The Pass-Through of RIN Prices to Wholesale and Retail Fuels under the Renewable Fuel Standard: Analysis of Post-March 2015 Data

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Summary

Knittel, Meiselman, and Stock (2015) (KMS)[1] examine the pass-through of RIN prices under the RFS to three categories of fuels: bulk wholesale petroleum fuels, bulk wholesale biofuels, and retail gasoline blends. The KMS period of analysis is January 1, 2013 – March 9, 2015. This note extends the analysis of bulk wholesale petroleum fuel prices in KMS to data through Nov. 14, 2016.

KMS compare wholesale prices of two similar fuels, one of which is regulated under the RFS and one of which is not. The regulated fuel must retire a bundle of RINs when it is sold into the fuel supply. Because the two fuels have different RIN obligations, the difference (spread) between their prices should respond to a change in RIN prices. Using daily prices of fuels and RINs, KMS regress the obligated/non-obligated fuel price spread on the price of the RIN obligation to estimate the fraction of the RIN price that is passed through to the price of the obligated fuel (the "pass-through coefficient"). They also estimate a dynamic system involving the spread and the RIN prices (a vector autoregression) to estimate the dynamic response of fuel prices to a change in the RIN price. The reason for using the spread between two chemically and/or geographically similar fuels, rather than just the price of the obligated fuel, is to control

[1] Knittel, C., B. Meiselman, and J.H. Stock, "The Pass-Through of RIN Prices to Wholesale and Retail Fuels under the Renewable Fuel Standard," NBER Working Paper 21343, July 2015. That paper was revised in July 2016 and again in November 2016, both times in response to comments by referees and editors. The references to KMS in this note all refer to the November 2016 revision. The July 2016 revision substantially shortened the July 2015 version including dropping and renumbering tables and figures; there was no change in the data and no change in conclusions, however there was one methodological change. In all versions, the base specifications include eight seasonal variables (sines and cosines at first four harmonics). In the July 2015 version, KMS reported sensitivity results in which the regressions were estimated dropping the seasonal variables. In the July 2016 version, KMS instead reported sensitivity results using seasonally adjusted data, where the seasonals were estimated using pre-2013 data. The November 2016 version updates the data used in the previous versions to the data set used here, but still restricted to the same sample as the original paper (Jan. 1, 2013 – March 9, 2016). This update filled in a few missing observations on RIN prices, and extended backwards the pre-2013 Rotterdam diesel and BOB series for use in estimating the seasonals for constructing seasonally adjusted spreads; this data update resulted in some second- and third-decimal changes in the results but no change in conclusions.

for non-RFS factors that affect the price of the obligated fuel, thereby reducing the risk of omitted variable bias and increasing precision.

Their main finding for bulk petroleum fuels is that RIN prices were passed through one-for-one in the prices of bulk petroleum fuels, specifically, they estimate a pooled levels pass-through coefficient of 1.00 (SE = 0.11).

This note uses the six spreads in KMS, extended using the same data sources. Three of these are diesel spreads: Gulf diesel – Gulf jet fuel, New York Harbor diesel – Rotterdam diesel, and Gulf diesel – Rotterdam diesel. Three are gasoline spreads: New York Harbor RBOB (prompt month future) – Rotterdam EBOB, New York Harbor RBOB (prompt month future) – Brent (spot), and Los Angeles RBOB (spot) – Brent (spot). In addition, in this note we augment the gasoline spreads by New York Harbor CBOB (spot) – Rotterdam EBOB. This provides a spot-spot comparison of NYH CBOB to EBOB, which complements the NYH RBOB future – EBOB comparison.

Our main findings are:

1. For the four spreads between refined products in KMS – that is, all the spreads in KMS except NYH RBOB-Brent and LA RBOB-Brent – and also for the additional refined product spread NYH CBOB-EBOB newly analyzed here, the findings of KMS hold in the extended sample. These findings are illustrated in the following figures, which show the refined product spread (in green); the predicted value of the spread (orange) from the benchmark estimated levels model from KMS (Table 2, regression 1); and the predicted value of the spread that modifies the orange line to impose a unit pass-through coefficient (blue). The benchmark KMS levels model (orange) regresses the spread against the RIN price over the KMS sample period. Results are shown for the Gulf diesel-Gulf jet spread and the NYH RBOB-EBOB spread. The red line denotes the end of the KMS sample, and subsequent dates denote the out-of-sample period. For the RBOB-EBOB spread, the fit is visually as good out of sample as in-sample, an observation supported by statistical tests. For the Gulf diesel-Gulf jet spread, there is a period during the summer of 2015 in which a gap of approximately $0.05 opens up for several months during the diesel glut of the summer of 2015, an unusual period in which wholesale diesel prices fell substantially below wholesale gasoline prices.[2] After those summer months in 2015 the spread returns to its predicted value.[3]

[2] Contemporaneous sources attributed the low diesel prices to excess supply of middle distillates as refineries increased production to meet strong gasoline demand, to gasoline supply pressures because of refinery outages earlier in 2015, and to recent expansion of middle distillate refining capacity (Wall Street Journal, July 22, 2015; EIA August 2015 STEO, July 22, 2015 EIA *This Week in Petroleum*).

[3] The gap in the summer of 2015 also appears if the model is estimated using seasonally adjusted data as discussed below. In contrast, the gap in September-November 2016 evident in the left panel of Figure A is not present using seasonally adjusted data, which suggests that this later gap is associated with the seasonal adjustment method in the benchmark model.

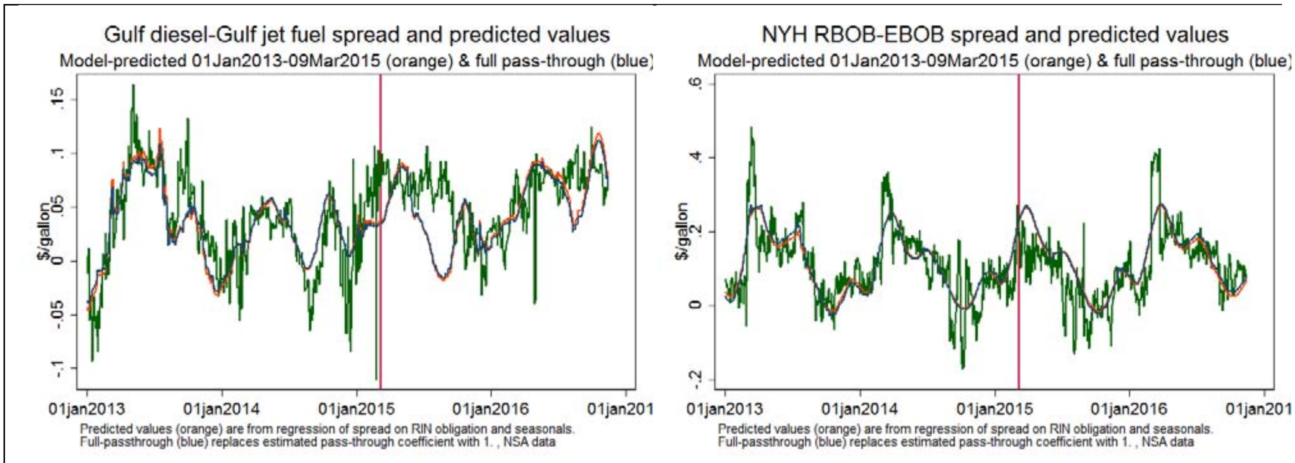


Figure A. Spread between obligated and nonobligated fuels: actual values (green), predicted values based on the KMS benchmark levels model estimated on the KMS sample (orange), and predicted values based on complete pass-through (blue). The vertical line separates the KMS sample and the out-of-sample period.

