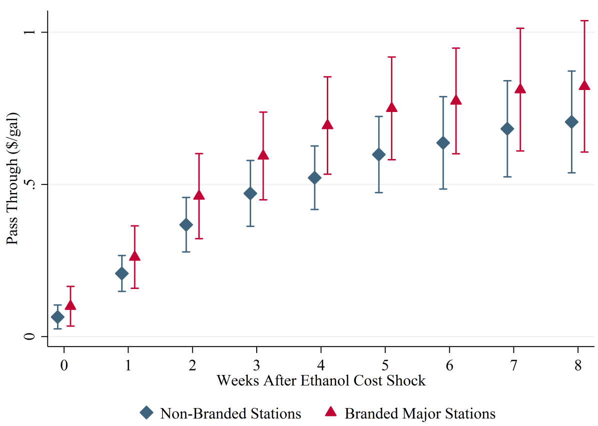
Figure 5: Pass-Through of Upstream Costs to Retail E85 Prices and Local Market Structure



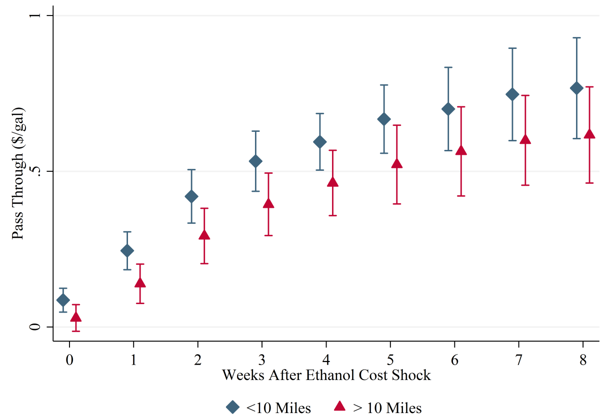
(a) E85 Subsidy: Branded vs. Non-Branded



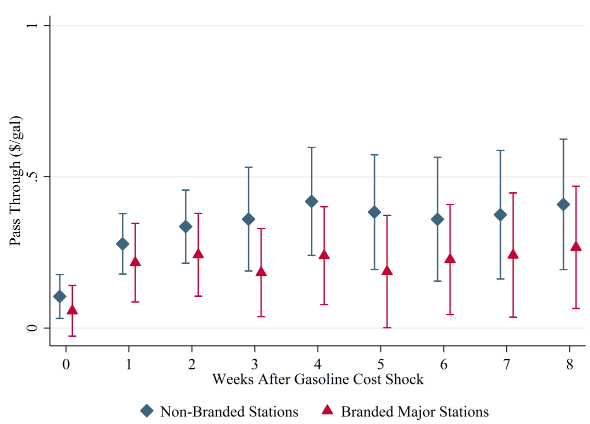
(b) E85 Subsidy: Distance to Rival



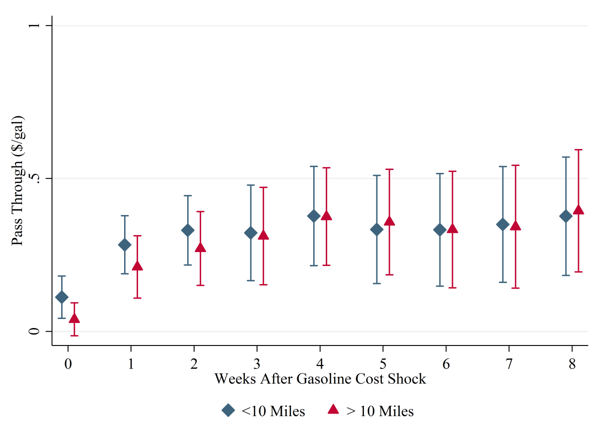
(c) Wholesale Ethanol: Branded vs. Non-Branded



(d) Wholesale Ethanol: Distance to Rival



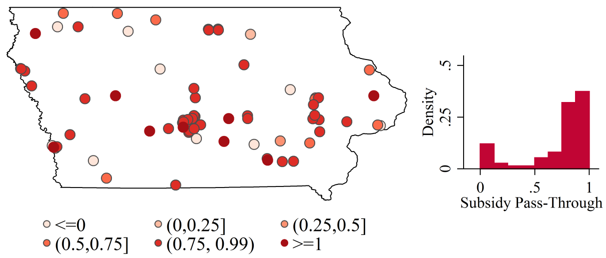
(e) Wholesale Gasoline: Branded vs. Non-Branded



