Cost Pass-Through to Higher Ethanol Blends at the Pump: Evidence from Minnesota Gas Station Data

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Abstract

We examine the pass-through of wholesale prices to retail prices in the market for E85, which contains 51% – 83% ethanol, and in the much larger market for E10 (regular unleaded gasoline), which contains 10% ethanol. We use a panel data set consisting of monthly observations from 2007-March 2015 on wholesale and retail prices for 274 Minnesota gas stations that sell both E10 and E85. The E10 market is dense and highly competitive, and we estimate a cumulative pass-through coefficient for E10 of 1.00 after one month. In contrast, the E85 market is sparse, and although the pass-through rate increased over time, we estimate it to be only 0.50 statewide from January 2012 to March 2015. Pass-through is higher at stations with more local E85 competitors. In the Twin Cities, which has a high density of E85 stations, pass-through is nearly complete, but outside the Twin Cities slightly less than half the wholesale discount of E85, relative to E10, is passed on to the consumer. Statewide, of any the RIN subsidy to E85 under the Renewable Fuel Standard that is present in the wholesale price paid by the retailer, roughly half is passed on to the consumer and half is retained at the station level.

JEL codes: Q42, C32
Key words: fuels markets, energy prices, E85, E10, retail fuel spreads

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1. Introduction

The Energy Independence and Security Act of 2007 set ambitious goals for blending renewable fuels into the U.S. surface transportation fuel supply. The regulatory structure for achieving these goals is the Renewable Fuel Standard (RFS). The RFS effectively provides a revenue-neutral tax on fuels with low renewable content and a subsidy to fuels with high renewable content, which operates through the market for tradable RFS compliance certificates, RINs (Renewable Identification Numbers).

For the past decade, the main renewable fuel in the United States has been ethanol made from corn kernels, and the dominant fuel blend sold at retail today is E10, which is 10% ethanol. Selling more ethanol into the fuel supply than provided through E10 entails increased sales of higher blends. Although there have been attempts to sell E15, the main higher blend available is E85, which is between 51% and 83% ethanol and can be used by flex fuel vehicles. Because E85 has lower energy content than E10 and thus requires more frequent refueling, boosting sales of E85 requires providing a price incentive to flex fuel vehicle owners to buy E85. This price incentive is provided by the RIN subsidy, assuming it is passed through to the consumer in the form of lower prices in the E85 market.

This paper studies the pass-through of wholesale prices and RIN values to pump prices in the retail market for E85. The retail market is the final of three steps in the gasoline supply chain. With considerable simplification, in the first (upstream) step importers and refiners sell bulk refined petroleum fuels on exchanges and at the bulk wholesale level. That petroleum blendstock is then transported to a regional distribution terminal, typically via pipeline. Separately, ethanol is produced then transported to the terminal, typically by rail. In the second (midstream) step, these two fuels are blended at the terminal, sold to retailers, and pumped into tanker trucks for delivery to the gas station. At the third (downstream) step, the retailer sells the fuel to the end consumer at the gas station.

The wholesale price considered in this paper is the price for blended fuel charged to the tanker truck operator. This price is called the “rack price” because it is the price charged at the facility within the terminal, the truck rack, at which the blended fuel is pumped into the tanker. The gas station owner then charges the public the retail (pump) price. As explained in the next section, if the entire RIN subsidy to E85 is fully passed through from bulk wholesale (exchange) prices to rack prices for blended fuels, and if rack prices for blended fuels are fully passed through to retail prices, then the consumer receives the full RIN subsidy.

Our core data are monthly observations at the retail gas station level on E85 retail prices collected by the Minnesota Department of Commerce. We augment these data with data from OPIS on retail prices for E10, matched at the month-station level. We also use OPIS rack prices for E10 and E85; by matching stations to racks, we estimate station-level wholesale prices for E10 and E85. Because we know the locations of the E85 stations, we can also compute regional station density measures, for example the number of competing E85 stations within a 10 minute drive. Our full data set spans January 2007 to March 2015, which includes the period of high ethanol RIN prices beginning in January 2013.

We have three main findings. First, consistent with a large literature on E10 pricing, we find complete pass-through in the E10 market: over the full sample period, we estimate a cumulative pass-through coefficient of 1.003 (SE = 0.003) using our sample of 247 stations for which we observe both E85 and E10 prices.

Second, we find only partial pass-through to the E85 retail price of the E85 wholesale price, controlling for the E10 wholesale price, that is, of the E85-E10 wholesale spread to the E85-E10 retail spread. This pass-through increased over the sample period from 0.323 (SE = 0.021) in 2007-December 2011 to 0.525 (SE = 0.053) in January 2012-March 2015.[1]

Third, there is considerable heterogeneity in E85 pass-through rates. Much of this variation is explained by observable factors. In particular, we find that pass-through is higher if there are more local stations that sell E85. Moreover, the entry of a nearby station into the E85 market reduces the markup on E85 charged by an E85 retailer. We also examine whether there is variation in pass-through or markups associated with whether the retailer is affiliated with an entity that is obligated under the RFS to retire RINs with the EPA. We find no meaningful association with obligation status, consistent with the profit-maximizing incentives for marketing E85 being the same at the station level whether or not the station is affiliated with an obligated party.

Taken together, these results are consistent with the E10 market being highly competitive, but the E85 market being comprised of local markets in which participants

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[1] As discussed in Section 4, our break at the end of 2011 aligns with the expiration of the Volumetric Ethanol Excise Tax Credit, and statistical tests find a break at this date.

frequently have considerable market power. Having more local E85 stations increases competition and is associated with higher pass-through. In the Twin Cities (Minneapolis-St. Paul) metro area, an area of relatively high E85 station density, we find essentially complete pass-through of the E85-E10 wholesale price discount at the rack to retail prices. Outside the Twin Cities, slightly less than half the E85-E10 wholesale price discount is passed along to consumers.

Returning to the RIN subsidy, we estimate that in the Twin Cities, nearly all of the RIN price subsidy for E85 is passed through the full supply chain and is received by the retail consumer. Outside the Twin Cities, however, we estimate that roughly three-fourths of the RIN value is passed through at the rack, and slightly less than half of that is passed through to retail prices. Statewide, we estimate that 0.35 (SE = 0.05) of the RIN subsidy passes through the full supply chain to retail E85 prices.

In a companion paper, Babcock, Pouliot, Smith, and Stock (2017) use daily data on rack prices of blended fuel and upstream bulk wholesale prices at 283 terminals in 63 cities (including most of the terminals used in this paper) to estimate pass-through at the rack. Our finding here of incomplete pass-through at some racks is consistent with their finding of heterogeneity of pass-through of RIN subsidies to rack prices for higher ethanol blends.

This paper complements independent work by Lade and Bushnell (2016), who use panel data on E85 retail prices at 450 gas stations in Iowa, Illinois, and Minnesota between 2013 and 2016 to estimate pass-through of the RIN subsidy to retail E85 prices. Their data set and ours have several differences. Lade and Bushnell's (2016) data has the advantage of being weekly. Their data covers more states and heavily represents urban areas, whereas our data set has mainly rural stations. The data set here has the advantage of having wholesale rack prices by station: Lade and Bushnell instead use upstream bulk wholesale prices, which prevents them from distinguishing pass-through at the retail outlet from pass-through at the rack, whereas our data allow estimation of pass-through at the retail level directly. In addition, our data include retail and rack prices for E10, which allows us to control for broader price swings in fuel markets by focusing on the E85-E10 spread at the retail and rack level. The longer span here allows examining stages of market development, however our data end earlier than Lade and Bushnell's (2016) so has fewer observations in the period of high RIN prices. Despite these differences, the two sets of empirical results are consistent. Lade and Bushnell (2016) find nearly complete pass-through of RIN prices to retail, which is what we find when we restrict attention to the Twin Cities to be comparable to their heavily urban sample. Our results outside the Twin Cities highlight the heterogeneity of pass-through and its dependence on the amount of local competition.

This paper also contributes to literatures on RIN price pass-through at other stages of the fuel supply chain, on gasoline pricing more generally, on the RFS more generally. Burkholder (2015), Burkhardt (2016), and Knittel, Meiselman and Stock (2016) examine the pass-through of RIN prices to the prices of obligated fuels in the bulk or exchange-traded wholesale market; their main finding is that there is essentially complete RIN pass-through at the bulk wholesale market. Relative to these papers, and to Babcock, Pouliot, Smith, and Stock (2017), we study the pass-through of wholesale E85 (rack) prices, and the wholesale E85-E10 spread, to retail E85 prices.

This paper also contributes to a large literature on gasoline pricing more generally, see for example Borenstein, Cameron, and Gilbert (1997), Borenstein and Shepard (2002), Bachmeier and Griffin (2003), Lewis (2011), and Owyang and Vermann (2014). These papers generally find complete pass-through of regular gasoline (now E10) over the course of 4-8 weeks, although price decreases are found to pass through more slowly than price increases. Stolper (2016) studies data on regular gasoline from Spain and finds complete pass-through on average, but also finds considerable heterogeneity in station-level pass-through coefficients, as we do for Minnesota E85 stations. Coglianese, Davis, Kilian, and Stock (2016) find anticipatory behavior of E10 stations in anticipation of tax increases, and in Section 5.3 we also find anticipatory behavior of E85 stations in advance of the entry of a nearby competitor. Anderson (2012), Corts (2010), Liu and Greene (2013), and Liu and Pouliot (2015) use the Minnesota Department of Commerce E85 data set (which also includes station sales volumes) to estimate the willingness to pay for E85, but none of these examined pass-through. Relative to this large literature, our main contribution is to examine E85 pricing behavior; the only other paper to do so with station level data is Lade and Bushnell (2016).

This paper also contributes to the economic literature on the RFS. See Lade, Lin, and Smith (2014) for a discussion of RFS policy surprises and RIN prices, see Stock (2015) for an overview of the economics of the RFS, and see Irwin (2013a, 2013b, 2014) for insightful real-time commentaries on RFS economic issues. Finally, although the Volumetric Ethanol Excise Tax Credit (VEETC) is not the focus of our paper, accounting for changes in the E85 market at its expiration plays an important role in our empirical analysis, and our findings in this regard are consistent with the more complete study of the expiration of the VEETC by Bielen, Newell, Pizer (2016).

The remainder of the paper is organized as follows. Section 2 provides more details on the RFS and the RIN mechanism and summarizes the empirical methods. Section 3 describes the panel data set. Section 4 examines the time series properties of the panel data, aggregated to Minnesota state-wide averages, and discusses the break that occurred with the expiration of the Volumetric Ethanol Excise Tax Credit. Empirical results using the panel data set are presented in Section 5. Section 6 interprets the results and discusses broader implications, including for RIN pass-through down the entire supply chain.

2. The RIN System and Empirical Methods

2.1 The RFS and RINs

Under the RFS, a gallon of renewable fuel blended into the surface transportation fuel supply generates a RIN. Conventional fuels, such as corn ethanol, generate a D6 RIN; advanced renewable fuels, such as cane ethanol, generate a D5 RIN; and biomass-based diesel (BBD) generates a D4 RIN[2]. Under the RFS, refiners and importers ("obligated parties") must turn in to the EPA ("retire") a bundle of D4, D5, and D6 RINS for each gallon of petroleum fuel sold into the fuel supply. The composition of this RIN bundle is established annually by the EPA. For example, during 2013-2015, the period of high RIN prices, an obligated party must retire 0.0113 D4 RINs to meet the biomass-based diesel standard, 0.0162 D4 or D5 RINs to meet the Total Advanced standard, and 0.0974 D4, D5, or D6 RINs to meet the Total Renewable standard. By increasing the fractions of RINs in this RIN bundle, the EPA increases the fraction of the fuel supply comprised by renewable fuels.

Because RINs are tradeable and priced, the RIN system serves as a tax on fuels with high petroleum content and a subsidy for fuels with high renewable content. For that part of the our sample with high RIN prices (January 2013 to March 2015), the prices of D4, D5, and D6 RINs were very close (D4 RINs were typically generated in excess of the BBD standard and used to

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[2] We ignore cellulosic fuels because they were produced in negligible volumes during our data period.

fulfill the advanced and total renewable standard), so for illustrative purposes here we suppose these prices are the same. Based on the 2013 standard, a fuel with volumetric fraction ω of ethanol generates ω D6 RINs and incurs a RIN obligation of 0.0974(1-ω) RINs. Assuming all RIN prices are the same and equal the D6 RIN price, P_t^{D6}, the net RIN subsidy is $[\omega - 0.0974(1-\omega)]\, P_t^{D6}$. Fuel blended at the rate ω = 8.88% incurs zero net tax or subsidy. If the RIN price is $1 and passed through to retail prices, E10 receives a very small net subsidy of $0.012/gallon. In contrast, for E85 that contains 83% ethanol, the subsidy is $0.813/gallon, a difference of $0.801/gallon.

The incidence of the RIN subsidy depends on the supply and demand for the biofuel. Figure 1 (which is Figure 4 in Knittel, Meiselman, and Stock (2016)) illustrates two different cases: biodiesel and corn ethanol. At current blending ratios, biomass-based diesel is well below any operational blend wall and can be blended smoothly into the diesel supply, so a gallon of biodiesel receives the same market price as petroleum diesel. However, biodiesel is more expensive to produce, so under perfect competition the RIN subsidy accrues to the producer. For corn ethanol, the supply curve is effectively flat in the narrow region at and just above the blend wall, but the demand curve drops steeply because flex fuel vehicle owners require an incentive to purchase ethanol as E85. In this case, under perfect competition the subsidy passes through entirely to the consumer. This basic reasoning motivates focusing on pass-through of RIN prices to retail E85 prices.

The specifics of the RFS RIN system determine where and how RIN pass-through can be measured. The obligation on petroleum fuels occurs upstream, when it is sold by a refiner or importer. No further obligation is incurred on the petroleum fuel from the point of sale at the upstream exchange through sale to the consumer. In contrast, the RIN is generated when a renewable fuel is produced, but remains attached to a biofuel electronically throughout its upstream supply chain: a purchaser of bulk ethanol on the Chicago Mercantile Exchange purchases the physical fuel (“wet” gallons) and the attached RIN. The RIN is detached, and can be sold separately from the physical fuel, when it is blended into the fuel supply at the rack. Thus, under complete pass-through, the price of blended fuel at the rack should equal the bulk wholesale (exchange) prices of the fuels in proportion to the blend, minus the price of the fraction of a D6 RIN generated upon blending the ethanol, plus a markup.