When these five refined product spreads are pooled together (using the pooling method in KMS), imposing the restriction that the pass-through coefficient is the same and using the benchmark levels regression from KMS (KMS, Table 3, regression 1), the pass-through coefficient is estimated to be 1.03 (SE=0.11) in the KMS sample. When this pooled regression is re-estimated using the full sample, the estimate is 1.12 (SE = 0.09).

2. For the five refined product spreads, the estimated RIN pass-through dynamics of KMS also hold up in the full sample and point to complete pass-through. The following chart presents the dynamic effect of a change in the RIN obligation on the spread, estimated in a pooled VAR using all five refined product spreads using the method of KMS Table 4. The left panel is estimated on the KMS sample, and the right panel is estimated on the full data set. In both the KMS sample and the full sample, approximately half the RIN price is passed through on the same day. Using the KMS sample and seasonally adjusted data, the pass-through coefficient after 10 days is .99 (SE = .28), and after 15 days is 1.01 (SE = .30). The dynamics estimated using the full sample are slightly slower, but not statistically different than, the KMS sample estimates: in the full sample, the 10-day pass-through coefficient is .91 (SE = .21) and the 15-day pass-through is .97 (SE = .22). The full-sample estimates are more precise than the KMS sample estimates.

Estimated Jan. 1, 2013 – March 9, 2015	Estimated Jan. 1, 2013 – Nov. 14, 2016

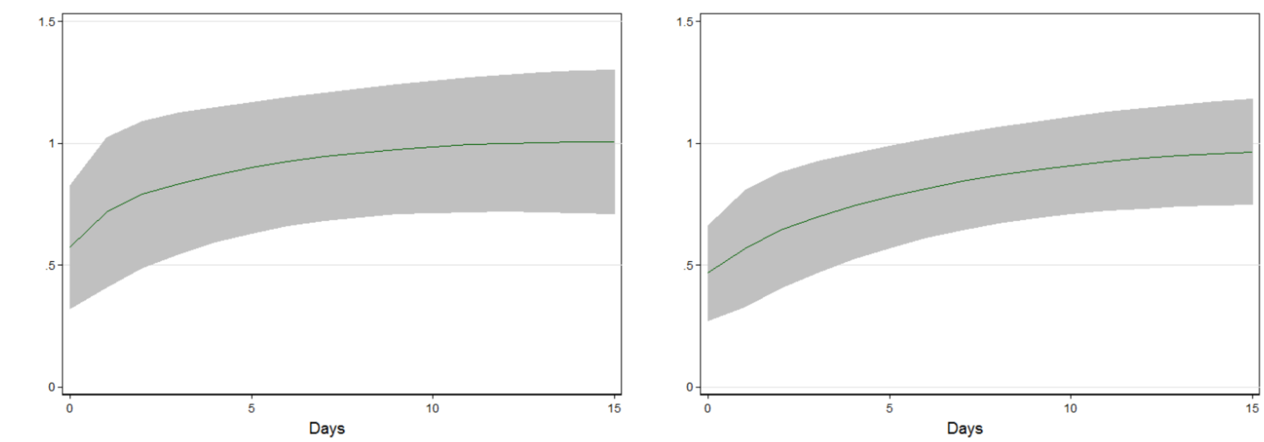


Figure B. Dynamic response of price spread between obligated and nonobligated fuels to a change in the price of the RIN obligation: pooled VAR for the five refined product spreads). Estimated using seasonally adjusted data.

3. Results from estimating pass-through using only the out-of-sample data are sensitive to how seasonals are handled. Because the spreads have seasonal swings, and because RIN price movements are mainly at the monthly or lower frequencies, it is important to control for normal seasonal variation in the spreads to reduce the risk of omitted variable bias. KMS do so in two ways: including seasonal variables (sines and cosines) in the regression, and using seasonally adjusted data, where the spread seasonal adjustment is done using data before the RFS had a material influence on spreads (pre-2013). The main results in KMS were robust to using either method, but for the shorter out-of-sample period here, the two different approaches give different results.

   The figure below shows the pass-through dynamics estimated using the pooled VAR for the five refined product spreads. The left panel includes seasonals in the VAR (the method of Figure B), the right panel uses seasonally adjusted data (the alternative method used in KMS). The upper panel shows results for the March 10, 2015 – Nov. 14, 2016 out-of-sample period. Although the two methods give very similar results in the KMS and full extended samples, the results differ when applied to just the out-of-sample period. The results when seasonally adjusted data are used are similar to those in the KMS and full sample with 15-day pass-through being within a standard error of 1, although with large standard errors because of the short out-of-sample period. The results when seasonals are included are quite different, and the differences are even more pronounced when the sample is shortened to end in May 31, 2016 (lower panel). The reason the results differ is that, when seasonals are included, the seasonals are being estimated with just over one year of data. Because RIN prices mainly move at relatively low frequencies – monthly swings, with typically small daily changes – including seasonals in the regression with just over one year of data confounds seasonal movements with RIN price movements when using only 19 months of data. Using seasonally adjusted data avoids this problem by estimating the spread seasonals on pre-sample data. Thus, for estimates based on the out-of-sample period only, the preferred specification is to include seasonals (although this distinction does not matter for the longer KMS and full extended samples, where both methods give the similar results).