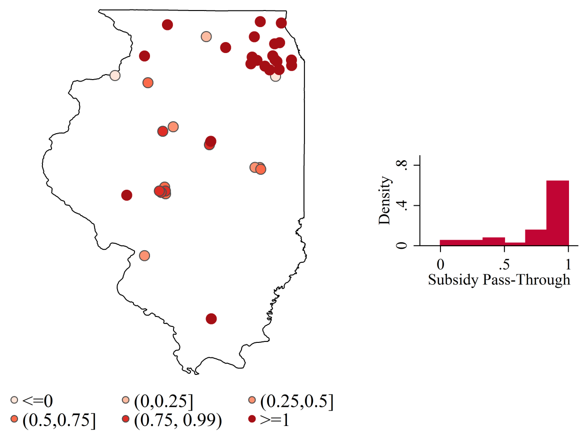
(f) Wholesale Gasoline: Distance to Rival

Note: The figure graphs the average speed with which a shock to the upstream E85 subsidy, wholesale ethanol price, and wholesale gasoline price are reflected in retail E85 prices broken out by two measures of market structure: (i) whether stations are branded (left column); and (ii) whether stations are close or far from their nearest rival (right column). Cost shocks occur in week 0.

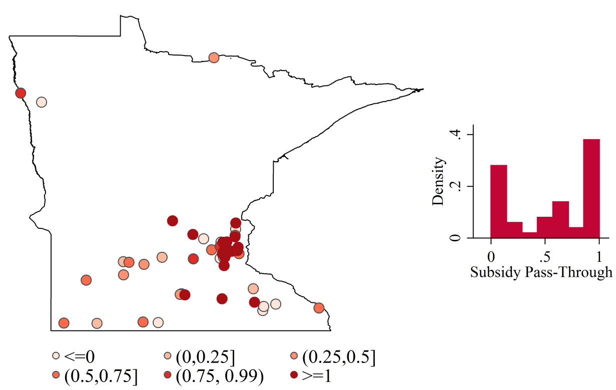
Figure 6: Station-Level E85 Subsidy Pass-Through