Because the blended fuel purchased at the rack does not come with a RIN, the RIN value no longer enters the price calculus of the retailer who pays the rack price for blended fuel. Pass-through at retail therefore does not involve RIN prices and simply entails the pass-through of rack prices to retail prices.

2.2 Empirical Methods

Our panel data analysis focuses on three related specifications. In the first, the retail price of E10 at station *i* in month *t*, R_{it}^{E10}, or the E85 retail price R_{it}^{E85}, is expressed as a distributed lag of the respective wholesale price, W_{it}^{E10} or W_{it}^{E85}, along with control variables X_{it}:

$$R_{it}^{EXX} = \alpha_i + \beta^{EXX}(L)W_{it}^{EXX} + \delta' X_t + u_{it}, \tag{1}$$

where L is the lag operator. Here and below we use generic notation for station-level fixed effects α_i, for the coefficients δ on the control variables, and for the error term u_{it}. In our base specification, the control variables are eleven monthly dummies to allow for potential seasonal variation in markups. The sum of the distributed lag coefficients, $\beta^{EXX}(1)$, is the cumulative pass-through of wholesale costs to retail costs for that fuel.

Because fuel prices move together, and because the RIN subsidy from blending ethanol for E85 is much larger than the subsidy for blending ethanol into E10, we decompose the E85 wholesale price as the sum of the E10 wholesale price and the difference between the E85 and E10 wholesale prices. The E10 component of the E85 wholesale price is driven by demand and supply in the oil and gasoline markets. The E85-E10 spread component is driven by factors that determine the price of ethanol and, most importantly for this study, by fluctuations in RIN prices. This logic leads us to the regression specification,

$$R_{it}^{E85} = \alpha_i + \beta_{E85}^{E10}(L)W_{it}^{E10} + \gamma(L)\left(W_{it}^{E85} - W_{it}^{E10}\right) + \delta' X_t + u_{it} \tag{2}$$

where $\beta_{E85}^{E10}(L)$ is the pass-through distributed lag of the E10 wholesale price to the E10 retail price, and γ(L) is the pass-through distributed lag on the E85-E10 wholesale spread, and $\beta_{E85}^{E10}(1)$

and $\gamma(1)$ are the respective cumulative pass-through. If these two costs are treated similarly in retail pricing, then $\beta_{E85}^{E10}(L)$ = γ(L), and if cumulative pass-through is complete, then $\beta_{E85}^{E10}(1)$ = $\gamma(1) = 1$.

If the distributed lags $\beta^{E10}(L)$ in (1) and $\beta_{E85}^{E10}(L)$ in (2) are equal, then subtracting (1) from (2) yields,

$$R_{it}^{E85} - R_{it}^{E10} = \alpha_i + \gamma(L)\left(W_{it}^{E85} - W_{it}^{E10}\right) + \delta' X_t + u_{it} \tag{3}$$

This specification has the intuitive interpretation of measuring the pass-through of the E85-E10 wholesale spread to the retail E85-E10 spread. In the context of the RIN subsidy, with perfect pass-through, a D6 RIN price of $1 would reduce the E85-E10 wholesale spread by the difference in their fractional ethanol content times $1, which in turn would reduce the retail E85-E10 spread by this amount. Although our primary specification for analyzing pass-through to retail E85 is (2), in cases in which we have few observations we use the additional restrictions of (3).

3. The Minnesota Gas Station Data

3.1. Data set sources and construction

Our data set consists of observations on retail prices of E10 and E85, wholesale prices of E10 and E85, RIN prices, and demographic data. The unit of observation is a retail gasoline station in Minnesota; all price observations are monthly averages of daily data. The full data span runs from January 2007 to March 2015.[3] All prices are nominal.

We use three subsets of our full data set.

The MN E10 data set consists of 231,257 monthly observations on retail and wholesale prices of E10 at 3,104 Minnesota gas stations. Most of these stations do not sell E85.

The MN E85 data set consists of 15,970 monthly observations on retail and wholesale prices of E85 at 398 Minnesota gas stations.

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[3] Our data set begins in January 2005, however the data on E85 prices are sparse prior to 2007 so the analysis in this paper beings in January 2007.

The MN E85-E10 data set is comprised of stations for which there are data on both E10 and E85 prices, both wholesale and retail. This data set is constructed by merging the Minnesota E10 and Minnesota E85 data sets. The data set is further restricted by dropping the smallest stations, which we define to be stations that either sell less than 300 gallons of E85 per month (averaged over months of nonzero volumes), or that report fewer than 8 months of E85 prices. There are also some stations in the MNDOC data set that report selling E85 but are not in the OPIS database, so E10 prices for those stations are not available; these stations were also dropped. With these exclusions, the MN E85-E10 data set consists of 9,983 monthly observations on 247 stations.

These data sets were assembled from multiple sources in four steps.

First, E85 retail price data were obtained from the Minnesota Department of Commerce (MNDOC), which maintains a monthly survey of retail E85 stations in Minnesota. Stations report volume-weighted prices obtained from monthly sales quantities and revenues; retail prices include all taxes. Earlier vintages of this data set have been used by Anderson (2012) and by Liu and Greene (2013) and are further described there. The data used in this study has two advantages over previous vintages. First, it contains observations during the period of high RIN prices after January 2013, which permits analyzing RIN price pass-through to retail prices. Second, our data set includes the station street address and brand. This permits matching E85 price data with E10 price data at the station level and also permits accurate estimation of E85 and E10 wholesale costs at the station level. During 2007-March 2015, 401 stations appear in the MNDOC E85 data.

Second, we obtained from OPIS data on the 3,106 Minnesota gas stations in the OPIS database. These data consist of station addresses, monthly E10 retail prices, and the OPIS estimate of the wholesale price paid by each station for E10. The OPIS estimate of the wholesale price depends on whether the station is branded or unbranded. For branded stations, OPIS estimates the wholesale price by the rack price for that brand at the closest rack at which the brand is available. For unbranded stations, the OPIS estimate is the average unbranded rack price at the closest rack. In both cases, OPIS estimates transportation costs to provide a delivered E10 wholesale price.

Third, OPIS could not provide an estimated E85 wholesale price at the station level, so we constructed our own estimate. To do so, we obtained monthly OPIS price data on neat (pure) petroleum gasoline (E0), on neat ethanol (E100), and on all ethanol blends available for wholesale purchase at twelve racks in Minnesota, North Dakota, and Iowa, including all seven racks in Minnesota. The non-Minnesota racks were selected to ensure matching the Minnesota retailer with the closest rack even if it is outside the state. The wholesale blends for which we have prices are E10, E60, E65, E70, E75, E80, and E85, however many racks do not have prices on all the higher blends. Based on discussions with industry, we assume that wholesale E85 contains 83% ethanol, wholesale E80 contains 78% ethanol, etc., so that all these wholesale blends can be sold at retail as E85. Our algorithm for estimating the station-level E85 wholesale price is a modified version of the OPIS algorithm used to estimate the E10 wholesale price. The modification addresses two key features of E85: first, the ethanol content of retail E85 can range from 51% to regionally and seasonally determined maximum. The maximum ethanol content is determined to ensure that the blended fuel meets Reid Vapor Pressure standards. The seasonal blend standards also vary over the period of our sample as environmental standards changed. The maximum blend percentage was determined for each month in our sample using American Society for Testing and Materials (ASTM, multiple) Standard Specifications. For the period of our data, the blending maximum ranges from 74% (sold at the rack as E75) during winter months to 83% (sold at the rack as E85) during summer months. Given the seasonal maximum, we used the following algorithm for estimating the station wholesale price. For a branded station, we use the wholesale price at the closest rack selling that brand at the seasonal blend maximum. If a price for that seasonal maximum blend is not available then we use the next-highest blend. For example, if the highest seasonal blend is 78% ethanol but a rack E80 price is not available, we use the rack E75 price; if that is not available, we use the rack E70 price, etc. We refer to the wholesale blend ratio thus determined (e.g. 78% if the wholesale price is for E80) as the month-station blend ratio. For unbranded stations, we use the same algorithm, except that the station is assumed to purchase at the OPIS low price for unbranded blends, using the same seasonal maximum and purchasing hierarchy.[4]

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[4] As a check, we applied this algorithm (without the higher blend hierarchy) to estimate E10 wholesale prices; the correlation between the station-level E10 wholesale price from our algorithm and the OPIS estimate of the station-level E10 wholesale price over the full data set is 0.997. Note that our wholesale cost estimates are FOB the rack, not delivered. Because distance

In addition, we used these data to compute a “blend-your-own” wholesale price for retail E85, which we use in Section 3 as an instrumental variable to address concerns of measurement error. The blend-your-own price is computed by assuming that the retailer purchases enough E100 so that, when blended with E10, the ethanol blend is at the seasonal maximum; for example, if the seasonal maximum is 83%, the blend is 81.1% E100 and 18.9% E10. We use the price of E100 with a RIN attached (during the pre-2003 period, when RIN prices were negligible, we ignore the distinction between E100 with and without the RIN), and assume that the retailer detaches and sells the RIN; thus this blend-your-own wholesale cost is net of the RIN subsidy. For the subset of stations that report a retail E85 price, the correlation between our estimated wholesale price and the blend-your-own price and is 0.907.

Fourth, we use RIN prices from OPIS and Bloomberg. Using the station-level blending ratio corresponding to the wholesale price, we computed the net RIN subsidy to station-level retail E85, compared with E10, that is, the RIN contribution to the E85-E10 retail spread.

3.2. Plots and summary statistics

Figure 2 presents heat plots of markups and spreads computed from the monthly data, January 2007 – March 2015, for the 302 stations in the E85-E10 data set. Table 1a provides summary statistics for the panel data sets (the E10 data set for E10 and the E85 data set for E85) and for the E85-E10 data set.

Several features of the data are noteworthy. First, E85 almost always sells at retail for a discount relative to E10 on a dollar per gallon basis (Figure 2(c)), consistent with E85 having lower energy content than E10. On average, this discount is $0.51, although there is substantial variation in this discount over time and across stations.

Second, the variation over time and across stations of the markup (= retail price – wholesale price) is substantially greater for E85 than for E10: the standard deviation of the E85 markup is three times the standard deviation of the E10 markup.

Third, as is well known, the E10 retail and wholesale prices exhibit seasonality. Table 1(b) reports a test for the significance of monthly dummy variables using the statewide average time series, in a regression also containing year dummies (Newey-West standard errors). The

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to the rack is fixed for a given station, however, transportation costs should largely be absorbed by station fixed effects in our panel data regressions.

markups also have seasonal movements, as do the markup spreads. While the seasonal range of the E10 markup ($0.091) is much smaller than the seasonal in wholesale E10 ($0.619), the seasonal range in the E85 markup ($0.205) is comparable to the seasonal range of wholesale E85 ($0.285). The seasonals in the E85 markup and E85-E10 markup spread, however, are not statistically significant.

Fourth, there are two time periods with multiple missing observations in the E85-E10 data set, indicated by white sections in the heat plots, in 2008 and in late 2012. These missing observations relate to lapses in the MNDOC data collection system, not based on the values of any of the variables, so we treat them as missing at random.

4. Aggregate Time Series Data and the Volumetric Ethanol Excise Tax Credit

We start by examining the aggregate monthly time series data formed by averaging the prices in the MN E85-E10 data set. These data are plotted in Figure 3.

***Behavior around the expiration of the volumetric ethanol tax credit*.** Inspection of the time series data shows an increase in the statewide mean E85 markup in January 2012 (Figures 2b and 2c). The timing of this increase coincides with the end of the federal volumetric ethanol excise tax credit (VEETC) on December 31, 2011. The VEETC was a subsidy provided for blending ethanol into motor fuel. During our data sample, this tax credit was $0.51 per gallon of ethanol through 2009, then $0.45 per gallon through 2011. Bielen, Newell, and Pizer (2016) undertake an event study of the behavior of prices before and after the VEETC expiration; they estimate that, at the close of the program, approximately 2/3 of the subsidy was accruing to ethanol producers, approximately one/third was accruing to blenders, and very little of the subsidy was accruing to consumers.

Our data are consistent with the findings in Bielen, Newell, and Pizer (2016). Table 2 reports prices and spreads in the three months before and after the expiration, from October 2011 to March 2012. The final two columns report changes in the row series from December 2011 to January 2012, both without seasonal adjustment and seasonally adjusted using the regression method in Table 1b. The data in Table 2 are consistent with Bielen, Newell, and Pizer's (2016) conclusion that very little of the VEETC subsidy was passed along to the consumer, at least at the end of the program. In December 2011, the seasonal maximum E85 ethanol content was

74%, so the full value of the VEETC for E85, minus its value for E10, was (.74-.1)×\$0.45 ≈ 29¢. From December 2011 to January 2012, however, the seasonally adjusted the retail E10 price rose by 2.2¢ and the retail E85 price rose by 6.6¢, for an increase in the E85-E10 spread of only 4.4¢, consistent with only 4.4¢ of the 29¢ subsidy having been passed on to consumers.

In these data, the main effect of the VEETC expiration was to decrease the wholesale price E85 by 25.0¢, and to increase the E85-E10 markup spread by 24.2¢. If the retailer received the tax credit, this is consistent with the retailer's markup, net of the VEETC, being left roughly unchanged by the VEETC expiration. If so, then the VEETC subsidy was largely accruing upstream, to the biorefiner or potentially the farmer. The blender eligible to receive the VEETC can be the terminal operator or the retailer depending on how the blending is done (splash blending or rack blending unit) and on ownership or contracting for the delivery truck, see University of Illinois (2007, p. 157). Even if only some of the retailers received the VEETC, the mean markup as measured here would change with the VEETC expiration.

Importantly, the VEETC subsidy was a fixed dollar per gallon subsidy, so the immediate effect of the expiration of the VEETC would be to change the intercept, but not the slope coefficients, in pass-through regressions relating wholesale and retail prices.