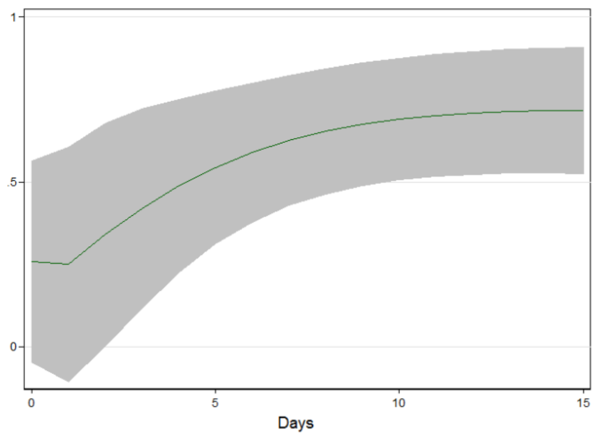
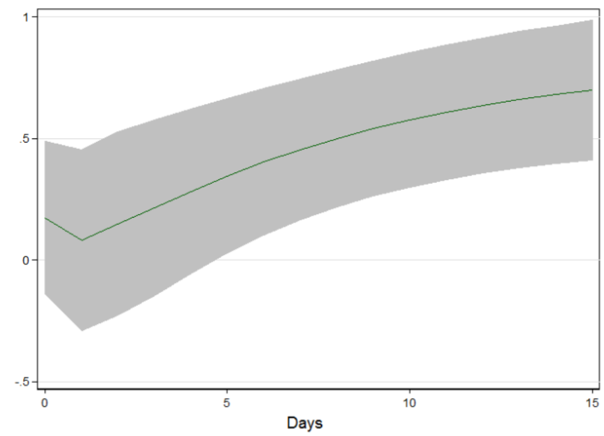
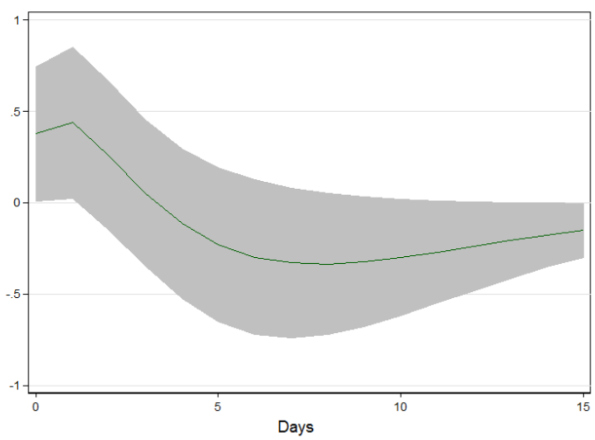
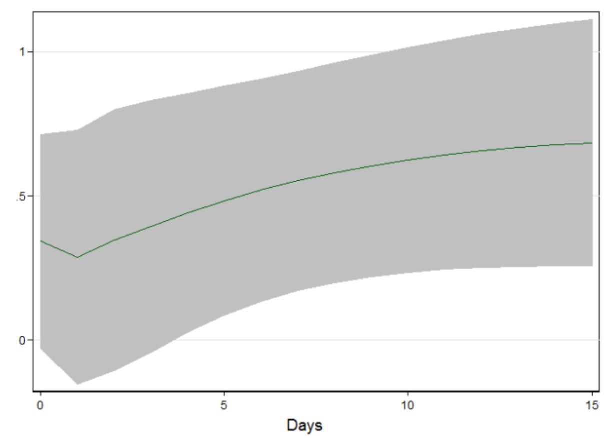
	With seasonals in regression	Seasonally adjusted data
Estimated 3/10/15-11/14/16		
Estimated 3/10/15-5/31/16		

Figure C. Effect of seasonal adjustment method and sample length on estimation of the dynamic response of spreads to RIN prices for the five refined product spreads in the out-of-sample period.

4. There were large and persistent departures of spreads involving Brent from normal seasonal patterns during 2015. Those large departures were related to supply disruptions and expanding gasoline demand because of low prices, not the RFS. The high crack spreads occurred when RIN prices were low; by the time they returned to normal, RIN prices had risen (see Figures D and E). Although the crack spreads returned to the model predicted values, the crack spread widened again towards the end of the sample. Because of these large swings in the crack spread due to non-RFS features of the oil and refined product markets, during the out-of-sample period Brent ceased to be a useful control fuel and instead introduced additional confounding factors.

It is important to keep in mind that the goal of this regression analysis is not to describe all the movements in the spreads, rather, it is to estimate the effect of a change in RIN prices on the price of an obligated fuel. The other non-RIN factors that move the spreads comprise the regression error term. In the out-of-sample period for the Brent spreads, those other factors (e.g, supply disruptions) were negatively correlated with RIN prices. Because those other factors are omitted from the regression but are correlated with RIN prices, the pass-through coefficient estimated during the out-of-sample period is subject to omitted variable bias and in fact estimates a nonsensical pass-through that is large and negative. This omitted variable bias undercuts the usefulness of Brent as a control fuel for estimating the pass-through coefficient in the out-of-sample period.

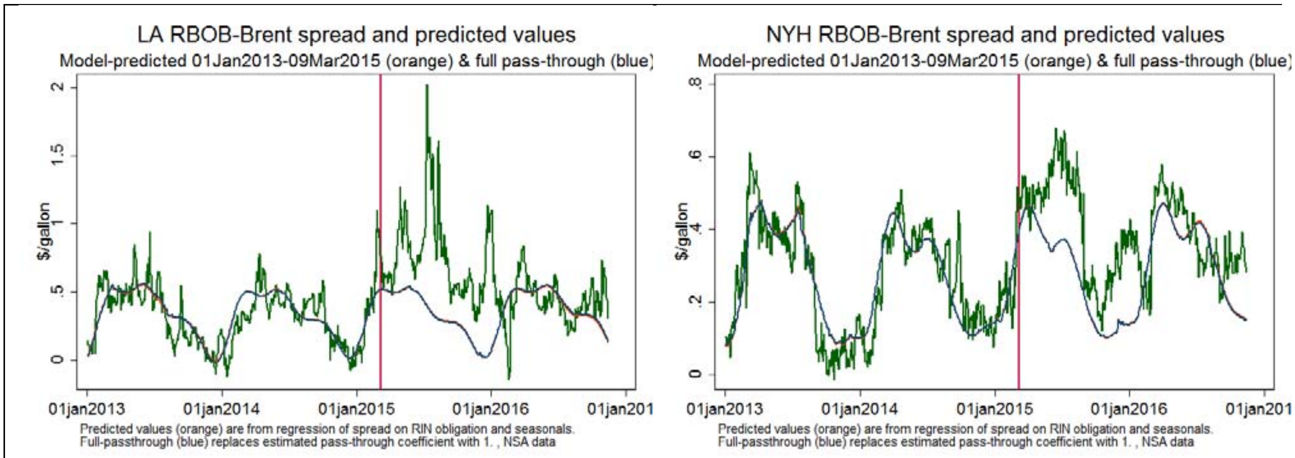


Figure D. Spread between obligated and nonobligated fuels: actual values (green), predicted values based on the KMS benchmark levels model estimated over the KMS sample (orange), and predicted values based on complete pass-through (blue). The vertical line separates the KMS sample and the out-of-sample period.