(a) Iowa



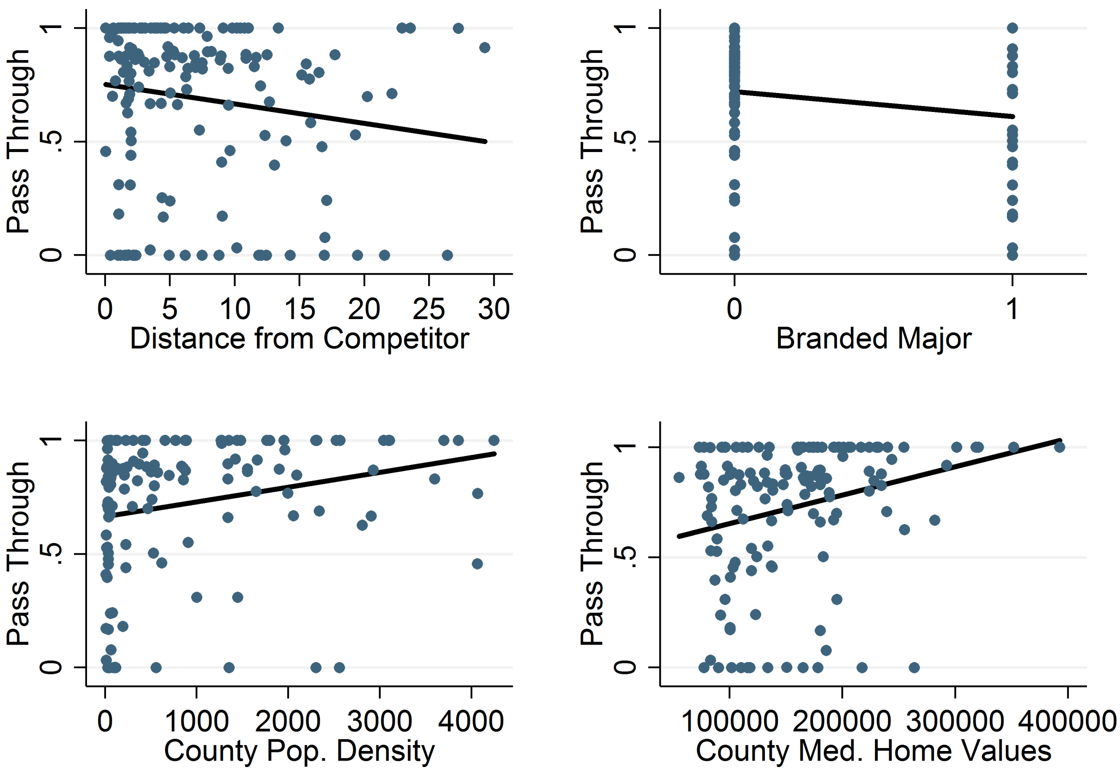
(b) Illinois



(c) Minnesota

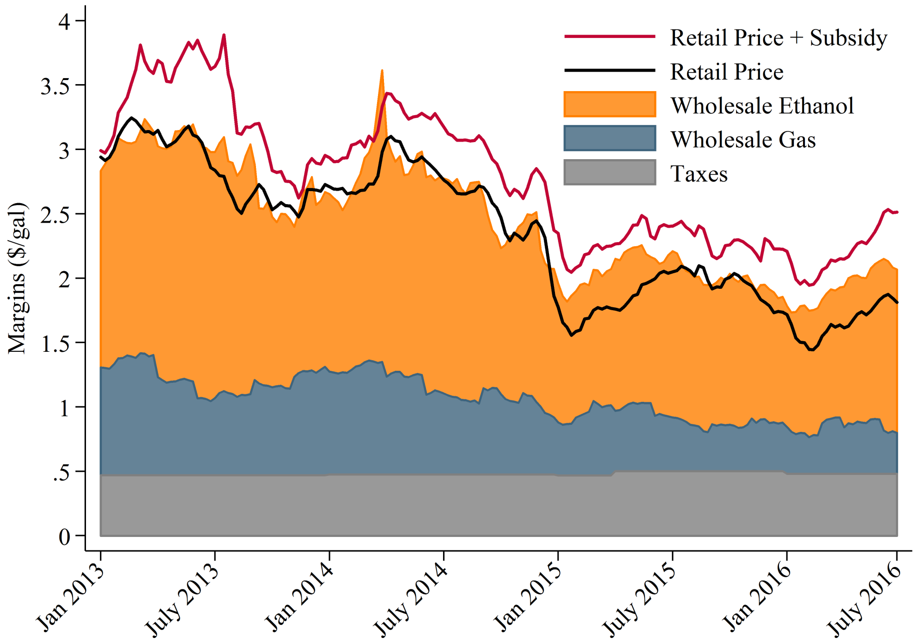
Note: The figures graph station-level pass-through estimates for the E85 subsidy as well as the density of E85 subsidy pass-through estimates in each state. Estimated pass-through rates are truncated at zero and one.

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



Note: The figure graphs raw correlations and best fit lines for station-level 6 week pass-through estimates and for measures of local market structure including: (i) the distance of the station from its nearest competitor; (ii) whether the station is affiliated with a major, vertically integrated oil company (i.e., branded); (iii) the population density of the county in which the station is located; and (iv) the median home value of the county in which the station is located.

Figure 8: Average E85 Margins



Note: The figure graphs the average E85 margins for all stations in our sample from 2013-2016. When we do not adjust retail prices by the RIN subsidy value, average margins are -$0.09/gal, while when we account for the RIN subsidy average margins are $0.33/gal.

A Appendix

A.1 Unit Root and Cointegration Tests

Testing whether retail E85 prices are stationary requires selecting a panel unit root test. A number of stationarity and cointegration tests are available. Many use variations of an augmented Dickey-Fuller (ADF) test (Levin et al., 2002; Im et al., 2003), while others use residual-based Lagrange multiplier tests (Hadri, 2000). The appropriateness of each test in a given empirical setting depends on the relative speeds of asymptotic convergence between the cross-sectional and time series observations, whether one assumes common or heterogeneous coefficients on the lagged independent variable, and whether the panel is balanced. Similar issues arise when determining whether panel data is cointegrated with other price series. A more practical matter guides our choice of a stationarity test for the retail E85 price data: our panel has gaps and is unbalanced. The most practical unit root test is the Fisher-type test proposed by Choi (2001) that combines p-values from individual ADF tests for every station in our sample.

Table B.2 reports the unit root test results for all of the price series used in our analysis. For E85 prices, we report three unit root test statistics: (i) a Fisher inverse chi-squared test that combines the p-values from station-level unit root tests; (ii) a Fisher test that subtracts the cross-sectional means from all E85 price series; and (iii) a summary of the percent of station-level ADF tests that are rejected at the 5% level. We also present approximate p-values for ADF tests on the E85 subsidy, the wholesale ethanol, and the wholesale gasoline price series. For every test, we include two, four, and six lags.

Results from the stationarity tests yield mixed conclusions regarding whether the E85 price series contain a unit root. We cannot reject the null hypothesis that every E85 price panel contains a unit root when we include a trend in the Fisher test, but can reject the null hypothesis with two and four lags when we control for cross-sectional correlation between E85 prices and demean the series. The null hypothesis of a unit root in each station's E85 prices is only rejected for around 5% of our stations, suggesting that a few extreme series may be driving the sensitivity of the panel unit root tests. We cannot reject the null hypothesis that the E85 subsidy or wholesale gasoline price series contain a unit root but can reject the null hypothesis of a unit root for wholesale ethanol at a 10% level when we include two and four lags.