Pass-through estimates using time series data. Table 3 reports regressions examining the dynamic relation between retail and wholesale E85-E10 spreads. Table 3a also reports tests for a break in one or more of the regression coefficients (including the intercept) at an unknown date. Table 3b estimates aggregate pass-through regressions using the time series data with seasonal dummies for the two samples before and after the VEETC expiration date of Dec. 31, 2011. The entries in Table 3b are cumulative pass-through coefficients estimated by regressing the retail E85-E10 spread on current and lagged values of the E85-E10 wholesale spread.

The results in Table 3 suggest four main points, which form the basis for the panel data regressions in the next two sections.

First, consistent with the visual evidence in Figure 3 and the discussion of the VEETC expiration above, the sup-Wald test for a break using the full sample (Table 3a) indicates a break in the spread regressions, with the break date estimated to be January 2012. In addition to the shift in the mean E85 markup evident in Figure 3b, the pass-through coefficients change between the two periods: in the 2007-2011 period, pass-through is only 0.42 after one month, but this increases to 0.72 in the 2012-2015 period. In both periods, pass-through is incomplete, however.

Second, the dynamic regressions indicate that lagged dynamics are significant both statistically and economically, with cumulative pass-through increasing from contemporaneous to one month, then increasing slightly again after two months. This is consistent with the time scale of pass-through found in other studies of retail gasoline pricing.

Third, although the fuel prices have large seasonal components, the pass-through coefficients are insensitive to whether seasonals are included or excluded from the regressions.

Because of the strong institutional and statistical evidence of a break not just in the mean markup and markup spreads, but also in the pass-through coefficients at the time of expiration of the VEETC, henceforth we conduct the empirical analysis separately for the two samples before and after the VEETC expiration date.

5. Panel Data Analysis of Rack-to-Retail Pass-through

We now turn to estimates of wholesale cost pass-through to retail E10 and E85 prices using the MN E85-E10 panel data set. We begin with estimates of average pass-through across stations, that is, the distributed lags $\beta(L)$ and $\gamma(L)$ in specifications (1) – (3), estimated by panel data regression with station fixed effects. We then estimate station-level heterogeneity in pass-through by estimating separate station-level regressions, where we adjust (deconvolute) the pass-through estimates for estimation error. Finally, we use panel data regressions with interactions to examine whether pass-through varies with local competition and with whether the station sells branded or unbranded gasoline.

This section describes and summarizes the empirical results; interpretation of the results is deferred to Section 6.

5.1. Pass-through regressions.

Table 4 presents OLS estimates of pass-through for the two periods, before and after the VEETC expiration, estimated using the MN E85-E10 data set. The regressions in Table 4 and all include monthly seasonal and station-level fixed effects. To allow for local demand disturbances that might be common to nearby stations, standard errors are clustered at the county level. The regressions in Table 4 are all of the form of a retail price or spread regressed on the current value and one lag of one or more wholesale prices or spreads. The reported coefficients are cumulative pass-through coefficients. Because all prices are in nominal dollars, a coefficient of 1.00 indicates complete pass-through of the relevant wholesale cost to the retail price.

The Appendix tables contain additional specifications and sensitivity checks. Appendix Table 1 includes an additional monthly lag, and Appendix Table 2 excludes the seasonal dummies. In Appendix Table 3, the regressions involving only E10 are estimated using the full MN E10 data set and the regressions involving only E85 are estimated using the MN E85 data set. Appendix Table 4 includes year effects. Additionally, some of the appendix tables include regressions estimated over the full sample period (not split in January 2012).

Four aspects of the results in Table 4 and Appendix Tables 1-4 are noteworthy.

First, For E10, pass-through is complete in both samples (Table 4, regressions (1) and (2)). In the regressions with lags, roughly 80-90% of E10 wholesale costs are passed through in the current month. Cumulative retail E10 pass-through is estimated to be 1.03 after one month in the pre-2012 sample and 0.98 in the post-2012 sample. The large number of station-level observations result in very small standard errors, even with clustering at the county level, so these estimates are statistically different from one; however we interpret them as economically the same as one and consistent with complete pass-through. Including year dummy variables, which allows for a shift in markups (but not pass-through coefficients) associated with the expiration of the VEETC,

Second, the pass-through dynamics for E85 are different from those for E10. Cumulative pass-through is estimated to be large, 0.94 in the first period and 0.95 in the second after one month, but in both periods is statistically and, we suggest, economically different from one. In addition, pass-through is slower for E85 than for E10, with current-month pass-through of 74% in the first period and 64% in the second.

Third, decomposing the wholesale price of E85 into the E10 component and the E85-E10 wholesale spread – that is, estimating specification (2) – reveals that pass-through is very different for these two components, and moreover that the pass-through coefficients on both components changed over the two periods. Before 2012, 91.4% (SE = 0.8 pp) of the E10 cost was passed through to E85 but only 32.3% (SE = 2.1 pp) of the E85-E10 wholesale spread was passed through. After 2012, there was complete pass-through of E10 costs (one-month cumulative pass-through of 1.010, SE = .016) to E85, and pass-through of the wholesale spread rose to 0.525 (SE = .053). In the second period, because the cumulative pass-through of E10 wholesale prices to E85 retail prices is statistically insignificantly different from one, we can impose this unit coefficient and estimate pass-through using the spread specification (3), which (not surprisingly) gives a similar pass-through estimate of .501 (SE = .049). These results are robust to removing the seasonal dummies, to including an additional monthly lag, and to including year effects.

Fourth, these results are robust to including an additional monthly lag (Appendix Table 1), however the pass-through coefficient is somewhat smaller if one ignores lagged effects and estimates only a contemporaneous pass-through regression (Table 4). The results are also robust to dropping the seasonals (Appendix Table 2). Because specification (1) only involves one fuel, it can be estimated using the full MN E10 or MN E85 data sets, depending on the fuel, and the results are robust to using these larger data sets (Appendix Table 3); this robustness is suggests that the merged MN E85-E10 data set does not introduce sample selection bias. With one exception, the results are also robust to including year effects in addition to the monthly seasonals (Appendix Table 4); the sole exception is the cumulative pass-through coefficient for E10 falls to 0.910 (SE = 0.011) in the second sample. However, when the E10 pass-through regression is estimated with seasonals and year effects over the full period 2007 – March 2015, the two-month pass-through coefficient is 1.003 (SE = 0.003).

5.2. Heterogeneity in station-level pass-through

We next estimate station-level E85 pass-through coefficients for stations for the two time periods, where estimates are restricted to stations with at least 18 monthly observations in a given time period; this restricts the sample to 145 stations in the first period and 94 in the second. To reduce the number of parameters, the pass-through coefficients are estimated using the spread – spread specification (3) with no control variables and with the current and a single lagged value of the wholesale spread, for a total of three coefficients. The station-level cumulative pass-through coefficients $\gamma(1)$ are estimated from the station-level time series, so HAC standard errors are used (Newey-West with 3 lags).

Because of the small number of time series observations per station, the coefficient estimates typically have substantial sampling error. We therefore estimate the station-level pass-through coefficient using a Gaussian-Gaussian decomposition. Specifically, write the OLS estimator of the cumulative pass-through coefficient for station *i* as $\hat{\gamma}_i(1) = \gamma_i(1) + \left(\hat{\gamma}_i(1) - \gamma_i(1)\right)$

= $\gamma_i(1) + e_i$, say, where $\gamma_i(1)$ is the unknown station-level pass-through coefficient and e_i is OLS estimation error. The OLS estimation error is plausibly independent of $\gamma_i(1)$ and, using the large-sample approximation, is approximately normally distributed, where var(e_i) is estimated by the Newey-West variance. With the additional assumption that $\gamma_i(1)$ is normally distributed, the Gaussian-Gaussian deconvolution formula can be used to estimate $\gamma_i(1)$ as $\tilde{\gamma}_i(1)$ = $E\left(\gamma_i(1) \mid \hat{\gamma}_i(1)\right)$.[5] We use $\tilde{\gamma}_i(1)$ as our estimator of the station-level pass-through coefficient.

Figure 4 presents a histogram of estimated E85-E10 spread pass-through coefficients $\tilde{\gamma}_i(1)$ for the two periods. The mean of this distribution is 0.38, with standard deviation 0.19, in the first period, and is 0.56, with standard deviation 0.21, in the second. These mean values are close to the coefficients (average treatment effects) estimated in the panel data estimates in regressions (6) and (8) in Table 4 and are consistent with the increase in pass-through from the first to the second period found in the fixed effect regressions.

5.3. Variation of pass-through with local competition and obligation under the RFS

The histograms in Figure 4 indicate considerable heterogeneity in station-level pass-through. We now investigate the extent to which this variation can be explained by factors related to the degree of local competition. In addition, we examine whether pass-through rates vary with the whether the station is affiliated with an obligated party under the RFS. We consider these in turn.

The motivation for examining the number of local competitors is that, under perfect competition, pass-through should be one. If there is limited local competition, then gas stations can exercise local market power, and if so pass-through will in general be different from one.

The variation of pass-through with local competition is is estimated using panel data regressions of the retail E85-E10 spread on distributed lags of the wholesale E85-E10 spread and the interactions of the wholesale spread with one of two measures of the number of local

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[5] Specifically, let var($\gamma_i(1)$) = σ^2 and let $\text{var}(\hat{\gamma}_i(1) \mid \gamma_i(1)) = \tau_i^2$. Then $\tilde{\gamma}_i(1)$ = $w_i\hat{\gamma}_i(1) + (1 - w_i)\bar{\hat{\gamma}}_i(1)$, where w_i = $\hat{\tau}_i^2 \big/ \left(\hat{\tau}_i^2 + \hat{\sigma}^2\right)$, where $\bar{\hat{\gamma}}_i(1)$ is the sample average of the $\hat{\gamma}_i(1)'s$, $\hat{\tau}_i^2$ is the Newey-West estimator of τ_i^2, and $\hat{\sigma}^2$ is an estimator of σ^2. In unreported results, we also modeled $\gamma_i(1)$ as a mixture of Gaussian distributions, with no appreciable change in the results.

competitors. The three measures of local competition are (i) the number of gas stations selling E85 within 0-3 and 3-10 mile annuli around the station, (ii) the number of gas stations selling E85 within 0-3 and 3-10 minute driving time from the station, and (iii) whether the station is located in the Twin Cities (Minneapolis-St. Paul metro area, specifically Hennepin and Ramsey counties). The Twin Cities has the highest density of E85 stations in our data set and is considered to be one of the most mature E85 markets in the nation. As in Table 4, all regressions include station fixed effects, and standard errors are clustered at the county level. We focus on the second period, which is when there is greater average pass-through.

The results are summarized in Table 5. In all cases, more local competition is associated with higher pass-through in each specification the interactions are jointly statistically significant, and the results are robust to including seasonals or not. The effect of local competitors is greatest if they are nearby, but remains positive and statistically significant if they are more distant. For example, having an E85 competitor within a 3 minute drive is associated with a pass-through coefficient that is higher by 0.055 (SE = 0.23).

The most striking results are when the stations are separated by being in the Twin Cities or not (regressions (3) and (4)), with stations in the Twin Cities having pass-through coefficients 0.31 greater than stations outside the Twin Cities. In the regression without seasonals, pass-through for Twin Cities stations is nearly complete, with a coefficients of 0.930 (SE = .003) and 0.780 (SE = 0.022) in the specifications without and with seasonals, respectively.

We now turn to variation in pass-through as it might be affected by obligation under the RFS. Recall that refiners and importers of petroleum fuels are obligated to retire a RIN bundle for each gallon of petroleum fuel it sells for blending into the surface transportation pool; that is, under the RFS, refiners and importers are the obligated parties. Some obligated parties have downstream gas stations that are owned by or otherwise affiliated with the obligated party, including “branded” stations that sell and advertise gasoline under the brand name of the obligated party. Other stations, including some retail chain and many individually-owned station, are not affiliated with obligated parties. Because obligated parties need to procure RINs, this raises the question as to whether obligated parties under the RFS behave more aggressively, and in particular pass through more of the RIN value. We can examine this proposition because the OPIS data set includes the brand of the gas station, and using public information we determined whether the station is affiliated with an obligated party.

Figure 5 presents histograms of pass-through coefficients, at the retail chain level, for stations not affiliated with an obligated party (upper) or affiliated with an obligated party (lower), estimated using the MN E85-E10 data set in the second sample period. The mean pass-through coefficient is higher in the non-obligated affiliated group, however there is considerable heterogeneity and we do not wish to over-interpret this difference. Our main conclusion from Figure 5 is that there is considerable heterogeneity in pass-through across brands, but that heterogeneity is not explained by differences in obligation.

Another measure of pricing aggressiveness is the difference between the E85 markup and the E10 markup at a station (the markup spread), with a lower markup spread indicating more aggressive E85 pricing. In the high-RIN period starting January 2013, this markup spread was essentially the same in obligated-affiliated and non-obligated-affiliated stations, being lower in obligated-affiliated stations by only \$0.037 (SE = 0.038). Again, there is no evidence of difference in pricing behavior between stations affiliated with obligated parties, and those not.

The lack of effect of obligation on pricing behavior is consistent with stations facing the same profit maximizing incentives. If a station has local E85 market power, it is in its financial interest to price accordingly, but if it is in a competitive local E85 market as in the Twin Cities, it will price competitively and pass through marginal cost. This incentive for station-level profit maximization is the same whether or not the station is affiliated with an obligated party.

5.4. Effect of entry

The regressions in Table 5 establish that pass-through is greater if there are more local competitors in the E85 market, but because the decision to sell E85 is endogenous, those regressions do not establish a formal causal link. Our data set allows us to examine the effect of entry of a local competitor, however, so here we exploit these entry events to estimate the effect of competition on markups and pass-through. We define an E85 entry event as an increase in the number of E85 stations within a circle of a given radius, compared to the previous month. In most cases, this entry event corresponds to a new station entering the MN DOC database. In some cases, stations appear to sell E85 either seasonally (not offering E85 in the winter) or have an extended period of E85 sales, an extended period of no sales, followed by a period of sales.[6]

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[6] Because stations are required to report prices and volumes if they received state funding for their E85 investment, it is plausible that most of these periods of no report sales actually

We consider separately the effect of entry on mean markups, and the effect of entry on pass-through.