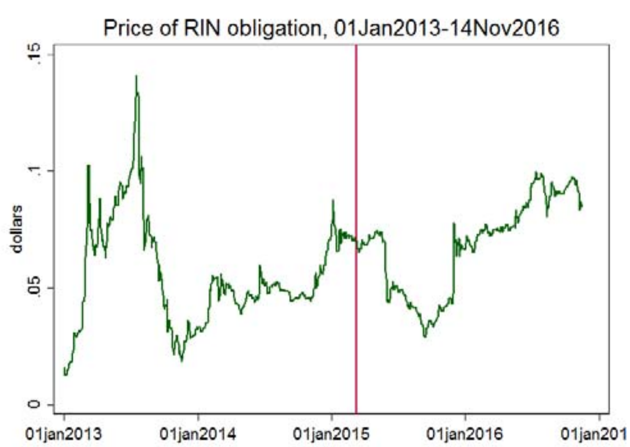


Figure E. Price of RIN obligation, Jan. 1, 2013 – Nov. 14, 2016

Data and methods

Data. The data were updated from the same source as in KMS; see the Data Appendix to this note. A seventh spread, newly added in this analysis, is the NYH CBOB spot – Rotterdam EBOB spread. Because the NYH RBOB is a prompt-month futures price while the Rotterdam EBOB is a spot price, adding this seventh spread creates a spot-spot comparison.

Each of the spreads is the price difference (in dollars per gallon) of an obligated petroleum fuel and a non-obligated fuel. Thus each spread has the same RIN obligation per gallon of fuel. The RIN obligation is the value, based on that day's RIN prices, of the bundle of RINs that an obligated party must retire with EPA per gallon of obligated fuel. The price of this RIN depends on the fractional RIN requirement for that year under the RFS.[4] The original KMS RIN price data set had some missing RIN observations, for which RIN prices were imputed using prior day data. For this analysis and for the concurrently updated KMS paper (see footnote 1), the missing values in the KMS data set have been filled in using OPIS data.

For convenience, henceforth we refer to the original KMS sample period of Jan. 1, 2013 – March 9, 2015 as the KMS sample, and the period March 10, 2015 – Nov. 14, 2016 as the out of sample (OOS) period. The full sample is the combined KMS and OOS periods, Jan. 1, 2013 – Nov. 14, 2016. The pre-sample period is the later of Jan. 1, 2005 or the first date at which a given series is available, through Dec. 31, 2012

Methods. We briefly summarize the two methods of KMS, highlighting two issues that are important for this extension, cointegration and the use of seasonals.

Let $S_t^{ij} \equiv P_t^i - P_t^j$ denote the spread between the price of an obligated fuel *i* and a non-obligated fuel *j*, and let R_t^{ij} denote the net RIN obligation on the spread.

The first set of methods are levels regressions of the form,

$$S_t^{ij} = \alpha_{ij} + \theta_{ij} R_t^{ij} + [\gamma' Seaonals] + u_t^{ij}, \tag{1}$$

see KMS equation (1). The (levels) pass-through coefficient is θ_{ij}, and full pass-through corresponds to $\theta_{ij} = 1$. This coefficient represents a long-run effect of RIN prices on the spread and this method does not estimate the dynamics of RIN price adjustment.

The second method estimates the dynamics of RIN price adjustment using a vector autoregression (VAR). Let $Y_t = (R_t^{ij}, S_t^{ij})$. The VARs are specified in levels of Y_t and have the form:

[4]In 2016, for each gallon of petroleum fuel imported or refined and sold into the domestic surface transportation market, the importer or refiner (obligated party) must turn in a total of 0.101 RINs, of which 0.0159 must be D4 (biomass-based diesel) and 0.0201 must be D4 or D5 (advanced), so up to 0.0809 can be D6 (conventional). Because the EPA delayed issuing the 2014 and 2015 rules, from Jan. 1, 2014 through the EPA proposed rule issued May 29, 2015, we use the 2013 fractional obligations. For May 29, 2015 – Dec. 31, 2015, we use the 2015 proposed fractional obligations. For 2016, we use the 2016 fractional obligations, which were finalized in November 2015.

$$Y_t = \Psi_0 + \sum_{k=1}^{p} \Psi_k Y_{t-k} + [\Gamma Seasonals_t] + \eta_t \ , \qquad (2)$$

where the coefficient matrix Ψ_k is a matrix of autoregressive coefficients on the k^{th} lag of Y. The coefficients in the matrices $\{\Psi_k\}$ and Γ are unrestricted.

Two methodological points, noted in KMS, turn out to be relevant in analyzing the extended data set.

First, the levels regression in equation (1) is valid either if the spread and the RIN obligation are jointly stationary (no unit root), or if they both have a unit root and are cointegrated. If, however, both the spread and RIN obligation have a unit root but they are not cointegrated, then the error term in equation (1) has a unit root and the levels regression is invalid in the sense of giving neither a consistent estimator of θ_{ij} nor a valid standard error. In contrast, the VAR in equation (2) is valid in all three cases (both stationary, both unit roots and cointegrated, both unit roots but not cointegrated) because it includes lags.

Second, many of the spreads have strong seasonal patterns, so it is important to handle that seasonality to avoid potential omitted variable bias. KMS provide two methods. The first is to include seasonal variables in the regression, specifically sines and cosines at the first 4 harmonic frequencies (a total of 8 seasonal variables). The second is to seasonally adjust the spreads, but not the RIN prices, using pre-sample data (pre-2013); see KMS equation (5) and the surrounding discussion. The logic of this second procedure is the standard logic of seasonal adjustment: the spreads typically have seasonal patterns, but because those seasonal patterns are driven by seasonal shifts in fuel demand they should not change substantially from one year to the next. Estimating the seasonals on pre-2013 data avoids confusing seasonals and RIN-driven movements. There is no reason that RIN prices should have seasonals[5] so in this second procedure, RIN prices are not seasonally adjusted.

Empirical results

We first explain the figures and tables of results before turning to a substantive discussion.

Figures 1-7 present charts for each of the 7 spreads. We explain figure 1 in detail for the Gulf diesel-Gulf jet fuel spread; figures 2-6 have the same format for the other six spreads. The upper left panel presents the time series plot of the spread (green) over the full sample, with the vertical line denoting the boundary between the KMS sample and the OOS sample. The orange line is the predicted value from regression (1), estimated over the KMS sample, using seasonally unadjusted data and including seasonals in the regression (this is model 1 in Table 2 of KMS). Values of the orange line in the OOS period are the out-of-sample predicted values of the spread,

[5] RINs are electronic and bankable and can be retired with the EPA at any point through the true-up period, typically February following the obligation year. As a result, they are not subject to storage costs or any of the demand, supply, and physical factors that drive seasonal fuel price fluctuations.

given RIN prices, computed using the coefficients estimated using the KMS sample. The blue line is the predicted value with full pass-through (the estimated pass-through coefficient in the orange line is set to 1).

The upper right panel presents the same set of results, except that the spreads are seasonally adjusted so the levels regression omits the seasonal variables (this is model 4 in Table 2 of KMS). The orange line is the predicted value estimated using the KMS sample and the blue line is full pass-through.