We also report the average rejection rates when we conduct station-by-station Engle-Granger tests of cointegration between each station's E85 prices, the RIN subsidy, and the wholesale fuel costs. When we include two and four lags, only about 5% of the station-level tests reject the null hypothesis of no cointegration. When we include six lags, less than 1% of the Engle-Granger tests are rejected. Thus, while the prices appear to contain a unit root, we do not have strong evidence that many of the stations' prices exhibit a long-run relationship with the E85 subsidy or wholesale fuel costs. Despite this, economics theory suggests that a long-run relationship should hold, and the result is likely driven by the relatively short time span over which we observe the prices and the long time it takes for series to reach a new equilibrium given the estimated delayed adjustment to upstream cost shocks.

A.2 Robustness

We explore the robustness of our results in a number of ways. First, we examine the evolution of pass-through rates over time. Second, our results may be sensitive if price reports to OPIS are endogenous, i.e., if those stations that regularly report prices have systematically higher pass-through than stations that report prices less frequently. We test this by splitting our sample to examine whether stations with less frequently reported prices have lower pass-through than stations that regularly report prices. Third, we use two instrumental variables strategies to test the sensitivity of our results to concerns regarding the endogeneity of the RIN subsidy and wholesale fuel costs. Fourth, given previous findings in the literature, we explore whether pass-through of each upstream costs is asymmetric. Our results are robust to all concerns.

Evolution of Pass-Through Over Time. To test whether pass-through rates have changed over time, we estimate equation (3) separated for the first and second half of our sample. Table B.3 presents estimated pass-through rates for the first-differenced CDM model after six and eight weeks. Results are largely similar for the first and second half of the sample, suggesting that fuel markets had already incorporated RINs into retail prices in early periods.[32] When we study pass-through over time, E85 prices responded quickly to changes in RIN prices in the second half of the sample. However, point estimates of the subsidy pass-through are nearly identical four to five weeks after the cost shock.

Pass-Through and Stations' Price Reporting Frequency. The data from OPIS have some limitations. Among the greatest concerns is that some stations report E85 prices to OPIS sporadically. OPIS collects price data through a combination of fleet credit card swipes, phone surveys, and direct station feeds. Our results may be biased if fleets are more likely to fill up when E85 prices are lowest or if stations report E85 prices when sales are highest. In addition, our market power results may be biased if rural stations report prices less frequently than urban stations and their reporting is correlated with E85 prices.[33] To test this, Tables B.4 and B.5 present estimation results of pass-through and the interaction of local market structure with pass-through separately for stations that report more than 2 years of E85 price data and stations that report less than two years of price data.

Average pass-through rates of the E85 subsidy are higher for stations that report more than two years of data, particularly after six weeks. However, the estimated results are statistically indistinguishable for the two samples, and pass-through rates of ethanol and gasoline wholesale costs do not suggest any systemic bias between stations that report more or fewer price data. The market power results are slightly more

[32]The one exception is with estimated pass-through of wholesale ethanol costs. Estimated pass-through of wholesale ethanol costs in the second half of the sample are higher, and the point estimates have much larger standard errors. The result is driven by relatively stable wholesale ethanol prices over the second half of our sample, as shown in Figure 3b.

[33]Our primary specifications partially address these concerns by controlling for fixed differences between stations that report more and less than others. Despite this, stations that report prices less frequently may be systematically different than those that report prices more often in ways that vary over our sample period.

sensitive to splitting the data by number of price reporting weeks. In both cases, estimated E85 subsidy pass-through rates are slightly higher for branded stations; however, the coefficients are identified off of even fewer branded stations than in the main specification. The coefficients on the indicator for whether stations are five or ten miles from their nearest competitor offering E85 are largely similar to the previous results, with the exception that we estimate that stations reporting less than two years of data that are greater than five miles from their nearest competitor do not have different subsidy pass-through rates than stations less than five miles from their competitor. As previously, similar results for the E85 subsidy pass-through hold for wholesale ethanol costs; however, wholesale gasoline costs do not appear to differ systematically based on the market power measures.

Instrumental Variables. A threat to identification is endogeneity of the E85 subsidy, wholesale ethanol, and wholesale gasoline prices. Consistent estimation of equation (3) requires that all the variables $\mathbf{X}_t$ and their lagged values are exogenous to the error term, i.e., $E(\epsilon_{it}|\mathbf{X}_t, \mathbf{X}_{t-1}, \mathbf{X}_{t-2}, \cdots) = 0$. The assumption is violated if contemporaneous and historical RIN prices and wholesale fuel costs are correlated with local E85 demand conditions.