Table 6A summarizes the dynamic effect of entry on markups, estimated for entry defined over circles of radii 3, 4, and 5 miles. The dependent variable is the markup spread, that is, the difference between the E85 markup and the E10 markup; the regressors are dummy variables indicating the months prior to entry (*t*+1, etc.), the month of entry, and months after entry (*t*-1, etc.). The change in the markup spread reported in the table is the difference between the average coefficient for the four months after the entry, minus the average for the four months before entry. The regressions have station fixed effects, so the coefficients have a triple differences interpretation (before vs. after, stations with entry at a given date vs. those without, E85 markup vs. E10 markup).

The estimates in Table 6A are consistent with substantial and statistically significant effects of entry on average markups: in the first period, an entry within four miles is estimated to decrease the markup by -13.5¢ (SE = 2.5). The point estimates of the effect of entry are similar in the two periods, although there are few entry events in the second period so the standard errors are large. (Results for a 3-mile radius in the second period are omitted because there are only 4 of these entry events, and there are only 12 within a 4 mile radius.) The dynamics of the markup response is similar across all estimates in Table 6A, with the markup beginning to decline in the month prior to entry and the largest decline occurring in the month of entry and the month after entry. The anticipatory decline is consistent with the ability of a retail operator to observe the construction associated with an existing local E10 station adding the ability to sell E85 as well by installing a blender pump or, possibly, upgrading its tanks.

Table 6B reports estimates of changes in pass-through coefficients, estimated in fixed effects regressions of the retail E85-E10 spread on the current and first lagged values of the wholesale E85-E10 spread and that spread interacted with two indicators, one denoting the twelve months up before the entry event and one denoting the twelve months commencing with the entry event. The difference in these coefficients is also a triple-difference estimate of the change in E85 pass-through associated with an entry event. In both samples, the estimates for

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represent zero sales rather than simply a lapse in reporting. To the extent that some of our identified entry events are in fact just periods of random data reporting lapses, our estimated effects of entry would be attenuated because of classical errors-in-variables bias.

entries within 4 and within 5 miles are positive, and the magnitude of the coefficients is comparable to that found in the specifications in Table 3. Because of the few entry events, however, the estimation error in this triple difference estimate of regression coefficients is large and none of these estimated differences in E85-E10 pass-through are statistically significant. Still, we take the results in Table 6B as (weakly) supportive of interpreting the more precise results in Table 5 as evidence that increasing local competition in turn increases passes through.

5.5. Alternative purchasing assumptions

The analysis so far assumes that retailers purchase blended fuel at the rack. Under this assumption, the blended fuel already has the RIN detached so the retailer never touches a RIN. There are two purchasing and blending strategies, other than buying blended fuel at the rack, used by some retailers. Under the first, examined in this subsection, a retailer purchases E10 and pure ethanol with a RIN at the rack (E100w) from a fuel supplier, and "splash blends" the two fuels as they flow into the tanker truck. Under the second, examined in the next section, the retailer purchases fuel above the rack and typically pays a price pegged to the bulk exchange at the origin of the pipeline and from the biorefiner. Both strategies change the RIN ownership chain, so the retailer ends up owning the RIN. As a result, both strategies have expression for the wholesale marginal cost that differ from each other and from the marginal cost for purchasers of blended fuels at the rack.[7]

For splash blending of fuels purchased at the rack, if the seasonal blend ratio is ω, then the retailer blends $\tilde{\omega} = (\omega - .1) / .9$ gallons of E100w with $(1-\tilde{\omega})$ gallons of E10, and detaches and owns $\tilde{\omega}$ D6 RINs. The retailer's wet fuel cost is $W_{it}^{E85,SB} = \tilde{\omega} W_{it}^{E100w} + (1-\tilde{\omega}) W_{it}^{E10}$. The full marginal wholesale cost for a splash blender (SB) subtracts off the value of the RIN detached and sold by the retailer, $W_{it}^{E85,SB} - \tilde{\omega} P_t^{D6}$, where P_t^{D6} is the price of the D6 RIN. Because E10 is sold at the rack without a RIN, the E85-E10 wholesale spread is $\left(W_{it}^{E85,SB} - W_{it}^{E10}\right) - \tilde{\omega} P_t^{D6}$, where the first term is the wet fuel spread between splash blended E85 and E10, and the second term is the value of the RIN sold by the retailer. With perfect competition, this marginal cost would be

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[7] Detaching and selling a RIN entails administrative overhead, including registering with the EPA to be part of the RIN chain of custody. Because of these fixed costs, this strategy tends to be used primarily by larger and more sophisticated retail outlets.

passed through to price, but under imperfect competition there could be incomplete pass-through and moreover the pass-through rates for the RIN price and the wet fuel spreads could be different. This leads to the pass-through regression for splash blending:

$$R_{it}^{E85} - R_{it}^{E10} = \alpha_i + \gamma^{SB,fuel}(L)\left(W_{it}^{E85,SB} - W_{it}^{E10}\right) + \gamma^{SB,RIN}(L)RIN_{it}^{E85,SB} + \delta' X_t + u_{it}\,, \qquad (4)$$

where $RIN_{it}^{E85,SB} = -\tilde{\omega}P_t^{D6}$ and $\tilde{\omega}$ is determined by the seasonal E85 blending ratio. Under perfect competition, the cumulative pass-through coefficients on the wet fuel and RIN components are both one: $\gamma^{SB,fuel}(1) = \gamma^{SB,RIN}(1) = 1$.

Table 7 presents estimates of specification (4) for the full state, the Twin Cities, and outside the Twin Cities, where the rack price of E100w is used to compute the splash-blend wholesale price for E85. The results without seasonals are very close to those with seasonals and we focus on the results with seasonals. Statewide, the splash-blending pass-through rate for the wholesale splash-blending E85-E10 spread is .574 (SE = .064), the pass-through for the RIN component is less (0.393), and the restriction that the pass-through rates equal each other is rejected. In the Twin Cities, both the wet fuel and RIN pass-through rates are larger, 0.864 (SE = 0.044) and 0.792 (SE = 0.046), respectively, and are not statistically different from each other.

The splash-blending results in Table 7 are similar to the results in Tables 4 and 5, which assume purchase of blended fuels: the statewide blended fuel pass-through coefficient is 0.525, for splash blending it is 0.574; in the Twin Cities, the blended fuel pass-through coefficient is 0.930, in the Twin Cities the splash-blended coefficient is 0.864. This result is not surprising: any retailer who has the administrative infrastructure in place to sell RINs can the opportunity to arbitrage at the rack between purchasing blended fuel or splash-blending and retaining the RIN.

Retailers have other blending options too. Large chains have the ability to purchase fuel upstream of the rack and pay the terminal owner a service charge for handling the fuel; whether the fuel is delivered blended or splash blended, the retailer retains the RIN and pays an upstream, not rack, price for the fuel. If the upstream price is a bulk exchange price (plus transportation charges), then rack pricing is bypassed altogether, and the wholesale price and RIN charge is that considered in the next section (equations (5) and (6) below). At a high level, although these strategies have different cost expressions, they all reflect different ways for the retailer to obtain blended fuel and thus to arbitrage the rack price. This arbitrage does not imply either perfect competition at the rack or perfect competition at the retail outlet, it only suggests that pass-through rates need not vary by the method used to obtain the blended fuel.[8]

6. Discussion and Implications for RIN Pass-Through

These empirical results in Sections 4 and 5 lead us to four main conclusions.

First, the complete pass-through of E10 after one month is consistent with the Minnesota E10 retail market being highly competitive. This conclusion is consistent with results in the existing literature, which finds complete pass-through in the U.S. retail E10 market, with pass-through dynamics lasting 4-8 weeks.

Second, these results are consistent with imperfect competition in the retail E85 market, with stations having local market power. When there are more local competitors, that market power is reduced, and there is greater pass-through. The magnitude of this effect is substantial: according to the estimates in Table 5 regression (2), a station with 2 competitors within a 3 minute drive and with 7 competitors within 3-10 minutes (both are the 90th percentile of these distributions) will pass through 22 percentage points more of the E85-E10 wholesale spread to its E85 retail customers than a station with no competitors within a ten minute drive.

Third, the weight of the evidence – the time series evidence in Table 3b, the panel data estimates of specification (2), and the histograms in Figure 4 – points to a change in the market structure around January 2012. Although we have highlighted the expiration of the VEETC as the event separating the two periods, the increasing pass-through coefficient could be unrelated to the VEETC expiration and could simply reflect maturing of the industry and an increase in

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[8] Another option for blending higher blends available to some retailers is purchasing E85 directly from a biorefinery, which splash blends its ethanol with natural gasoline, which is an inexpensive denaturant. In this arrangement, the biorefinery retains and sells the RIN, so it is competing directly with blended fuel at the rack. To the extent that the biorefinery sets its blended fuel price as a discount off the blended fuel rack price (which is plausible, since the retailer can instead buy the blended fuel from the terminal), this strategy would be captured by the specifications in Tables 4 and 5, and the biorefinery discount would be captured in the station fixed effect. We are not able to study this pricing approach because data on pure ethanol prices at the refinery gate are not available in Minnesota (although they are in Iowa), nor is the price of natural gasoline. This strategy has the disadvantage of being illegal because the natural gasoline blend does not satisfy other environmental regulations for E85.

consumer awareness of where E85 stations are, facilitated by state highway signage indicating E85 stations (Minnesota Department of Transportation (2006)). Alternatively, this change in pass-through could instead be associated with changing pricing dynamics in the high-RIN period starting in January 2013. Despite this evolution towards increasing pass-through, our estimates suggest that on average pass-through of the E85-E10 wholesale spread to E85 retail prices remained partial, with our preferred pass-through estimate of .525 (SE = .053).

Implications for RIN pass-through. Because the net effect of a movement in RIN prices on E10 prices is negligible, both in theory and based on empirical evidence (Knittel, Meiselman, and Stock (2016)), the RIN subsidy to E85 operates through the E85-E10 wholesale spread. The partial pass-through of the E85-E10 spread to E85 prices suggests that any RIN price subsidy passed through at the rack in the form of lower prices for blended fuels, passes through only partially to the end retail customer. Our preferred overall estimate of 0.525 pass-through indicates that only half the RIN subsidy at the rack is passed through to lower retail E85 prices.

We examine RIN pass-through by two additional sets of regressions, in this case with RIN prices and upstream bulk wholesale cost spreads as regressors. These regressions examine the extent to which the subsidy for blending ethanol at the rack is passed on to posted rack prices, and then downstream to retail prices. The subsidy for blending ethanol into E10 is 0.1 times the D6 RIN price, and the subsidy for blending ethanol into E85 is the seasonal blend rate times the D6 RIN price. As before, we focus on the E85-E10 spread, which controls for fluctuations in oil prices and the fuels markets, and the net ethanol blending subsidy $RIN_t^{E85-E10}$ is the difference between the E85 and E10 blending subsidies. We estimate bulk wholesale costs using the Gulf CBOB price and the Chicago Mercantile Exchange ethanol price (daily data from the Energy Information Administration and Bloomberg, respectively, aggregated to monthly), using the E10 and the seasonal E85 blending ratios. Our regressions have the form,

$$W_{it}^{E85} - W_{it}^{E10} = \alpha_i + \gamma^{WB}(L)\left(B_t^{E85} - B_t^{E10}\right) + \theta^{W}(L)RIN_t^{E85-E10} + \delta' X_t + u_{it} \tag{5}$$

$$R_{it}^{E85} - R_{it}^{E10} = \alpha_i + \gamma^{RB}(L)\left(B_{it}^{E85} - B_{it}^{E10}\right) + \theta^{R}(L)RIN_t^{E85-E10} + \delta' X_t + u_{it} \tag{6}$$

where B_t^{E85} and B_t^{E10} are the bulk wholesale costs of E85 and E10.

The key thing to note is that B_t^{E10} is a price above the rack, so that the ethanol component includes a RIN; the RIN is detached upon blending at the rack. If there is complete pass-through at the rack, then $\gamma^{WB}(1) = \theta^W(1) = 1$. If there is complete pass-through all the way down the supply chain, from bulk wholesale to retail, then $\gamma^{RB}(1) = \theta^R(1) = 1$. If the cost of the wet fuels is passed on at the rack, but the RIN subsidy is only partially passed on, then $\gamma^{WB}(1) = 1$ but $\theta^W(1) < 1$. Because the blended fuel does not have a RIN attached, there is no reason to think that the RIN price would affect the price at retail other than through the price of the blended fuel. In the notation of equation (3), the long-run pass-through in the E85-E10 spread is $\gamma(1)$ from rack (blended) to retail. Thus, one would expect long-run RIN pass-through at retail to satisfy $\theta^R(1) = \gamma(1)\theta^W(1)$. Said differently, a fraction $\theta^W(1)$ of the RIN value is passed along at the rack, and of that, a fraction $\gamma(1)$ is passed along at the pump; thus the consumer sees $\gamma(1)\theta^W(1)$ of the RIN value in the retail spread between E85 and E10.

Equation (6) has an additional interpretation. As discussed in Section 5.5, some retail chains occasionally purchase petroleum blendstock (E0) and E100w above the rack, then blend it at the rack, paying a user fee to the terminal operator. In this case, the retailer does not pay the rack price for fuel and retains the RIN. If the price paid for the fuel above the rack is pegged to the bulk exchange prices, then Equation (6) is the relevant pass-through equation for retail chains that purchase fuel above the rack.

Table 8 presents results of estimation of regressions (5) and (6). The table separates the Twin Cities from the rest of Minnesota because of the large differences in pass-through (and competition) found between the two areas in Table 5; pooled results for the full state are presented in the final two columns. Results are only for the second period, which is the only relevant period with nontrivial D6 RIN prices.

The results in Table 8 are consistent with complete pass-through at the rack, with cumulative pass-through coefficients insignificantly different from 1 and insignificantly different from each other; these coefficients are imprecisely estimated because there is a single rack in our data and we use time series regression with HAC standard errors. In the Twin Cities, the RIN pass-through to retail is estimated to be 0.803 (SE = 0.049), consistent with the pass-through of blended rack to retail of 0.78 (Table 5(6)) and complete rack pass-through. These pass-through rates are estimated to even higher without the seasonals (0.988, SE = 0.080, in Table 8(3)). Thus, the results for Minneapolis are consistent with complete pass-through at the rack, complete or nearly complete pass-through at retail, and with the retail consumer seeing the full, or nearly full, RIN subsidy.