The middle left panel is a scatterplot of the change in the spread versus the change in the price of the RIN obligation, both expressed as changes in the weekly average. The green dots are from the KMS sample, the blue triangles are from the OOS sample, and the green and blue lines are the regression lines for the KMS and OOS samples respectively. The black line is the 45º line that represents complete pass-through. This scatterplot updates KMS Figure 6 (working paper version).

The final three panels are impulse response functions from the VAR in equation (2), estimated using the seasonally adjusted data. The middle-right panel is for the KMS sample, the bottom-left panel is for the OOS sample, and the bottom-right panel is for the full sample. The grey areas denote ± one standard error bands.

Figures 8-10 present impulse response functions for pooled VARs, in which the same dynamics are imposed for multiple spreads (see KMS for the details). Figure 8 presents results for VARs that pool the three diesel spreads. Figure 9 presents results for VARs that pool the same six wholesale spreads analyzed by KMS. Figure 10 presents results for VARs that pool five refined product spreads (the four refined product spreads analyzed by KMS and also the NYH CBOB spot-EBOB spread). The two Brent spreads that were analyzed by KMS are not included in the pooled VARs in Figure 10. In figures 8-10, impulse response functions in the left column are for VARs that include seasonal variables, and impulse response functions in the right column are for VARs estimated on seasonally adjusted spreads. The top row is for the KMS sample, the middle row is for the OOS sample, and the bottom row is for the full sample.

Table 1 presents the levels regressions results. The first panel presents results for the KMS sample and corresponds to Table 2 in KMS (regressions 1, 2, and 4). The second panel presents results for the OOS sample, and the third panel presents results for the full sample. For the full sample, Table 1 also reports results of the *t*-test for a break in the coefficients between the two samples.

Table 2 presents pooled levels regression results for various combinations of spreads: diesel, the original KMS gasoline spreads, the original KMS pooled diesel and gasoline spreads, and in the final column, the five refined product spreads (original KMS four and also CBOB-EBOB). Regressions 1, 2, and 4 in Table 2 extends the same regressions in KMS Table 3 to the new estimation samples.

Table 3 presents the impulse response functions from the pooled VARs for the diesel spreads and the five refined product spreads, for the two methods of handling seasonals and for the KMS and full sample. The first two columns of the first panel are the first two columns of KMS, Table 4.

Discussion

Broadly speaking, the results for the five spreads between refined product prices are similar to each other, the results for the two RBOB-Brent spreads are similar to each other, and the results for these two groups differ. We begin by discussing the five refined product spreads.

1. For the five refined product spreads, the pooled models estimated on the KMS sample are stable out of sample, both in the levels specifications and in the dynamics estimated by the VARs. Dynamic pass-through estimates from the pooled VARs estimated using seasonally adjusted data are quantitatively and qualitatively similar in the KMS sample, the OOS sample, and in the full sample. Using the KMS sample and seasonally adjusted data, the pass-through coefficient after 10 days is .99 (SE = .28), and after 15 days is 1.01 (SE = .30). The dynamics estimated using the full sample are slightly slower, but not statistically different than, the KMS sample estimates: in the full sample, the 10-day pass-through coefficient is .91 (SE = .21) and the 15-day pass-through is .97 (SE = .22). Using the seasonal adjustment method in KMS (that is, including seasonals in the VAR), the 10-day pass-through coefficients for the five pooled refined product spreads are 1.25 (SE = .26) for the KMS sample and .96 (SE = .18) for the full sample. Static and dynamic pass-through estimates for individual spreads differ between the KMS sample and the OOS sample but with no particular pattern across the five refined product spreads, with estimates for some spreads indicating greater pass-through and for others indicating less, frequently with large standard errors in the OOS period. Overall, the results for these five refined product spreads are consistent with complete pass-through.

    a. The amount of information in the OOS period is more limited than in the KMS period, both because the number of observations is fewer and because the variation in RIN prices is less during the OOS period than during the KMS period. This is most readily seen by inspecting the scatterplots in Figures 1-7, in which the spread of green dots is substantially larger than the spread of the blue triangles. In the scatterplots, the correlations in the OOS period seem to be driven by a few large outliers, which suggests caution interpreting results for the OOS period.

    b. The fact that the OOS period is only 19 months creates a challenge for handling seasonal variation using only the OOS sample. Regressions that include seasonals in the model estimated on the OOS sample are effectively estimating seasonal patterns based just over a single observation (~1½ years). Consequently, including seasonal terms in the regression absorb fluctuations at the monthly level, whether or not those actually are seasonals. A preferable approach to handling seasonals in such a short sample is to use prior data to estimate the seasonals, then estimate regressions using the seasonally adjusted data. Comparing results across the two approaches – including seasonals in the model, or using seasonally adjusted data – shows that they yield similar results in the longer KMS sample and in the full sample, but can yield sharply different results in the short OOS sample. Because the method of using seasonally adjusted data is better suited for the OOS sample, we focus here on results using seasonally adjusted data.

c. The upper panel of Figures 1-4 and 7 indicates generally stable performance of the in-sample fit during the OOS period. Qualitatively, the RIN-predicted value (KMS sample estimated and full pass-through) tracks a smooth mean of these noisy spreads, both in the model with seasonals and using seasonally adjusted data. However, tests for a break in the pass-through coefficient are mixed, with two rejecting stability at the 5% level, one at the 10% level, and two not rejecting. We discuss two of these spreads that reject, the Gulf diesel-Gulf jet spread and the NYH CBOB-EBOB spread, below.

d. The results of the levels regressions for the five refined product spreads are consistent with complete pass-through. Of the 15 pass-through coefficients (five refined product spreads estimated over the KMS, OOS, and full sample) estimated using seasonally adjusted data, only three reject complete pass-through at the 10% significance level (Gulf diesel-Rotterdam diesel in the KMS sample, and Gulf diesel-Gulf jet and NYH CBOB-EBOB in the OOS sample). Two of these rejections are in the direction of less-than complete pass-through, while one is in the direction of more-than-complete pass-through. This said, the standard errors in the OOS sample are quite large for some of the spreads, consistent with point 1a about there being limited information in the OOS period.