To address this, we use two instrumental variables strategy to assess the robustness of our results to such concerns. First, we assume that only contemporaneous values of $\mathbf{X}_t$ are endogenous, i.e., $E(\epsilon_{it}|\mathbf{X}_{t-1}, \mathbf{X}_{t-2}, \cdots) = 0$. In this case, short-run E85 demand shocks may be correlated with contemporaneous RIN and wholesale market prices; however, they are not correlated with lagged prices. Second, we assume all current and lagged values of $\mathbf{X}$ are endogenous.

To instrument for wholesale gasoline prices, we use weekly average prompt-month CME Brent crude oil futures contract prices downloaded from Quandl. Brent crude oil serves as a benchmark price for world crude oil and is therefore not affected by market conditions in the U.S. Midwest. To instrument for U.S. wholesale ethanol prices, we use weekly average prompt-month futures prices for number 11 sugar, the benchmark world price for raw sugar. The relevance of the instrument comes from the connection between ethanol imports from Brazil and world sugar prices. Brazilian ethanol has played a volatile but important role in U.S. ethanol markets, with almost all imports of ethanol into the U.S. coming from the country (Energy Information Agency, 2016b). Given the small share of E85 in the U.S., supply condition in the U.S. are unlikely to affect worldwide sugar markets. Because ethanol in Brazil is produced from sugarcane, however, ethanol imports from the country decrease as world sugar prices increase and opportunity costs of shifting sugarcane into sugar production increases. Recent high world sugar prices have been cited as a key factor driving U.S. biofuel producers to export ethanol to Brazil as sugarcane ethanol plants production has fallen (Prentice and Ewing, 2016).

Last, we use indicator variables for the week of and up to three weeks following key policy developments in the RFS to instrument for the ethanol subsidy. Figure 3c graphs the six events used along with the RIN subsidy. As discussed in the main text, the policy announcements shifted industry expectations regarding whether the mandates would be above or below the blend wall and led to significant changes in RIN prices. So long as the timing of the announcements is exogenous to E85 market conditions, changes in RIN prices (conditional on ethanol and gasoline wholesale prices as well as our month-by-year or seasonality controls) around the weeks following each announcement are valid instruments. The exogeneity of the timing of the announcements is likely satisfied given that the enacting legislation and requirements to address stakeholder comments guide the timing of the EPA's announcements.

Table B.6 presents the estimated pass-through rates after eight weeks for the two instrumental variables strategies. The top panel presents estimates for the specifications instrumenting for contemporaneous and lagged wholesale prices. The bottom panel shows the results instrumenting only for the contemporaneous subsidy and wholesale fuel prices. We estimate the model in both levels and first-differences with and without month fixed effects. In all specifications, the instrument prices of crude oil and sugar are specified in first differences. When we instrument only for the contemporaneous subsidy and wholesale fuel costs, we include the contemporaneous and two lags of each instrument (including all policy announcement indicators). When we instrument for the contemporaneous and lagged subsidy and wholesale fuel costs, we include the contemporaneous and eight lags of Brent and sugar futures prices and contemporaneous and three lags of each policy announcement indicator as instruments. All standard errors are clustered by fuel station and year-month and include a small sample adjustment of the covariance matrix. We report Kleibergen-Paap F-statistics from the first stage regression at the bottom of each panel.

Results are similar to those in Table 2 when we instrument only for contemporaneous fuel prices. We find that RIN prices are mostly passed through to retail prices, with pass-through estimates ranging between 65% and 95% after eight weeks. Complete pass-through cannot be rejected at a 5% level for any specification except for in column (1), where we include no seasonality controls. The coefficients on ethanol and gasoline wholesale costs reflect their respective blend rates in E85, particularly in the regressions where only contemporaneous prices are treated as endogenous. In addition, all estimated short-run dynamics are very similar to our previous estimates.

Results are similar, albeit noisier, when we instrument for contemporaneous and all lagged values of the subsidy and wholesale fuel costs as shown in the top panel of Table B.6. However, the first stage F-statistics are notably lower, and the number of instrumented variables is large. Thus, the results should be interpreted with caution and are offered as only suggestive that endogeneity is not a large concern in our setting. This is not surprising given the small size of the E85 market. As the market continues to grow, however, local shocks may play an increasingly important role in influencing upstream fuel costs and invalidate our approach.

Exploring heterogeneity in pass-through rates becomes more involved in an IV setting as the already large number of endogenous variables in the regression grows even greater. Thus, to the extent that local demand conditions affect upstream RIN, ethanol, and gasoline markets conditional on our controls, endogeneity may remain a concern in our empirical results.