In contrast, outside the Twin Cities, pass-through is estimated to be less both at the rack and at retail: with seasonals, $\hat{\theta}^W(1)$ = 0.743 and $\hat{\theta}^R(1)$ = 0.311. This latter estimate is consistent with the estimate of $\hat{\theta}^R(1) = \hat{\gamma}(1)\hat{\theta}^W(1)$ = 0.466×0.743 = 0.346. Outside the Twin Cities, in our sample approximately three-fourths of the RIN value is passed on at the rack, and of that just under one-half is passed on at retail, so the consumer sees roughly one-third of the RIN value in the E85-E10 spread.[9]

The estimates of pass-through of RIN prices to the E85-E10 spread found here are greater than found in Knittel, Meiselman, and Stock (2016). Using weekly data on national average E85 prices, they estimated cumulative RIN pass-through to the E85-E10 retail spread of 0.23 after six weeks in their distributed lag specification that is closest to the distributed lag specifications used here. Their results used national average E85 prices, which we would expect to represent less areas with less competition than is found in Minnesota. Our results indicate lower pass-through in areas of lower competition, and we suspect this, or issues of data quality in the national time series, is the most likely reason for the national RIN pass-through being lower than the Minnesota RIN pass-through estimated here.

These estimates of RIN pass-through are also consistent with those in Lade and Bushnell (2016). As they point out, their data sample heavily represents urban centers (Minneapolis, Des Moines, and Chicago) where there is strong competition in E85. In contrast, our data set contains many rural stations that have few if any local competitors. The results for our data, restricted to the Twin Cities, are consistent with their finding of complete pass-through.

The variation in pass-through with the degree of competition suggests caution in generalizing these results to other regions of the country. Minnesota has one of the most mature E85 markets. We speculate, but do not have data to confirm, that E85 pass-through rates at

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[9] These estimated pass-through findings at the rack are consistent with estimates in Babcock, Pouliot, Smith, and Stock (2017). This said, their results on rack pass-through are preferable to those here because they use daily rack data and have more racks.

stations outside the Midwest could be similar to the low pass-through rates found here for stations without local competition and in the less-mature earlier part of our data.

***Broader implications*.** The mechanism whereby the RFS incentivizes consumers to use more ethanol is through the RIN subsidy. For this subsidy to be effective, it must in fact reach the consumer in the form of lower prices for higher ethanol blends. The evidence presented here suggests that this occurs incompletely, mainly in areas with high E85-on-E85 competition. Overall in our data, roughly half the rack discount of E85 off E10 – including that part of the discount due to the RIN subsidy – is passed along to the consumer, while half the amount of the RIN subsidy that is passed through at the rack accrues to the station operator. At the same time, these results suggest that increased E85-on-E85 competition increases RIN pass-through. The most obvious form for this increased competition is through increased station density, but other methods on which we do not have data, such as improved signage or Web posting of E85 prices could also matter. A specific implication of this analysis is that programs such as the $210 million USDA Biofuels Infrastructure Partnership in 2015 could increase the RIN subsidy passed along to the consumer and thus increase the efficiency of the RFS program. Such subsidies, however, should be targeted to promote E85 on E85 retail competition through increasing station density, otherwise they will simply help the participating retailer establish a chain of local E85 monopolies.

References

American Society for Testing and Materials (multiple): Standard Specifications for Ethanol Fuel Blends for Flexibile-Fuel Automotive Spark-Ignition Engines, ASTM International: D5798-06.21306, D5798-07.16159, D5798-09.9170, D5798-09a.4376, D5798-09B.39298, D5798-10.33882, D5798-10a.28876, D5798-11.22603, D5798-12.17402, D5798-13.10747, D5798-13a.3129, D5798-14.32148, D5798-99.31268, D5798-99R04.26202, and D5798.17164.

Anderson, Soren. 2012. “The Demand for Ethanol as a Gasoline Substitute.” *Journal of Environmental Economics and Management* 63(2), 1512-168.

Babcock, Bruce, Sebastian Pouliot, Aaron Smith, and James H. Stock (2017) “RIN Pass-Through to Prices of E10 and Higher Ethanol Blends at the Terminal Rack.” manuscript.

Bachmeier, Lance J., and James M. Griffin. 2003. “ New evidence on asymmetric gasoline price responses. ” *Review of Economics and Statistic*s 85 (3): 772-776.

Borenstein, Severin, A. Colin Cameron, and Richard Gilbert. 1997. “Do gasoline prices respond asymmetrically to crude oil price changes? ” *The Quarterly Journal of Economics* 112 (1): 305-339.

Borenstein, Severin, and Andrea Shepard. 2002. “Sticky prices, inventories, and market power in wholesale gasoline markets”. *RAND Journal of Economics* 33 (1): 116–139.

Burkhardt, Jesse. 2016. “Incomplete regulation in an imperfectly competitive market: the impact of the renewable fuel standard on U.S. oil refineries. ” manuscript, School of Forestry and Environmental Studies, Yale University.

Burkholder, Dallas. 2015. “A Preliminary Assessment of RIN Market Dynamics, RIN Prices, and their Effects.” http://www.regulations.gov/#!documentDetail;D=EPA-HQ-OAR-2015-0111-0062.

Corts, K. (2010). “Building Out Alternative Fuel Retail Infrastructure: Government Fleet Spillovers in E85.” *Journal of Environmental Economics and Management* 59(3), 219-234.

Irwin, Scott. 2013a. “What’s behind the plunge in RIN prices? ” *farmdoc daily* (3):193. Department of Agricultural and Consumer Economics, University of Illinois. October 10.

Irwin, Scott. 2013b. “More on ethanol RINs pricing. ” *farmdoc daily* (3):208. Department of

Agricultural and Consumer Economics, University of Illinois. October 31.

Irwin, Scott. 2014. "Rolling back the write down of the renewable mandate for 2014: The RINs market rings the bell again. *farmdoc daily* (4):148. Department of Agricultural and Consumer Economics, University of Illinois. August 8.

Irwin, Scott. 2015. "Implications of changing the biodiesel tax credit from a blender to a producer credit". *farmdoc daily* (5):142. Department of Agricultural and Consumer Economics, University of Illinois. August 8.

Knittel, Christopher R., and Aaron Smith. 2015. "Ethanol production and gasoline prices: A spurious correlation." *The Energy Journal* 36 (1): 73-113.

Lade, Gabriel E. and James Bushnell (2016). "Fuel Subsidy Pass-through and Market Structure: Evidence from the Renewable Fuel Standard." Working Paper 16-WP 570, CARD, Iowa State University, December 2016.

Lade, Gabriel E., C.-Y. Cynthia Lin, and Aaron Smith. 2015. "The effect of policy uncertainty on market-based regulations: Evidence from the Renewable Fuel Standard." manuscript, Department of Agricultural and Resource Economics, University of California, Davis.

Lewis, Matthew S. 2011. "Asymmetric price adjustment and consumer search: An examination of the retail gasoline market." *Journal of Economics & Management Strategy* 20 (2): 409–449.

Liu, Changzheng and David Greene. 2013. "Modeling the Demand for E85 in the United States," manuscript, at http://info.ornl.gov/sites/publications/files/Pub45616.pdf.

Liao, Kenneth and Sebastien Pouliot. 2015. "Econometric Analysis of Motorists' Preference for Ethanol in Motor Fuels." manuscript, Iowa State University, 2015.

Minnesota Department of Transportation. 2006. Minnesota E85 Highway Signage Program.

Owyang, Michael, and E. Katarina Vermann. 2014. "Rockets and feathers: Why don't gasoline prices always move in sync with oil prices?" *The Regional Economist*. https://www.stlouisfed.org/Publications/Regional-Economist/October-2014/Rockets-and-Feathers-Why-Dont-Gasoline-Prices-Always-Move-in-Sync-with-Oil-Prices.

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

University of Illinois. 2007. "Corn-Based Ethanol in Illinois and the U.S.: A Report from the Department of Agricultural and Consumer Economics," University of Illinois.

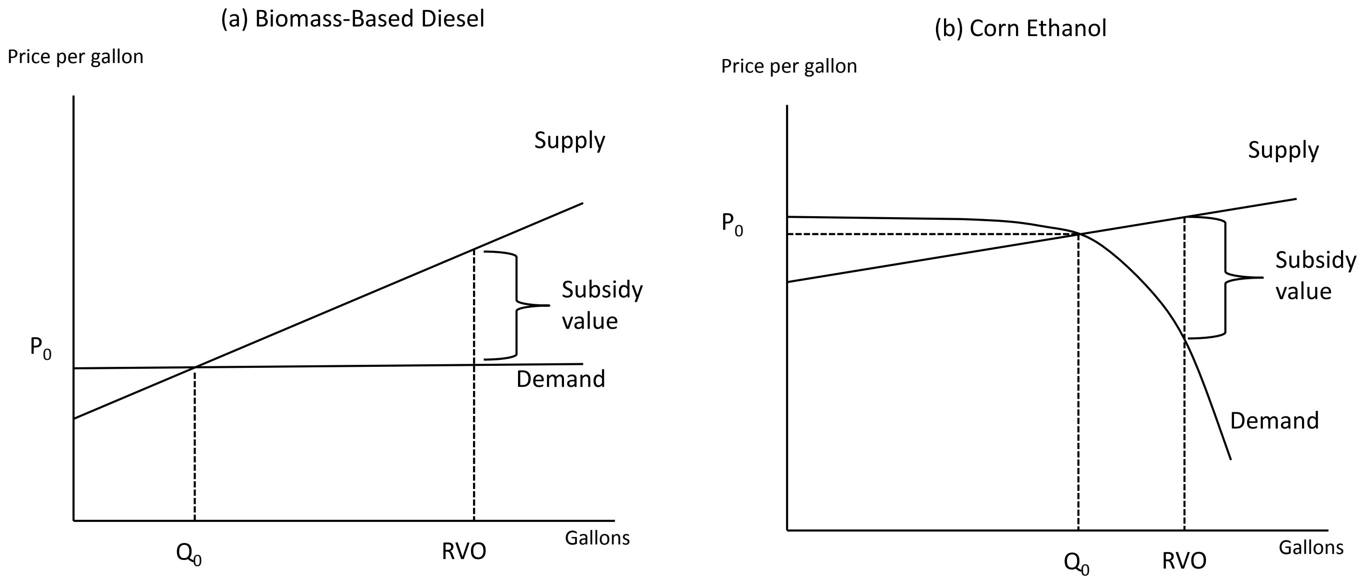
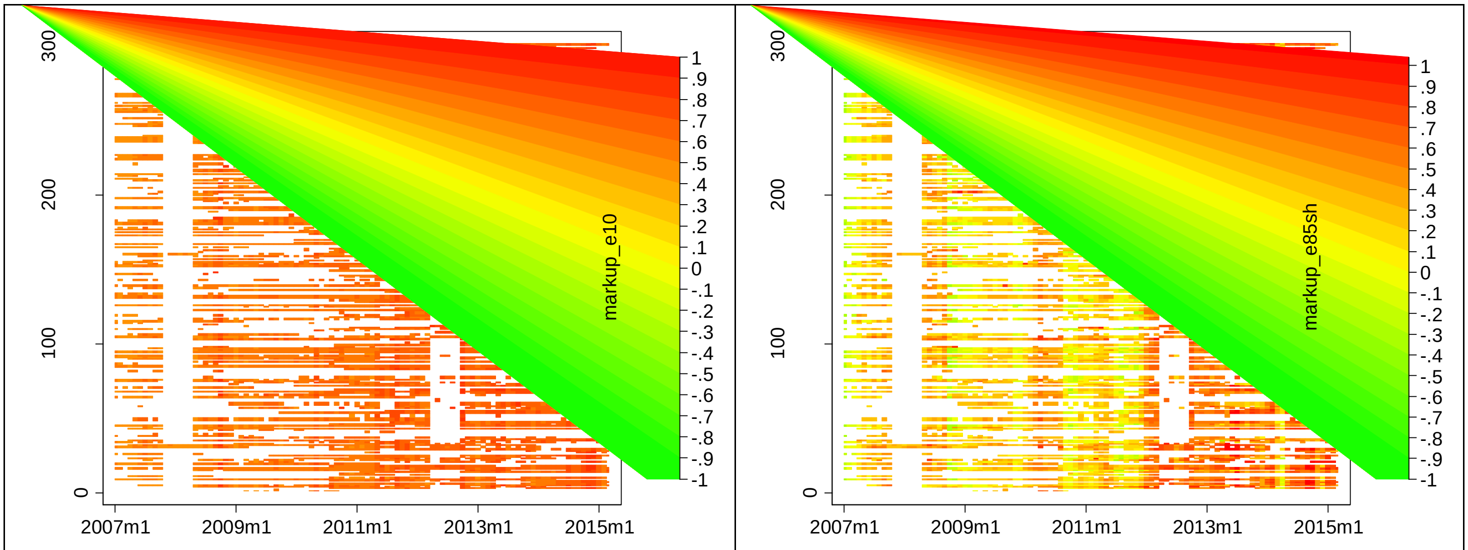
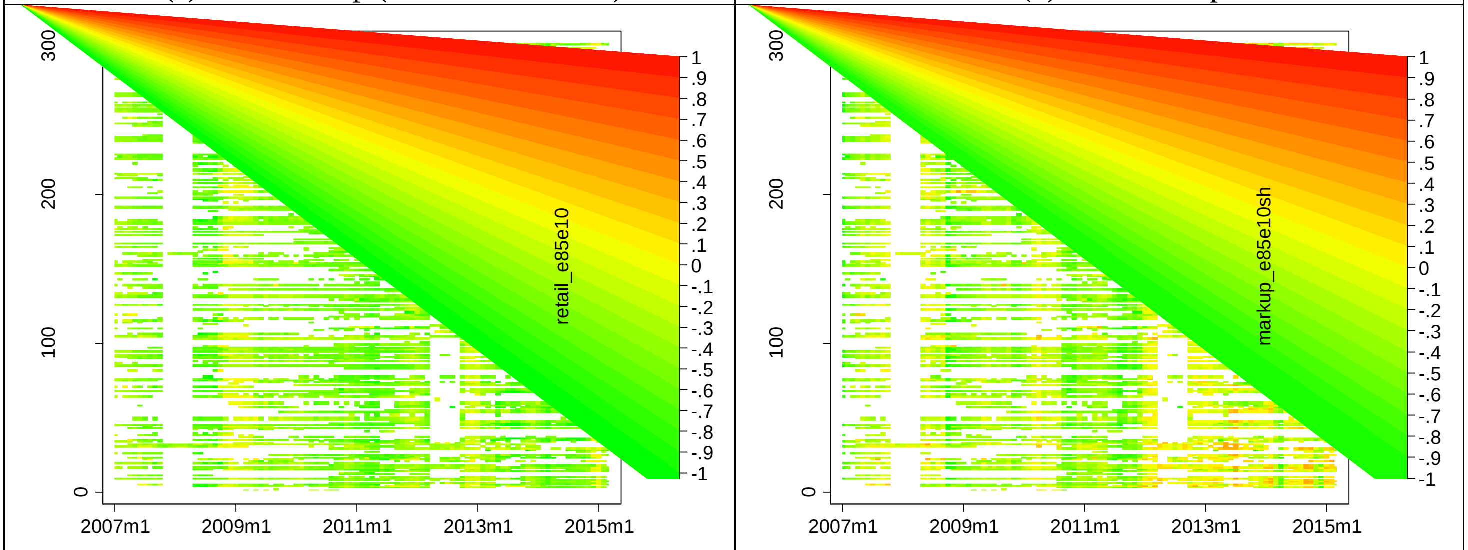