e. Two of the refined product spreads exhibit large but transitory departures from their RIN-predicted value during the OOS period. The Gulf diesel-Gulf jet spread remained high during the summer of 2015, in contrast to its estimated seasonal pattern As a result, the estimated pass-through coefficient for this spread is attenuated in the OOS period (high spread but low RIN obligation for the first part of the OOS period). This period coincides with the "diesel glut" of the summer of 2016, in which there was a relative oversupply of diesel and undersupply of gasoline (see footnote 2). Re-estimating the pass-through coefficient for the Gulf diesel-Gulf jet spread from September 1, 2015 – Nov. 14, 2016, i.e. after the "diesel glut" subsided, results in a pass-through coefficient of .88 (SE = .20) using seasonally adjusted data, compared to .49 in the OOS sample. For the CBOB-EBOB spread, the aberrant period is in the spring of 2016, where the RIN price is high but the spread is even higher, even after seasonal adjustment. Mechanically, this results in a large pass-through coefficient for the CBOB-EBOB spread (high RIN prices, even higher spread) during the OOS period. These periods of departure account for the rejection for these two series of the test for coefficient stability. From a theoretical perspective, price spreads are determined by multiple factors including inventory developments, supply chain disruptions, and refinery decisions, and RIN prices are only one of these multiple factors. In these regressions, those factors are relegated to the error term, and because they are persistent (lasting several months, a substantial fraction of the OOS sample) they can pose problems for the levels regressions with RIN prices in the short sample. In the longer samples (KMS and full), these departures are a smaller fraction of the sample so they pose less of a risk of omitted variable bias.

f. The pooled levels regressions (Table 2, final column) for the diesel spreads, and for the five refined product spreads, are consistent with the findings for the individual spreads levels regressions. Of the pooled estimates using all five spreads, among the 9 estimates, the only ones that reject at the 5% level are those in which seasonals are included in the model and the regression is estimated in the subsample. As discussed before this is an inappropriate method for handling seasonals in a short sample. When seasonally adjusted data are used in the KMS sample for the five refined product spreads, the pass-through coefficient is 0.81 (SE = 0.15). In the full sample, all estimates are within a standard deviation of one, regardless of the seasonal adjustment method. The KMS abstract refers to a pooled pass-through coefficient of 1.00 (SE = 0.11). Using the full sample and the same method, for the five refined product spreads, the estimate is 1.12 (SE = 0.09). Using seasonally adjusted data, it is 1.00 (SE = 0.14).

g. The IRFs for the VAR estimated using the pooled diesel spreads, estimated on seasonally adjusted data, are similar (within one standard error) in the KMS sample and in the OOS period (Figure 8, right column). For the five pooled refined product spreads, the IRFs are again similar in the KMS and OOS periods using seasonally adjusted data (Figure 10, right column). For the pooled three diesel spreads and the pooled five refined product spreads, the IRFs using seasonally adjusted data and the IRFs using seasonals in the VAR are similar in both the KMS and OOS samples. For the pooled diesel spreads and the pooled refined product spreads, the dynamic estimates using the full sample point to complete pass-through. Using the full sample improves the precision of the estimates relative to using just the KMS sample.

2. In contrast to the five refined fuel spreads, the two BOB-Brent spreads exhibit large and persistent departures from the RIN-predicted value. In brief, supply developments unrelated to the RFS, such as the Exxon-Torrance refinery fire, produced high crack spreads in the spring through fall of 2015, when RIN prices were relatively low, and the spreads returned to normal later in the sample, when RIN prices were relatively high. As a result, in the out-of-sample period, the levels regressions spuriously estimate negative pass-through coefficients.

    a. The central idea of using spreads between obligated and non-obligated fuels is that the non-obligated fuel serves as a "control" for common factors that influence the price of the two fuels. The closer the two fuels are chemically and geographically, the better the control. On *a-priori* grounds, the most compelling comparisons are Gulf diesel to Gulf jet, and NYH RBOB (or CBOB) to Rotterdam EBOB. In contrast, comparing refined product prices to Brent introduces the additional determinants of the crack spread including crude and refined inventories and changes in refiner operations. As noted in KMS, the crack spreads are much noisier than the refined product spreads, making the econometric exercise of finding the RIN price signal more difficult. Thus, on *a-priori* grounds, Brent is a less reliable control fuel than a comparable refined product.

    b. It further appears that developments in the crude and refined product market in 2015 undercut the statistical utility of Brent as a control fuel. The LA RBOB – Brent spread fluctuated in the range of zero to fifty cents during the KMS period but rose to around one dollar during the spring through fall of 2015. This persistently high price of LA RBOB, relative to crude, was associated with particularly high gasoline prices in California, relative to the rest of the country, and these high prices attracted a great deal of public attention. These high prices have been variously attributed to the February 18, 2015, fire at Exxon's Torrance refinery, to the expansion of California's cap and trade program to gasoline on January 1, 2015, to supply restrictions stemming from the limited number of refineries that produce CARBOB, and to other factors.[6] High LA RBOB prices during the spring-fall of 2015 in the presence of low RIN prices, followed by normal LA RBOB prices by the end of the sample when RIN prices had risen, produce a negative correlation that results in a large negative estimated pass-

[6] See Borenstein (2015) at https://energyathaas.wordpress.com/2015/09/28/why-are-californias-gasoline-prices-so-high/.

through coefficient. This large negative pass-through coefficient can be attributed to omitted variable bias, where the omitted variables are the supply-side disturbances that widened the California BOB-Brent spread. The persistent, supply-side factors that affected California gasoline markets confound the relationship between spreads and RIN prices, rendering unreliable the econometric analysis of the LA RBOB-Brent spread. In principle, this omitted variable bias could be addressed by including additional regressors that control for the supply disruptions and other factors leading to the high crack spread. However, needing to look for such factors underscores that Brent is not a useful control fuel during the out-of-sample period.

c. The NYH RBOB-Brent spread also exhibits persistent departures from the RIN-predicted value during this period. EIA attributed the historically high crack spreads in the spring of 2015 to expanding demand in the face of low oil prices, among other factors.[7]

d. The dynamic pass-through estimates using the six pooled spreads in KMS are statistically close to each other in both the KMS sample and the full sample (Figure 9) using both seasonal adjustment methods, and these four estimates are consistent with complete pass-through after ten days (0.89, SE = 0.25 with seasonals in the regression, 0.87, SE = 0.26 for seasonally adjusted data, both for the full sample). That said, the foregoing discussion of the persistent departures of the crack spreads in 2015 lead us to prefer the pooled estimates in Figure 10 based on the five refined product spreads, omitting the two crack spreads because of the supply-side omitted variables discussed above.

[7] See http://www.eia.gov/forecasts/steo/uncertainty/pdf/may15_uncertainty.pdf and https://www.eia.gov/forecasts/steo/archives/feb16.pdf.

Data Appendix

Prices of D4, D5, and D6 RINs are from the following hierarchy: Progressive Fuels Limited[8] when available (through 30Nov2014); if missing, then from OPIS (through 14Nov2016). The July 2015 version of KMS had some missing RIN prices during the KMS period, here and in the contemporaneous revision of KMS we have used OPIS data to fill in those missing RIN prices.