Asymmetric Pass-Through. Last, we consider whether retail E85 prices respond asymmetrically to changes in the value of the upstream E85 subsidy as well as wholesale fuel costs. The extant literature has found that such asymmetries play an important role in many retail fuel markets. To test this, we estimate the following model:

$$\Delta Y_{it} = \alpha_i + \sum_{j=0}^{L} \beta_j^+ \Delta \mathbf{X}_{t-j}^+ + \sum_{j=0}^{L} \beta_j^- \Delta \mathbf{X}_{t-j}^- + \gamma_\tau + \epsilon_{it},$$

where,

$$\Delta X_t^+ = \max\{0, \Delta X_t\}, \quad \Delta X_t^- = \min\{0, \Delta X_t\}.$$

Figure B.1 graphs the cumulative pass-through rates over time for decreases and increases in each price. For both the E85 subsidy and ethanol cost increases and decreases, estimated dynamic pass-through rates are nearly identical.[34] Asymmetries do appear in wholesale gasoline cost pass-through for three to four weeks after a cost shock, with cost decreases being passed through more quickly than cost decreases. The result counters the previous literature and may be driven by noise in the data as evidenced by the large standard errors. Overall, asymmetries do not appear to play a major role in our setting.

[34]We also estimated the model including an error correction term. Error correction models introduce nonlinearities in the dynamic pass-through (Borenstein et al., 1997). Despite this, point estimates are similar to the first-differenced model presented here, with increases and decreases for ethanol and the RIN subsidy being nearly equivalent.

B Appendix Tables and Figures

Table B.1: 2013-2016 RFS Statutory vs. Proposed Mandates (Billion Gallons)

	Statutory Mandates			Proposed Rule (11/2013)	Proposed Rule (05/2015)			Final Rule (11/2015)			Proposed Rule (5/2016)
	2014	2015	2016	2014	2014	2015	2016	2014	2015	2016	2017
Cellulosic Biofuel	1.75	3	4.25	0.017	0.033	0.106	0.206	0.033	0.123	0.23	0.312
Biomass-Based Diesel	>1	>1	>1	1.28	1.63	1.7	1.8	1.63	1.73	1.9	2
Advanced Biofuel	3.75	5.5	7.25	2.2	2.68	2.9	3.4	2.67	2.88	3.61	4
Total Biofuel	18.15	20.5	22.25	15.21	15.93	16.3	17.4	16.28	16.93	18.11	18.8

Source: EPA

Table B.2: Stationarity and Cointegration Test Results

		Fisher Inv. χ^2 (Trend)		
		2 Lags	4 Lags	6 Lags
	p-value	0.2389	0.339	0.9971
		Fisher Inv. χ^2 (Trend, Demeaned)		
Retail E85 Prices		2 Lags	4 Lags	6 Lags
	p-value	<0.000	<0.000	0.8985
		Station ADF (Trend)		
		2 Lags	4 Lags	6 Lags
	% Reject	0.068	0.049	0.051
		ADF (Trend)		
E85 Subsidy		2 Lags	4 Lags	6 Lags
	MacKinnon p-value	0.225	0.334	0.125
		ADF (Trend)		
Wholesale Ethanol		2 Lags	4 Lags	6 Lags
	MacKinnon p-value	0.059	0.077	0.198
		ADF (Trend)		
Wholesale Gasoline		2 Lags	4 Lags	6 Lags
	MacKinnon p-value	0.389	0.387	0.256
		Engle-Granger (Trend)		
Station-Cointegration		2 Lags	4 Lags	6 Lags
	% Reject	0.052	0.048	0.009

The top panel presents panel and station-level unit root test results. P-values for the Fisher Inverse χ^2 panel unit root test combine ADF test statistics for all stations' ADF tests. The null hypothesis of the Fisher test is that all stations' prices contain a unit root. The station ADF test present the average 5% confidence level rejection rate of stations using an ADF test with the listed number of lags. For E85, wholesale ethanol and wholesale gasoline, MacKinnon approximate p-values for an ADF test with the listed number of lags are reported. The null hypothesis of all ADF tests is that the series contains a unit root. The station-cointegration panel presents average rejection rates of station-level Engle-Granger cointegration tests. The null hypothesis is that the series are not cointegrated.