Figure 1. RIN price determination in terms of market fundamentals



(a) E10 markup (retail – wholesale)

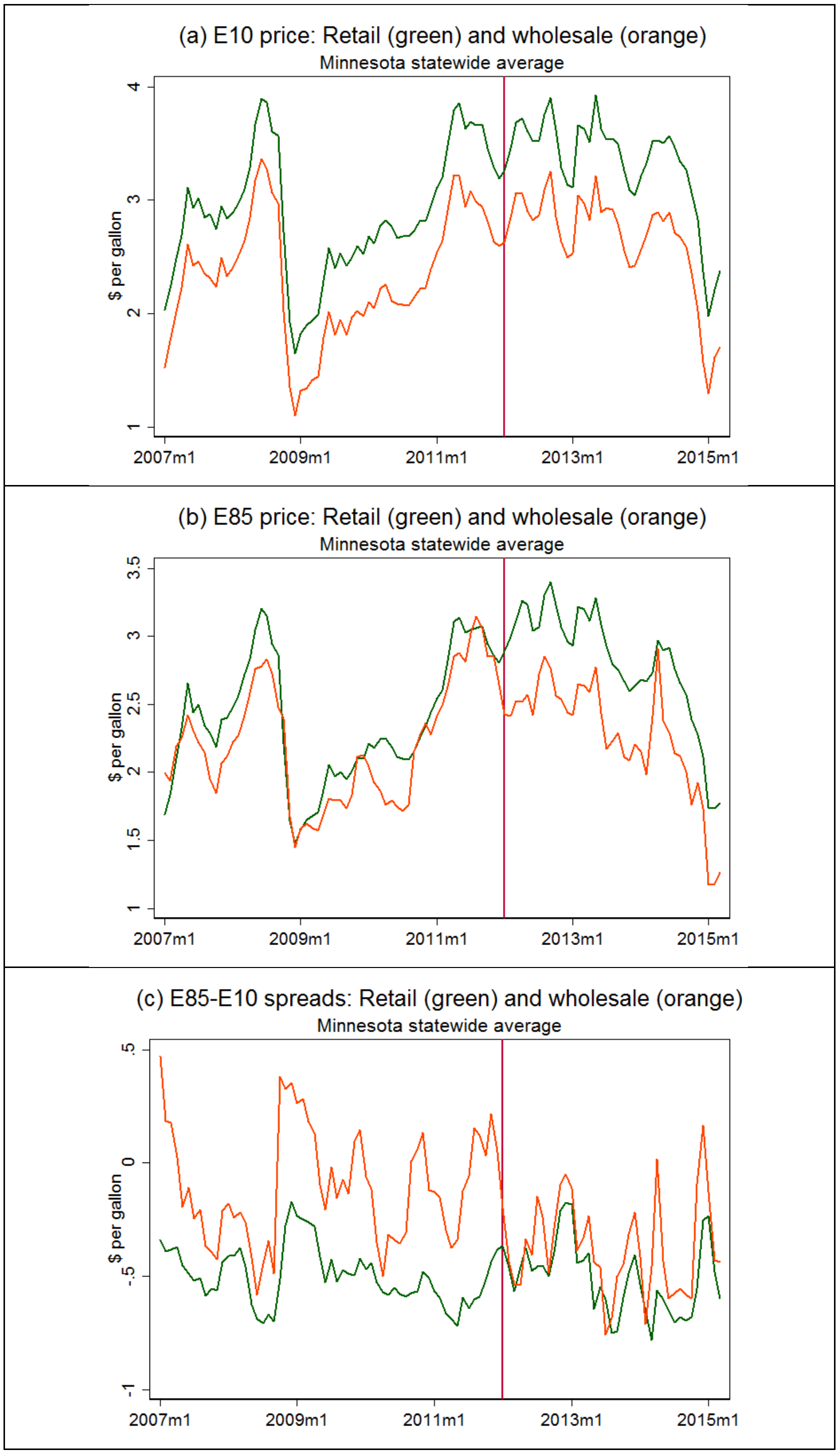
(b) E85 markup



(c) Retail E85-E10 spread

(d) E85-E10 markup spread (= (b) – (a))

Figure 2. The Minnesota E10-E85 data: markups and markup spread. Vertical axis is station number, horizontal axis is month. White denotes missing observations. Units are $/gallon



(a) E10 price: Retail (green) and wholesale (orange)

Minnesota statewide average

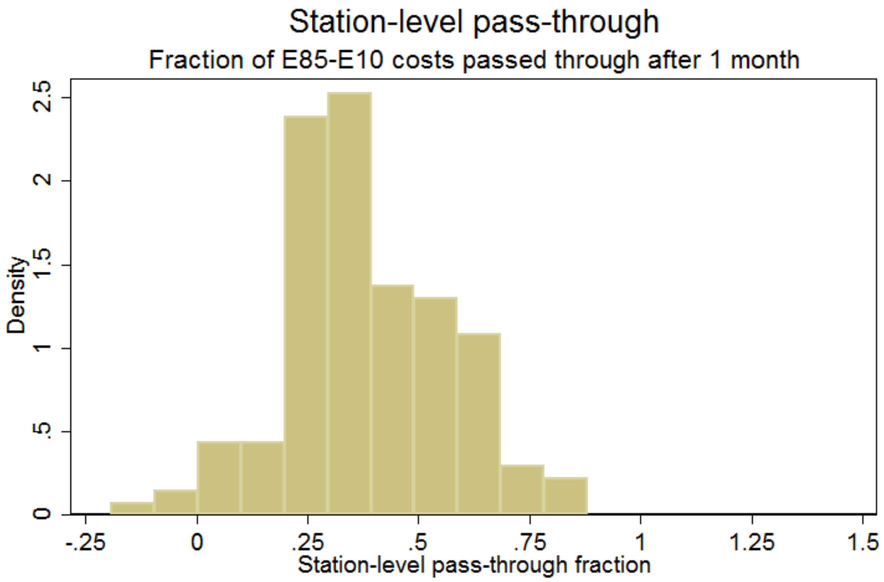
(b) E85 price: Retail (green) and wholesale (orange)

Minnesota statewide average

(c) E85-E10 spreads: Retail (green) and wholesale (orange)

Minnesota statewide average

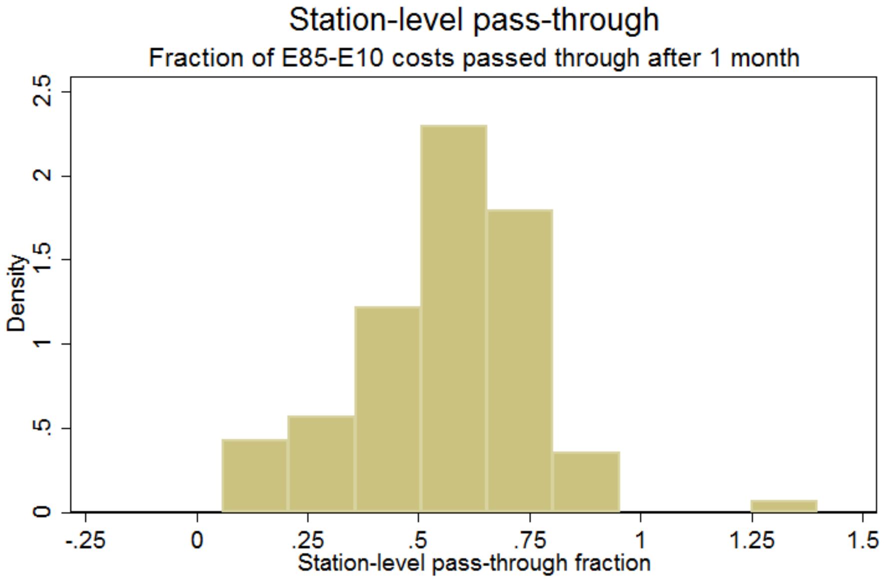
Figure 3. E10 and E85 prices and spreads: statewide average time series constructed from the E85-E10 data set. Vertical line denotes January 2012.


Station-level pass-through

Fraction of E85-E10 costs passed through after 1 month

Data source: Minnesota Department of Commerce and OPIS.
Estimates are de-noised (Gaussian-Gaussian deconvolution)

(a) January 2007 – December 2011


Station-level pass-through

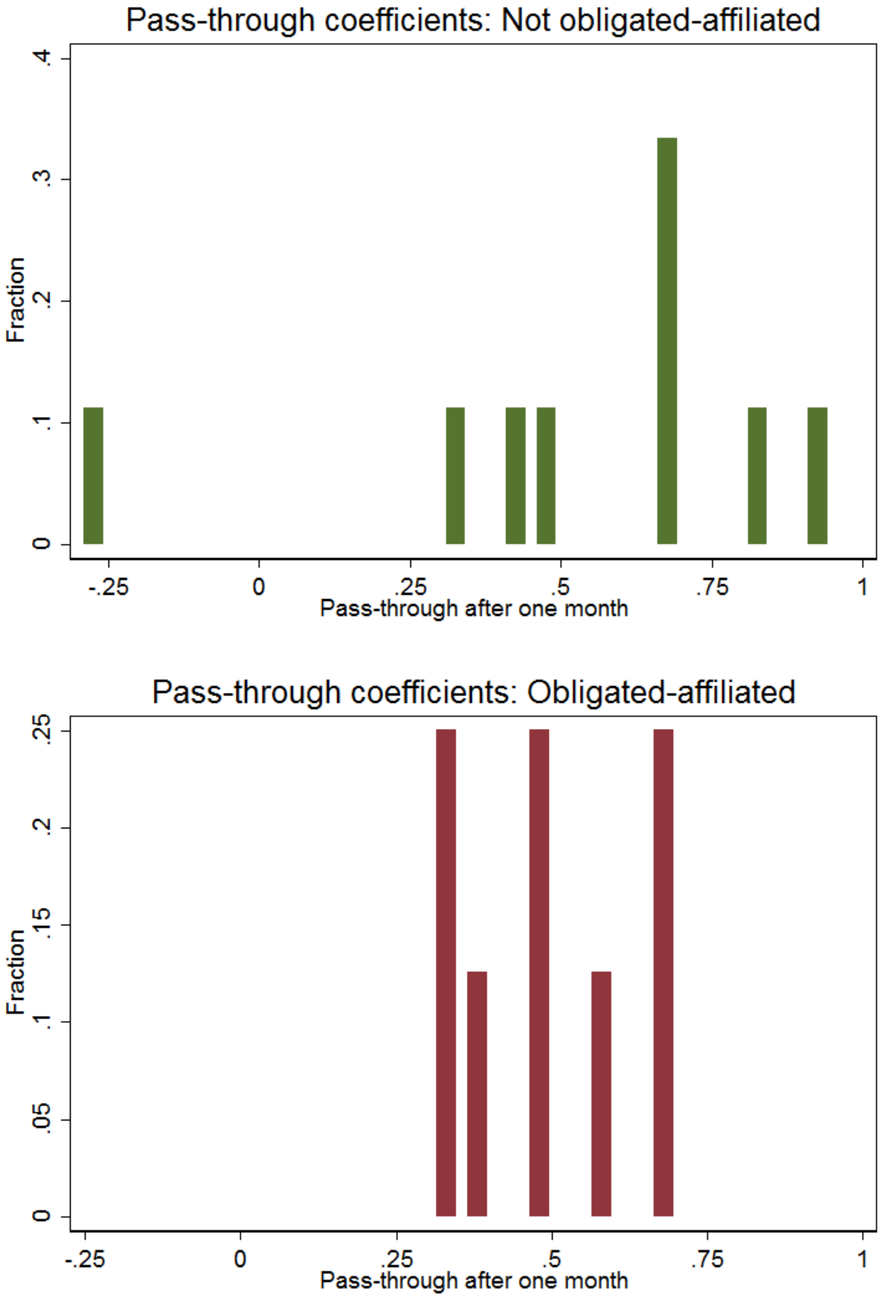
Fraction of E85-E10 costs passed through after 1 month

Data source: Minnesota Department of Commerce and OPIS.
Estimates are de-noised (Gaussian-Gaussian deconvolution)

(b) January 2012 – March 2015

Notes: E85-E10 data set, restricted to stations with at least 18 observations. Individual coefficients are means of Gaussian deconvolution of OLS estimated coefficients, assuming latent coefficients have a Gaussian distribution with unknown variance.