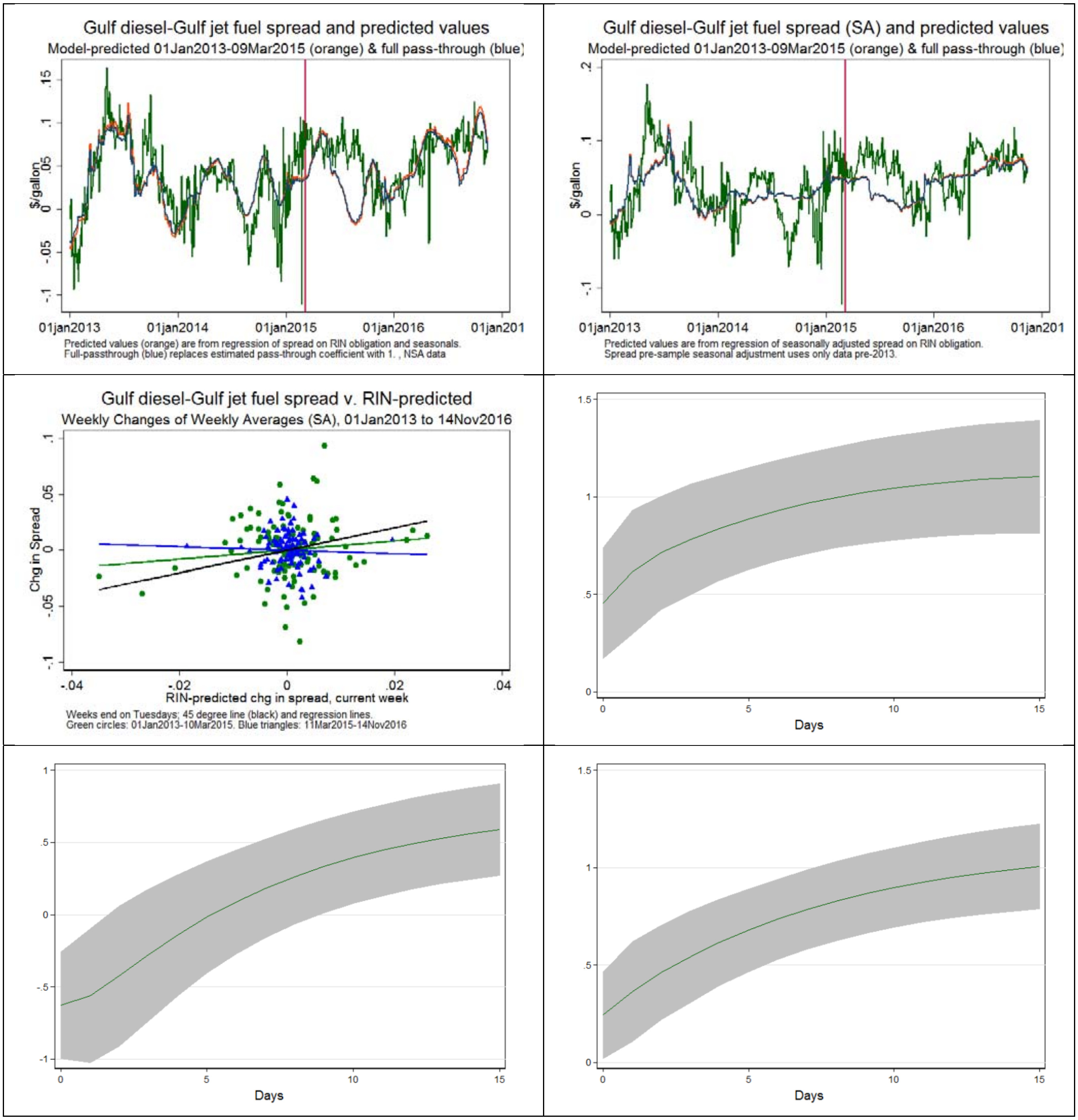
Domestic wholesale prices were obtained from the Energy Information Administration:[9] New York Mercantile Exchange prompt-month futures prices for reformulated blendstock for oxygenated blending (RBOB) New York Harbor, and spot prices for Brent oil, RBOB Los Angeles, CBOB New York Harbor, Ultra-low sulfur No. 2 diesel New York Harbor and U.S. Gulf Coast, and Kerosene-type jet fuel U.S. Gulf Coast.

Two wholesale European prices are used: the price of Rotterdam barge German diesel (10ppm sulfur), and the price of European blendstock for oxygenated blending (EBOB) free on board Rotterdam (both quoted in dollars per ton, converted to dollars per gallon). We use Argus data 03Jan2012-10Mar2015, before and after that Rotterdam diesel and Rotterdam EBOB prices are from Bloomberg. During the period that the Argus data are available, the standard deviations of the difference between the Bloomberg and Argus series are very small: \$.0056 for Euro diesel and \$.0067 for EBOB.

The data are for U.S. business days, typically close of business local time. For this analysis and in KMS, business days are defined to be days for which the NYMEX prices from EIA are non-missing.