Table B.3: E85 Subsidy Pass-Through: Evolution Over Time

	(1)	(2)	(3)	(4)
E85 Subsidy ($/gal)	0.872***	0.718***	0.925***	0.914***
	(0.157)	(0.216)	(0.150)	(0.165)
Ethanol ($/gal)	0.620***	0.915***	0.709***	0.945***
	(0.066)	(0.212)	(0.079)	(0.195)
Gasoline ($/gal)	0.377**	0.299***	0.379*	0.364***
	(0.181)	(0.104)	(0.194)	(0.096)
Observations	8751	8962	8118	7795
Model	CDM	CDM	CDM	CDM
Specification	FD	FD	FD	FD
Period	2013-2014	2015-2016	2013-2014	2015-2016
Lags (Weeks)	6	6	8	8

The dependent variable is the first difference of retail E85 prices ($/gal). The estimates are the cumulative dynamic multipliers for each variable after the specified number of weeks. Standard errors are robust to heteroskedasticity and are two-way clustered at the station and year-by-month. *, **, *** denotes significance at the 10%, 5%, and 1% level.

Table B.4: E85 Subsidy Pass-Through: Reporting Weeks

	(1)	(2)	(3)	(4)
E85 Subsidy ($/gal)	0.888***	0.682***	0.962***	0.831***
	(0.129)	(0.123)	(0.132)	(0.116)
Ethanol ($/gal)	0.604***	0.763***	0.705***	0.854***
	(0.071)	(0.111)	(0.078)	(0.118)
Gasoline ($/gal)	0.376***	0.296***	0.385***	0.305***
	(0.102)	(0.104)	(0.110)	(0.090)
Observations	12,071	5,642	11,307	4,606
Model	CDM	CDM	CDM	CDM
Specification	FD	FD	FD	FD
Lags (Weeks)	6	6	8	8
Reporting Data	≥2 Years	<2 Years	≥2 Years	<2 Years

The dependent variable is the retail E85 price ($/gal). The estimates are of the cumulative dynamic multipliers for each variable after the number of lagged periods specified in the bottom panel. Standard errors are robust to heteroskedasticity and are two-way clustered at the station and year-by-month. *, **, *** denotes significance at the 10%, 5%, and 1% level.

Table B.5: E85 Subsidy Pass-Through and Market Structure: Reporting Weeks

	(1)	(2)	(3)	(4)	(5)	(6)
E85 Subsidy (\$/gal)	0.977***	0.895***	0.844***	0.716***	1.010***	0.920***
	(0.141)	(0.132)	(0.140)	(0.145)	(0.138)	(0.121)
× Branded Major	-0.069	-0.127				
	(0.054)	(0.111)				
× Major Retailer			0.184*	0.228		
			(0.101)	(0.223)		
× > 10 mi. to E85 Station					-0.205***	-0.278
					(0.050)	(0.174)
Ethanol (\$/gal)	0.699***	0.696***	0.659***	0.674***	0.737***	0.901***
	(0.085)	(0.141)	(0.073)	(0.170)	(0.083)	(0.145)
× Branded Major	0.034	0.388				
	(0.063)	(0.296)				
× Major Retailer			0.073	0.275		
			(0.076)	(0.303)		
× > 10 mi. to E85 Station					-0.133***	-0.181
					(0.040)	(0.263)
Gasoline (\$/gal)	0.393***	0.418***	0.355***	0.362***	0.382***	0.286**
	(0.121)	(0.102)	(0.095)	(0.103)	(0.111)	(0.106)
× Branded Major	-0.045	-0.411				
	(0.073)	(0.255)				
× Major Retailer			0.041	-0.089		
			(0.065)	(0.155)		
× > 10 mi. to E85 Station					0.010	0.071
					(0.017)	(0.130)
Observations	11,307	4,606	11,307	4,606	11,307	4,606
Model	CDM	CDM	CDM	CDM	CDM	CDM
Specification	FD	FD	FD	FD	FD	FD
Lags (Weeks)	8	8	8	8	8	8
Reporting Data	≥2 Years	<2 Years	≥2 Years	<2 Years	≥2 Years	<2 Years

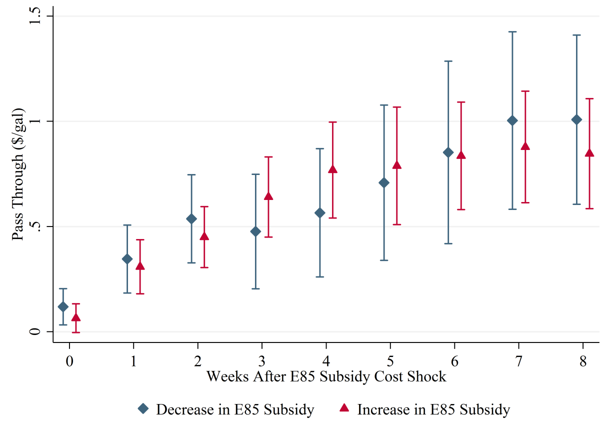
The dependent variable is the first difference of the retail E85 price (\$/gal). (Branded Major) is an indicator variable for whether a station is affiliated with a large, vertically integrated oil company. **1**(Major Retailer) is an indicator for whether the station is affiliated with a large, independent gasoline retail company. (> 10 mi. to E85 Station) is an indicator variable that equal one if the closest rival station selling E85 is more than 10 miles away. Standard errors are robust to heteroskedasticity and are two-way clustered at the station and year-by-month. *, **, *** denotes significance at the 10%, 5%, and 1% level.