Figure 4. Histograms of de-noised station-level cumulative pass-through coefficients after one month



Notes: E85-E10 data set. Pass-through coefficients are estimated at the brand level (brand interactions), with station-level fixed effects and monthly seasonals. The panel separate out stations affiliated, or not affiliated, with an entity that is obligated under the RFS (i.e. is affiliated with a refiner or importer of petroleum fuels).

Figure 5. Histogram of pass-through by brand

Table 1. Summary statistics

(a) Panel data sets

	mean	**Std. dev.**	**min**	**max**
MN E10 data set: No. stations = 3,104, N = 231,257				
retail E10	3.07	0.56	1.76	3.94
wholesale E10	2.45	0.53	1.21	3.34
E10 markup = retail E10 – wholesale E10	0.62	0.10	0.43	0.87
MN E85 data set: No. stations = 398, N = 15,970				
retail E85	2.59	0.50	1.47	3.48
wholesale E85	2.29	0.47	1.11	3.35
E85 markup = retail E85 – wholesale E85	0.30	0.28	-0.32	1.02
MN E85 data set: No. stations = 247, N = 9,983				
E85-E10 retail spread = retail E85 – retail E10	-0.51	0.22	-1.03	0.01
E85-E10 wholesale spread = wholesale E85 – wholesale E10	-0.21	0.28	-0.85	0.42
E85-E10 markup spread = E85 markup – E10 markup = E85-E10 retail spread – E85-E10 wholesale spread	-0.30	0.28	-0.96	0.37

(b) Seasonality in time series data: January 2007 – March 2015

	***F*-statistic**	***p*-value**	**seasonal range ($/gal)**
retail E10	3.64	0.000	0.629
wholesale E10	3.09	0.002	0.619
E10 markup	7.95	0.000	0.091
retail E85	1.85	0.060	0.422
wholesale E85	1.55	0.130	0.285
E85 markup	2.92	0.003	0.205
E85-E10 retail spread	3.59	0.000	0.263
E85-E10 wholesale spread	2.53	0.009	0.367
E85-E10 markup spread	1.55	0.129	0.205

Notes: The E85-E10 data set consists of observations on stations which (i) have at least eight months in which retail and wholesale prices of E10 and E85 are all observed, and (ii) have monthly E85 sales averaging least 300 gallons. The test for seasonality in part (b) is computed using the monthly time series equaling the statewide average by month, averaged over observations in the E85-E10 data set. This series is regressed on eleven monthly dummy variables and a full set of year dummies; the reported *F*-statistic tests the hypothesis that the coefficients on the monthly dummies are zero (Newey-West variance, 6 lags), and the seasonal range is the range of the predicted seasonals in this regression. All units are dollars per gallon.

Table 2. Prices and spreads around the Dec. 31, 2011 expiration of the VEETC

	Monthly prices and spreads, $/gallon, not seasonally adjusted						**Change, 2011m12 – 2012m1**	
	2011m10	**2011m11**	**2011m12**	**2012m1**	**2012m2**	**2012m3**	**NSA**	**Seasonally adjusted**
retail E10	3.458	3.293	3.193	3.261	3.455	3.681	0.068	0.022
wholesale E10	2.818	2.633	2.593	2.624	2.846	3.062	0.031	-0.052
E10 markup	0.640	0.660	0.600	0.637	0.609	0.619	0.037	0.074
retail E85	2.940	2.855	2.808	2.892	2.992	3.113	0.084	0.066
wholesale E85	2.850	2.849	2.641	2.426	2.413	2.527	-0.215	-0.250
E85 markup	0.090	0.006	0.168	0.467	0.579	0.586	0.299	0.316
E85-E10 wholesale spread	0.033	0.217	0.047	-0.198	-0.433	-0.535	-0.246	-0.198
E85-E10 markup spread	-0.550	-0.654	-0.432	-0.170	-0.030	-0.034	0.262	0.242

Notes: The data are monthly time series for Minnesota computed by averaging the station-level data in the E85-E10 data set.

Table 3. Time series regressions: pass-through estimates, break tests, and dynamics

(a) January 2007 – June 2015

Dependent variable: Retail E85-E10 spread

	(1)	**(2)**	**(3)**
Wholesale E85-E10 spread, lag, cumulative pass-through after:			
0 months	0.330***	0.195***	0.192***
	(0.0501)	(0.0547)	(0.0519)
1 month		0.383***	0.395***
		(0.0558)	(0.0723)
2 months			0.391***
			(0.0579)
Monthly seasonals?	No	No	No
Sup-Wald *F*	4.359	7.071***	6.517***
Sup-Wald break date	2011m12	2012m1	2012m2

(b) Sample split at VEETC expiration date

Dependent variable: Retail E85-E10 spread

	2007m1-2011m12				**2012m1-2015m3**			
	(1)	**(2)**	**(3)**	**(4)**	**(1)**	**(2)**	**(3)**	**(4)**
Wholesale E85-E10 spread, cumulative pass-through after:								
0 months	0.355***	0.185***	0.182***	0.224***	0.569***	0.415***	0.461***	0.295**
	(0.0673)	(0.0580)	(0.0536)	(0.0701)	(0.104)	(0.0960)	(0.103)	(0.120)
1 month		0.418***	0.362***	0.370***		0.718***	0.683***	0.631***
		(0.0768)	(0.0956)	(0.0980)		(0.0883)	(0.0846)	(0.146)
2 months			0.453***				0.785***	
			(0.0804)				(0.106)	
Monthly seasonals?	No	No	No	Yes	No	No	No	Yes

Notes: The data are monthly time series for Minnesota computed by averaging the station-level data in the E85-E10 data set. Coefficient entries are cumulative pass-through coefficients in the regression of the retail E85-E10 spread on current and past values of the wholesale E85-E10 spread, with Newey-West standard errors (3 lags) in parentheses. The Sup-Wald statistic tests the hypothesis of no break in the regression coefficients (including the intercept) against the alternative of a break at an unknown date; the Sup-Wald break date is the date of the largest break test statistic. Significantly different from zero at the: ***1%, **5%, *10% significance level.

Table 4. Station-level pass-through regressions using the E85-E10 data set

A. Retail E10

Dependent variable	**Retail E10**				
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Dates	2007m1-2011m12	2007m1-2011m12	2012m1-2015m3	2012m1-2015m3	2007m1-2015m3
Cumulative pass-through					
Wholesale E10, lag 0	1.021***	0.898***	0.953***	0.831***	0.856***
	(0.00249)	(0.00846)	(0.00459)	(0.00807)	(0.00729)
Wholesale E10, lag 1		1.032***		0.979***	1.003***
		(0.00223)		(0.00433)	(0.00310)
N	5,582	5,582	4,288	4,288	9,921
Number of stations	215	215	175	175	247
Monthly seasonals?	Yes	Yes	Yes	Yes	Yes

B. Retail E85

Dependent variable	**Retail E85**					**Retail E85-E10 Spread**
	(1)	(2)	(3)	(4)	(5)	(6)
Dates	2007m1-2011m12	2007m1-2011m12	2012m1-2015m3	2007m1-2011m12	2012m1-2015m3	2012m1-2015m3
Cumulative pass-through						
Wholesale E10, lag 0				0.759***	0.712***	
				(0.0267)	(0.0327)	
Wholesale E10, lag 1				0.914***	1.010***	
				(0.00779)	(0.0155)	
Wholesale E85, lag 0	0.932***	0.741***	0.644***			
	(0.00840)	(0.0216)	(0.0274)			
Wholesale E85, lag 1		0.944***	0.953***			
		(0.00871)	(0.0203)			
Wholesale E85-E10 spread, lag 0				0.170***	0.230***	0.160***
				(0.0156)	(0.0360)	(0.0311)
Wholesale E85-E10 spread, lag 1				0.323***	0.525***	0.501***
				(0.0214)	(0.0529)	(0.0491)
N	5,582	5,485	4,277	5,391	4,277	4,277
Number of stations	215	215	175	215	175	175
Monthly seasonals?	Yes	Yes	Yes	Yes	Yes	Yes

Notes: Entries are pass-through coefficients in the regression of the retail price or the retail price spread (regression (6), panel B) on the current value, or current and one lagged value, of the indicated wholesale price or price spread. For regressions including the lag, the reported coefficient is the cumulative pass-through (cumulative sum of coefficients on lagged values). Panel A, regression (5) includes year fixed effects to allow for the expiration of the VEETC; none of the other regressions include year fixed effects. Standard errors are clustered at the county level and are given in parentheses. All regressions include station-level fixed effects. Significantly different from zero at the: ***1%, **5%, *10% significance level.

Table 5. Variation of pass-through with local competition

Dependent variable: retail E85-E10 spread

	(1)	(2)	(3)	(4)	(5)	(6)
Dates	**2012m1-2015m3**	**2012m1-2015m3**	**2012m1-2015m3**	**2012m1-2015m3**	**2012m1-2015m3**	**2012m1-2015m3**
Cumulative pass-through						
Wholesale E85-E10 spread, lag 0	0.328***	0.330***	0.351***	0.119***	0.122***	0.140***
	(0.0247)	(0.0228)	(0.0210)	(0.0330)	(0.0318)	(0.0268)
Wholesale E85-E10 spread, lag 1	0.574***	0.580***	0.622***	0.414***	0.423***	0.466***
	(0.0360)	(0.0338)	(0.0323)	(0.0485)	(0.0466)	(0.0455)
Wholesale E85-E10 spread × Number E85 stations 0-3 miles, lag 0	0.00833 (0.0123)			0.0118 (0.0114)		
Wholesale E85-E10 spread × Number E85 stations 0-3 miles, lag 1	0.0246 (0.0212)			0.0284 (0.0211)		
Wholesale E85-E10 spread × Number E85 stations 3-10 miles, lag 0	0.00895*** (0.00206)			0.00785*** (0.00203)		
Wholesale E85-E10 spread × Number E85 stations 3-10 miles, lag 1	0.0128*** (0.00332)			0.0129*** (0.00329)		
Wholesale E85-E10 spread × Number E85 stations 0-3 min, lag 0		0.0272* (0.0151)			0.0267* (0.0144)	
Wholesale E85-E10 spread × Number E85 stations 0-3 min, lag 1		0.0553** (0.0232)			0.0549** (0.0242)	
Wholesale E85-E10 spread × Number E85 stations 3-10 min, lag 0		0.0101*** (0.00240)			0.00960*** (0.00272)	
Wholesale E85-E10 spread × Number E85 stations 3-10 min, lag 1		0.0156*** (0.00302)			0.0165*** (0.00335)	
Wholesale E85-E10 spread × Twin Cities, lag 0			0.201*** (0.0210)			0.187*** (0.0217)
Wholesale E85-E10 spread × Twin Cities, lag 1			0.308*** (0.0325)			0.314*** (0.0335)
N	4,277	4,277	4,277	4,277	4,277	4,277
Number of stations	175	175	175	175	175	175
F: all interactions	13.66	17.45	47.89	13.80	16.78	43.95
(*p*-value)	<.0001	<.0001	<.0001	<.0001	<.0001	<.0001
Monthly seasonals?	No	No	No	Yes	Yes	Yes

Notes: All results are for the E85-E10 data set. For columns (1)-(6), all available non-missing observations are used. For columns (7) and (8), the regressions are estimated using the E85-E10 data set, restricted to stations with average monthly E85 sales of at least 1000 gallons per month. All regressions include station fixed effects and the main effects of the interacted variables (branding is absorbed by station fixed effects). Standard errors are clustered at the county level. See the notes to Table 4.

Table 6. Effect of entry on E85-E10 markups and pass-through

	January 2007 – December 2011			**January 2012 – March 2015**	
	(1)	**(2)**	**(3)**	**(4)**	**(5)**
Entry distance ring	≤3 mile	≤4 mile	≤5 mile	≤4 mile	≤5 mile
Number of entry events	34	49	61	12	19
A. Fixed effects regression estimates of the effect of entry on E85 markups, relative to E10 markups					
Dependent variable: retail E85-E10 markup spread (E85 markup – E10 markup)					
Entry, *t*+4	0.0759**	0.120***	0.121***	0.0232	0.0189
	(0.0312)	(0.0249)	(0.0264)	(0.0385)	(0.0264)
Entry, *t*+3	0.0700***	0.0975***	0.0982***	-0.0208	-0.00835
	(0.0267)	(0.0225)	(0.0218)	(0.0668)	(0.0448)
Entry, *t*+2	0.0661**	0.0571**	0.0478**	-0.00440	0.0177
	(0.0319)	(0.0230)	(0.0211)	(0.0740)	(0.0530)
Entry, *t*+1	0.0316	0.0159	0.0156	0.0441	0.0851**
	(0.0379)	(0.0284)	(0.0262)	(0.0625)	(0.0419)
Entry, *t*	-0.00461	-0.0306	-0.0258	-0.0717	-0.0846**
	(0.0368)	(0.0272)	(0.0247)	(0.0593)	(0.0417)
Entry, *t*-1	-0.0849**	-0.0822***	-0.0666***	0.0289	0.0379
	(0.0349)	(0.0284)	(0.0250)	(0.0404)	(0.0379)
Entry, *t*-2	-0.0782**	-0.0866***	-0.0581*	0.0498	0.0270
	(0.0387)	(0.0311)	(0.0299)	(0.0476)	(0.0355)
Entry, *t*-3	-0.0794**	-0.0821***	-0.0744***	-0.0845	-0.0835
	(0.0360)	(0.0305)	(0.0277)	(0.0802)	(0.0579)
Entry, *t*-4	-0.0267	-0.0319	-0.0249	-0.194	-0.225**
	(0.0315)	(0.0259)	(0.0257)	(0.126)	(0.108)
Change in markup spread	-0.116***	-0.135***	-0.121***	-0.065	-0.094**
SE	(0.030)	(0.025)	(0.024)	(0.055)	(0.038)
B. Fixed effects regression estimates of the effect of entry on cumulative pass-through					
Dependent variable: E85-E10 retail spread					
Change in pass-through: $\Delta\gamma(1)$	-0.0047	0.0382	0.0359	0.102	0.0191
SE	(0.0405)	(0.0336)	(0.0319)	(0.101)	(0.0996)
Monthly seasonals?	No	No	No	No	No

Notes: All results are for the E85-E10 data set. The number of entry events in the data set within the specified rings are given in the fourth header row. In panel A, entries are coefficients on the indicated month before (+) or after (-) entry, in fixed effects panel data regressions with the E85-E10 markup spread as the dependent variable. The change in the markup is the average of the coefficients on *Entry* for 1-4 months after the entry, minus the average of the coefficients for 1-4 months before entry. In panel B, the dependent variable is the E85-E10 retail spread and the regressors are the current and first lag of the E85-E10 wholesale spread, the wholesale spread interacted with a dummy indicating the twelve months before an entry event, and the wholesale spread indicating the twelve months after an entry event; these regressions also include station fixed effects. The reported change in pass-through is the difference between the before- and after- cumulative pass-through coefficients. Standard errors (in parentheses) are clustered at the station level. See the notes to Table 4.