Table B.6: E85 Subsidy Pass-Through: Instrumental Variables Estimation

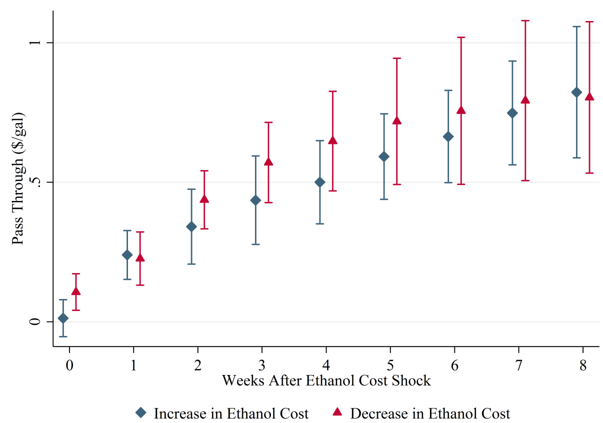
	(1)	(2)	(3)	(4)
Contemporaneous and Lagged Values Endogenous				
E85 Subsidy ($/gal)	0.739***	0.838***	0.954***	0.650***
	(0.117)	(0.120)	(0.220)	(0.228)
Ethanol ($/gal)	1.006***	0.976***	1.185***	0.940***
	(0.140)	(0.105)	(0.279)	(0.226)
Gasoline ($/gal)	0.190**	0.197***	0.400	0.755**
	(0.074)	(0.062)	(0.372)	(0.290)
Kleibergen-Paap F statistic	7.975	10.301	8.005	8.387
Observations	15,880	15,880	15,096	15,096
Contemporaneous Values Endogenous				
E85 Subsidy ($/gal)	0.720***	0.784***	0.891***	0.795***
	(0.067)	(0.066)	(0.137)	(0.140)
Ethanol ($/gal)	0.862***	0.868***	0.780***	0.828***
	(0.075)	(0.073)	(0.130)	(0.119)
Gasoline ($/gal)	0.276***	0.267***	0.358***	0.369***
	(0.040)	(0.038)	(0.097)	(0.086)
Kleibergen-Paap F statistic	12.192	8.063	29.660	5.492
Observations	16,772	16,772	15,913	15,913
Model	CDM	CDM	CDM	CDM
Specification	Level	Level	FD	FD
Lags (Weeks)	8	8	8	8
Station FE	Yes	Yes	No	No
Month FE	No	Yes	No	Yes

The dependent variable is the retail E85 price ($/gal). The top panel presents estimates from our IV model that assumes all contemporaneous and lagged prices are endogenous, and the bottom panel presents estimates from our IV model assuming only contemporaneous prices are endogenous. The CDM columns present estimates of the cumulative dynamic multipliers for each variable after the number of lagged periods specified in the bottom panel. Standard errors are robust to heteroskedasticity and are two-way clustered at the station and year-by-month. *, **, *** denotes significance at the 10%, 5%, and 1% level.

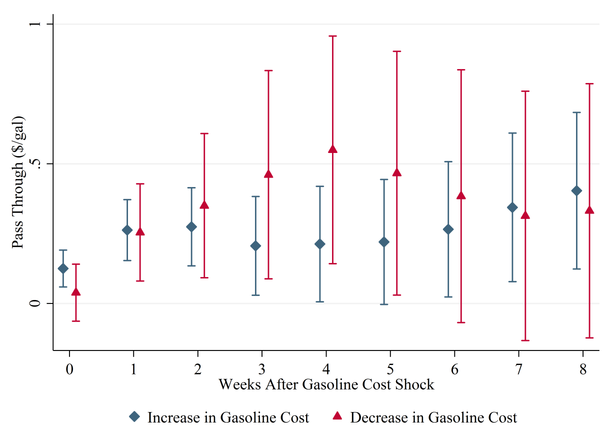
Figure B.1: Pass-Through of Upstream Costs to Retail E85 Prices: Asymmetric Responses



(a) E85 Subsidy



(b) Wholesale Ethanol



(c) Wholesale Gasoline

Note: The figure graphs the average speed with which a shock to the upstream E85 subsidy, wholesale ethanol price, and wholesale gasoline price are reflected in retail E85 prices. The coefficients are estimated separately for increases and decreases in each cost variable. All cost shocks occur in week 0.