Table 7. Pass-through, rack-to-retail, if retailer splash-blends and retains RIN

Dependent variable: retail E85-E10 spread
Sample period: January 2012 – March 2015

	(1)	(2)	(3)	(4)	(5)	(6)
Regional subset	all	Twin Cities	outside Twin Cities	all	Twin Cities	outside Twin Cities
Cumulative pass-through:						
Splash blend wholesale E85-E10 spread, lag 0	0.238***	0.376**	0.217***	0.400***	0.420**	0.394***
	(0.036)	(0.008)	(0.037)	(0.026)	(0.010)	(0.029)
Splash blend wholesale E85-E10 spread, lag 1	0.574***	0.864**	0.537***	0.662***	0.819**	0.639***
	(0.064)	(0.044)	(0.067)	(0.036)	(0.023)	(0.037)
Splash blend RIN value, lag 0	-0.353***	-0.078	-0.382***	-0.169***	-0.005	-0.182***
	(0.047)	(0.018)	(0.046)	(0.033)	(0.060)	(0.035)
Splash blend RIN value, lag 1	0.393***	0.792**	0.351***	0.429***	0.753**	0.392***
	(0.048)	(0.046)	(0.045)	(0.037)	(0.053)	(0.032)
F statistic testing equality of cumulative coefficient on spread and RIN value	14.66	0.646	12.79	29.75	0.770	29.04
(*p*-value)	0.0003	0.569	0.0007	<0.0001	0.541	<0.0001
N	4,288	441	3,847	4,288	441	3,847
Number of stations	175	16	159	175	16	159
Standard errors clustered at:	county	station	county	county	station	county
Monthly seasonals?	Yes	Yes	Yes	No	No	No

Notes: The reported coefficients are the cumulative pass-through. The splash blend wholesale spread is the difference between the splash-blend wet-fuel wholesale price of E85 and the rack price of E10, where E85 is produced by splash blending E10 with E100 with a RIN at the appropriate seasonal blending rate. The splash blend RIN value is $-((\omega-.1)/.9)P_t^{D6}$, where ω is the seasonal blend rate for E85. All regressions have station fixed effects, with standard errors clustered as indicated. Results are for the E85-E10 data set over the period January 2012 – March 2015.

Table 8. RIN pass-through to rack E85-E10 spread and to retail E85-E10 spread

Sample period: January 2012 – March 2015

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Pass through from bulk wholesale to:	rack	retail	retail	rack	retail	retail	rack	retail
Dependent variable	wholesale E85-E10	retail E85 – E10	retail E85 – E10	wholesale E85-E10	retail E85 – E10	retail E85 – E10	wholesale E85-E10	retail E85 – E10
regional subset	Twin Cities			outside Twin Cities			Full state	
Cumulative pass-through:								
Net E85-E10 RIN subsidy, lag 0	0.274	-0.027	0.101	0.226**	-0.405***	-0.108***	0.209**	-0.371***
	(0.341)	(0.036)	(0.054)	(0.080)	(0.054)	(0.039)	(0.079)	(0.055)
Net E85-E10 RIN subsidy, lag 1	1.261***	0.803***	0.988*	0.743***	0.311***	0.522***	0.757***	0.354***
	(0.152)	(0.049)	(0.080)	(0.063)	(0.046)	(0.040)	(0.058)	(0.050)
Bulk (exchange) E85-E10 cost spread, lag 0	0.721***	0.118	0.242**	0.586***	-0.018	0.164***	0.590***	-0.004
	(0.139)	(0.035)	(0.014)	(0.033)	(0.020)	(0.016)	(0.030)	(0.021)
Bulk (exchange) E85-E10 cost spread, lag 1	1.219***	0.597***	0.765**	0.951***	0.335***	0.596***	0.954***	0.360***
	(0.132)	(0.061)	(0.027)	(0.044)	(0.040)	(0.035)	(0.042)	(0.041)
***F* statistic testing coefficient equality on cost, lag 1 = RIN subsidy, lag 1**								
	0.138	3.560	4.284	19.22	0.341	3.19	20.96	0.0218
(*p*-value)	0.714	0.310	0.287	0.002	0.561	0.079	0.00133	0.883
Clustering for standard errors:	Newey-West	station	station	rack	county	county	Rack	county
N	39 (time series)	441	441	3,847	3,847	3,847	4,288	4,288
Number of stations	16	16	16	159	159	159	175	175
Number of racks	1	1	1	11	11	11	12	12
Monthly seasonals?	Yes	Yes	No	Yes	Yes	No	Yes	Yes

Notes: The reported coefficients are the cumulative pass-through. The RIN subsidy is computed using the seasonal E85 blending ratio. All regressions have station fixed effects, with clustered standard errors as indicated. For Minneapolis-St. Paul, we have only one rack, so regression (1) is a time series regression for that rack with standard errors computed by Newey-West with 4 lags. Results are for the E85-E10 data set over the period January 2012 – March 2015.

Appendix Table 1. Station-level pass-through regressions with additional monthly lag

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Dependent variable	Retail E10	Retail E85	Retail E85	Retail E85-E10 Spread	Retail E10	Retail E85	Retail E85	Retail E85-E10 Spread
Sample	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10
Dates	2007m1-2011m12	2007m1-2011m12	2007m1-2011m12	2007m1-2011m12	2012m1-2011m12	2012m1-2011m12	2012m1-2015m3	2012m1-2015m3
Cumulative pass-through								
Wholesale E10, lag 0	0.894***		0.754***		0.846***		0.668***	
	(0.00877)		(0.0228)		(0.00851)		(0.0314)	
Wholesale E10, lag 1	1.041***		0.862***		1.036***		0.908***	
	(0.00399)		(0.0158)		(0.00731)		(0.0193)	
Wholesale E10, lag 2	1.030***		0.924***		0.960***		1.034***	
	(0.00238)		(0.00830)		(0.00431)		(0.0160)	
Wholesale E85, lag 0		0.762***				0.626***		
		(0.0189)				(0.0272)		
Wholesale E85, lag 1		0.833***				0.805***		
		(0.0132)				(0.0253)		
Wholesale E85, lag 2		0.945***				0.984***		
		(0.00957)				(0.0194)		
Wholesale E85-E10 spread, lag 0			0.152***	0.210***			0.255***	0.179***
			(0.0152)	(0.0227)			(0.0358)	(0.0317)
Wholesale E85-E10 spread, lag 1			0.212***	0.364***			0.446***	0.432***
			(0.0178)	(0.0337)			(0.0443)	(0.0409)
Wholesale E85-E10 spread, lag 2			0.370***	0.480***			0.561***	0.544***
			(0.0230)	(0.0263)			(0.0527)	(0.0514)
N	5,582	5,391	5,391	5,391	4,288	4,247	4,247	4,247
Number of stations	215	215	215	215	175	175	175	175
Monthly seasonals?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: See the notes to Table 4.

Appendix Table 2. Station-level pass-through regressions: No seasonals

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
Dependent variable	Retail E10	Retail E85	Retail E85	Retail E85-E10 Spread	Retail E10	Retail E85	Retail E85	Retail E85-E10 Spread
Sample	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10
Dates	2007m1-2011m12	2007m1-2011m12	2007m1-2011m12	2007m1-2011m12	2012m1-2011m12	2012m1-2011m12	2012m1-2015m3	2012m1-2015m3
Cumulative pass-through								
Wholesale E10, lag 0	0.889***		0.768***		0.836***		0.720***	
	(0.00775)		(0.0245)		(0.00849)		(0.0358)	
Wholesale E10, lag 1	1.036***		0.913***		1.006***		0.965***	
	(0.00216)		(0.00819)		(0.00275)		(0.0126)	
Wholesale E10, lag 2								
Wholesale E85, lag 0		0.884***				0.639***		
		(0.0247)				(0.0231)		
Wholesale E85, lag 1		0.955***				0.934***		
		(0.00938)				(0.0148)		
Wholesale E85, lag 2								
Wholesale E85-E10 spread, lag 0			0.134***	0.183***			0.325***	0.373***
			(0.0153)	(0.0219)			(0.0322)	(0.0233)
Wholesale E85-E10 spread, lag 1			0.292***	0.445***			0.612***	0.658***
			(0.0212)	(0.0251)			(0.0426)	(0.0359)
Wholesale E85-E10 spread, lag 2								
N	5,582	5,485	5,485	5,485	4,288	4,277	4,277	4,277
Number of stations	215	215	215	215	175	175	175	175
Monthly seasonals?	No	No	No	No	No	No	No	No

Notes: See the notes to Table 4.

Appendix Table 3. Station-level pass-through regressions: Different data samples

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**
Dependent variable	Retail E10	Retail E85	Retail E10	Retail E85	Retail E10	Retail E85
Sample	E10	E85	E10	E85	E10	E85
Dates	2007m1-2011m12	2007m1-2011m12	2012m1-2015m3	2012m1-2015m3	2007m1-2015m3	2007m1-2015m3
Cumulative pass-through						
Wholesale E10, lag 0	0.891***		0.852***		0.857***	
	(0.0113)		(0.00833)		(0.00923)	
Wholesale E10, lag 1	1.028***		0.983***		1.052***	
	(0.00219)		(0.00228)		(0.00311)	
Wholesale E10, lag 2						
Wholesale E85, lag 0		0.703***		0.516***		0.542***
		(0.0179)		(0.0296)		(0.0135)
Wholesale E85, lag 1		0.937***		0.841***		0.922***
		(0.0101)		(0.0167)		(0.0101)
Wholesale E85, lag 2						
Wholesale E85-E10 spread, lag 0						
Wholesale E85-E10 spread, lag 1						
Wholesale E85-E10 spread, lag 2						
N	135,997	8,934	95,251	6,480	231,248	15,414
Number of stations	2,913	352	2,724	282	3,100	396
Monthly seasonals?	Yes	Yes	Yes	Yes	Yes	Yes

Notes: For columns (1)-(6), all available non-missing observations are used. For columns (7) and (8), the regressions are estimated using the E85-E10 data set, restricted to stations with average monthly E85 sales of at least 1000 gallons per month. See the notes to Table 4.

Appendix Table 4. Station-level pass-through regressions: Including year effects

	(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**	**(9)**
Dependent variable	Retail E10	Retail E85	Retail E85	Retail E85-E10 Spread	Retail E10	Retail E85	Retail E85	Retail E85-E10 Spread	Retail E10
Sample	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10	E85-E10
Dates	2007m1-2011m12	2007m1-2011m12	2007m1-2011m12	2007m1-2011m12	2012m1-2011m12	2012m1-2011m12	2012m1-2015m3	2012m1-2015m3	2007m1-2015m3
Cumulative pass-through									
Wholesale E10, lag 0	0.860***		0.678***		0.808***		0.669***		0.856***
	(0.00856)		(0.0276)		(0.00929)		(0.0367)		(0.00729)
Wholesale E10, lag 1	1.011***		0.911***		0.910***		0.970***		1.003***
	(0.00282)		(0.0119)		(0.0108)		(0.0387)		(0.00310)
Wholesale E10, lag 2									
Wholesale E85, lag 0		0.682***				0.428***			
		(0.0217)				(0.0372)			
Wholesale E85, lag 1		0.947***				0.669***			
		(0.0122)				(0.0374)			
Wholesale E85, lag 2									
Wholesale E85-E10 spread, lag 0			0.119***	0.250***			0.232***	0.180***	
			(0.0162)	(0.0201)			(0.0366)	(0.0305)	
Wholesale E85-E10 spread, lag 1			0.319***	0.410***			0.470***	0.433***	
			(0.0198)	(0.0290)			(0.0556)	(0.0522)	
Wholesale E85-E10 spread, lag 2									
N	5,521	5,424	5,424	5,424	4,288	4,277	4,277	4,277	9,921
Number of stations	215	215	215	215	175	175	175	175	247
Monthly seasonals?	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

Notes: The specifications and data are the same as in Table 4, except that all specifications include year effects. See the notes to Table 4.

Appendix Table 5. Station-level pass-through regressions: replacing the OPIS E85 rack price for blended fuel with the "blend-your-own" price

	(1)	**(2)**	**(3)**	**(4)**
Dependent variable	Retail E85	Retail E85-E10 Spread	Retail E85	Retail E85-E10 Spread
Sample	E85-E10	E85-E10	E85-E10	E85-E10
Dates	2007m1-2011m12	2007m1-2011m12	2012m1-2015m3	2012m1-2015m3
Cumulative pass-through				
Wholesale E10, lag 0	0.682***		0.561***	
	(0.0296)		(0.0306)	
Wholesale E10, lag 1	0.939***		1.013***	
	(0.00753)		(0.0152)	
Wholesale E10, lag 2				
Wholesale E85, lag 0				
Wholesale E85, lag 1				
Wholesale E85, lag 2				
Wholesale E85-E10 spread, lag 0	0.149***	0.306***	0.0260	0.0251
	(0.0160)	(0.0230)	(0.0270)	(0.0236)
Wholesale E85-E10 spread, lag 1	0.377***	0.476***	0.362***	0.358***
	(0.0241)	(0.0255)	(0.0383)	(0.0428)
Wholesale E85-E10 spread, lag 2				
N	5,521	5,521	4,288	4,288
Number of stations	215	215	175	175
Monthly seasonals?	Yes	Yes	Yes	Yes

Notes: The regressions and data are the same as in Table 4, except that all regressions include year effects. See the notes to Table 4.