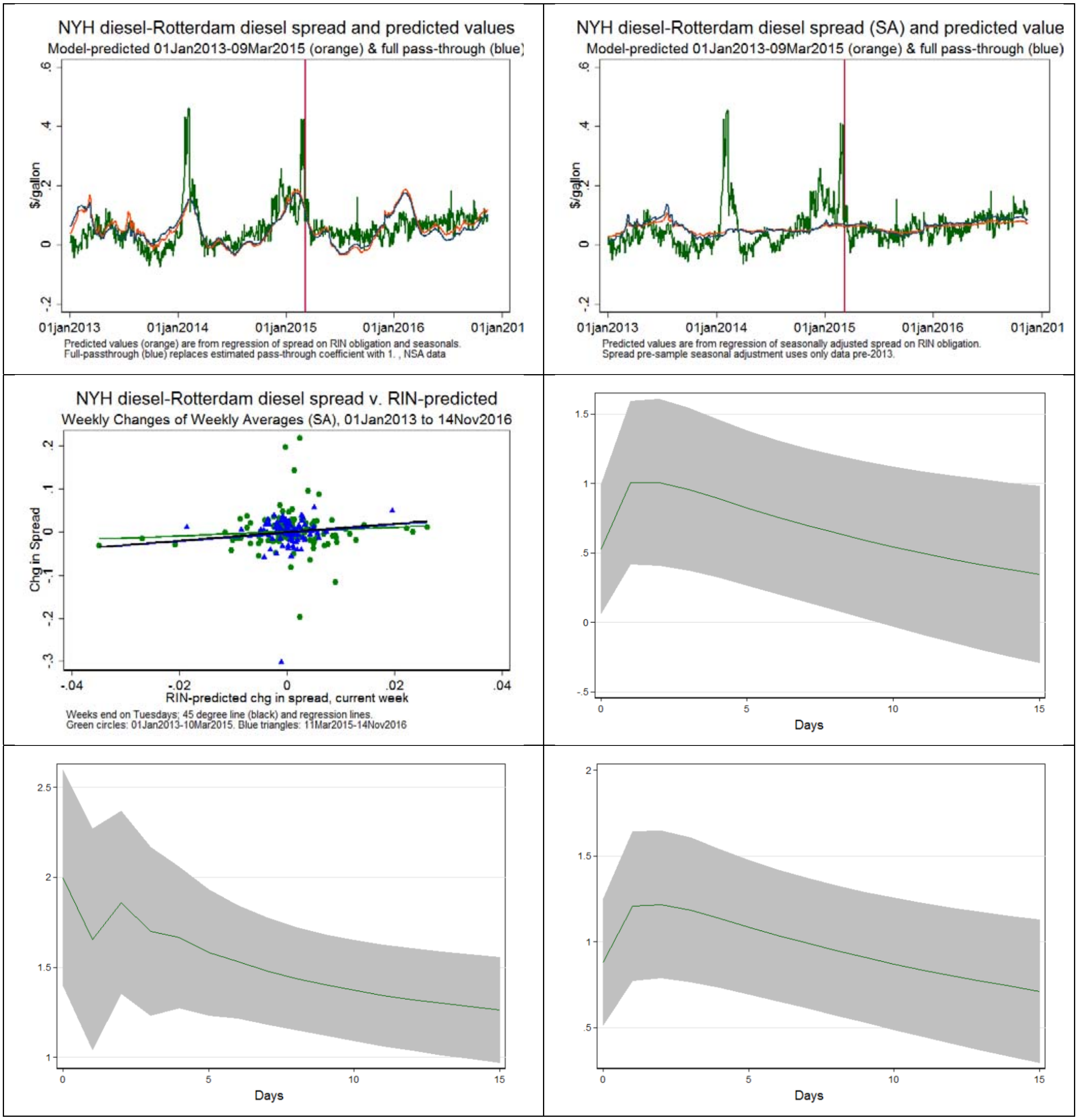
[8] RIN price data from Progressive Fuels Limited are proprietary. Progressive Fuels Limited can be reached online at www.progressivefuelslimited.com and by phone at 239-390-2885. These RIN prices are traded prices and do not necessarily reflect prices embedded long-term contracts for RINs.

[9] Spot prices were downloaded from http://www.eia.gov/dnav/pet/pet_pri_spt_s1_d.htm, and futures prices were downloaded from http://www.eia.gov/dnav/pet/pet_pri_fut_s1_d.htm.



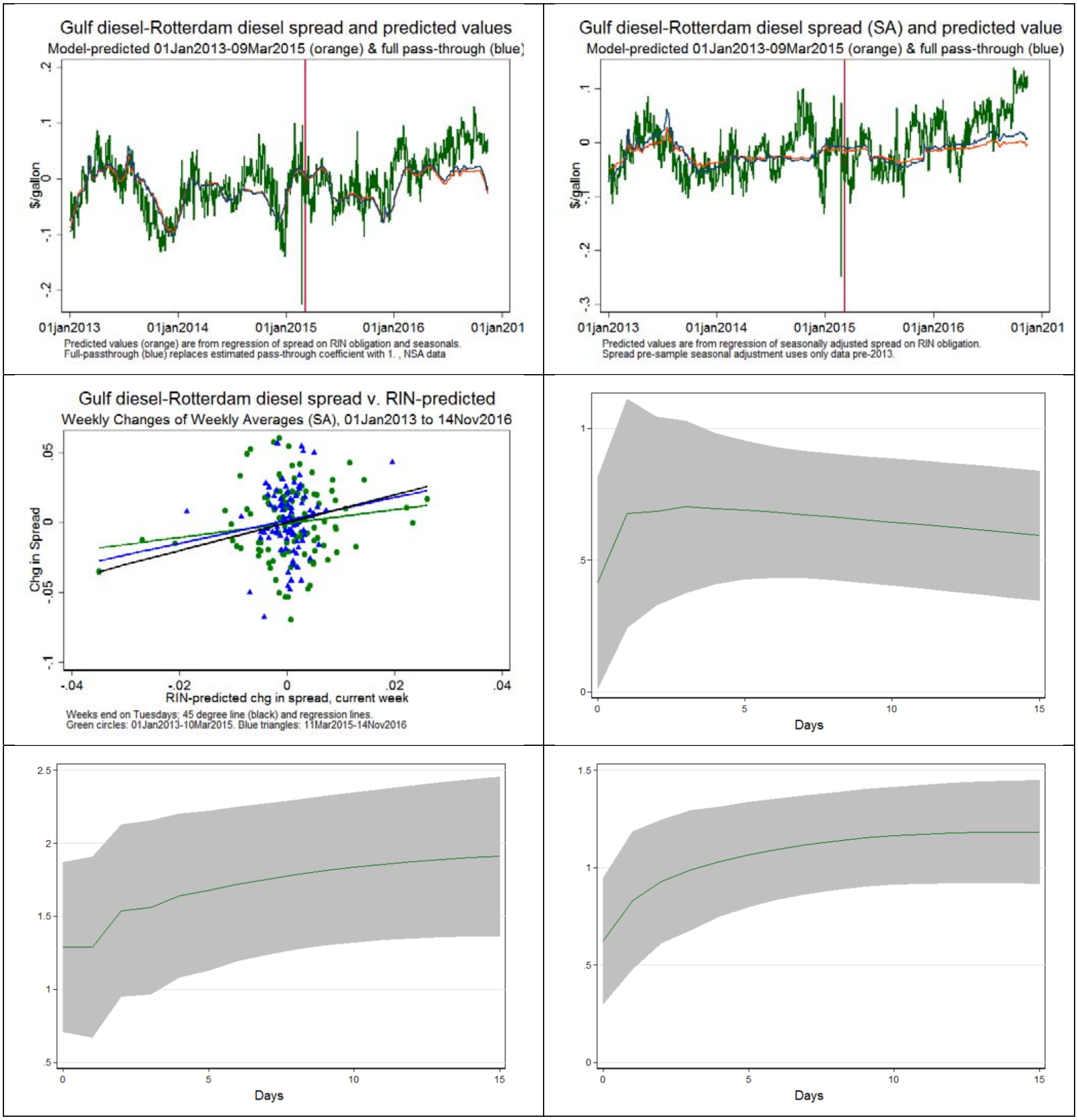
Notes: upper panels present spreads (green), KMS-sample predicted values (orange), and predicted under full pass through (blue), for seasonally unadjusted data/seasonals in model (left) and seasonally adjusted data (right). Middle left is scatterplot of weekly changes in spread on weekly changes in RIN obligation. Remaining panels are VAR impulse response presenting dynamic response of a change in the RIN obligation price on the spread, estimated using seasonally-adjusted data, in the KMS sample (middle-right), OOS (bottom-left), and full sample (bottom right).

Figure 1. Results for Gulf diesel – Gulf jet



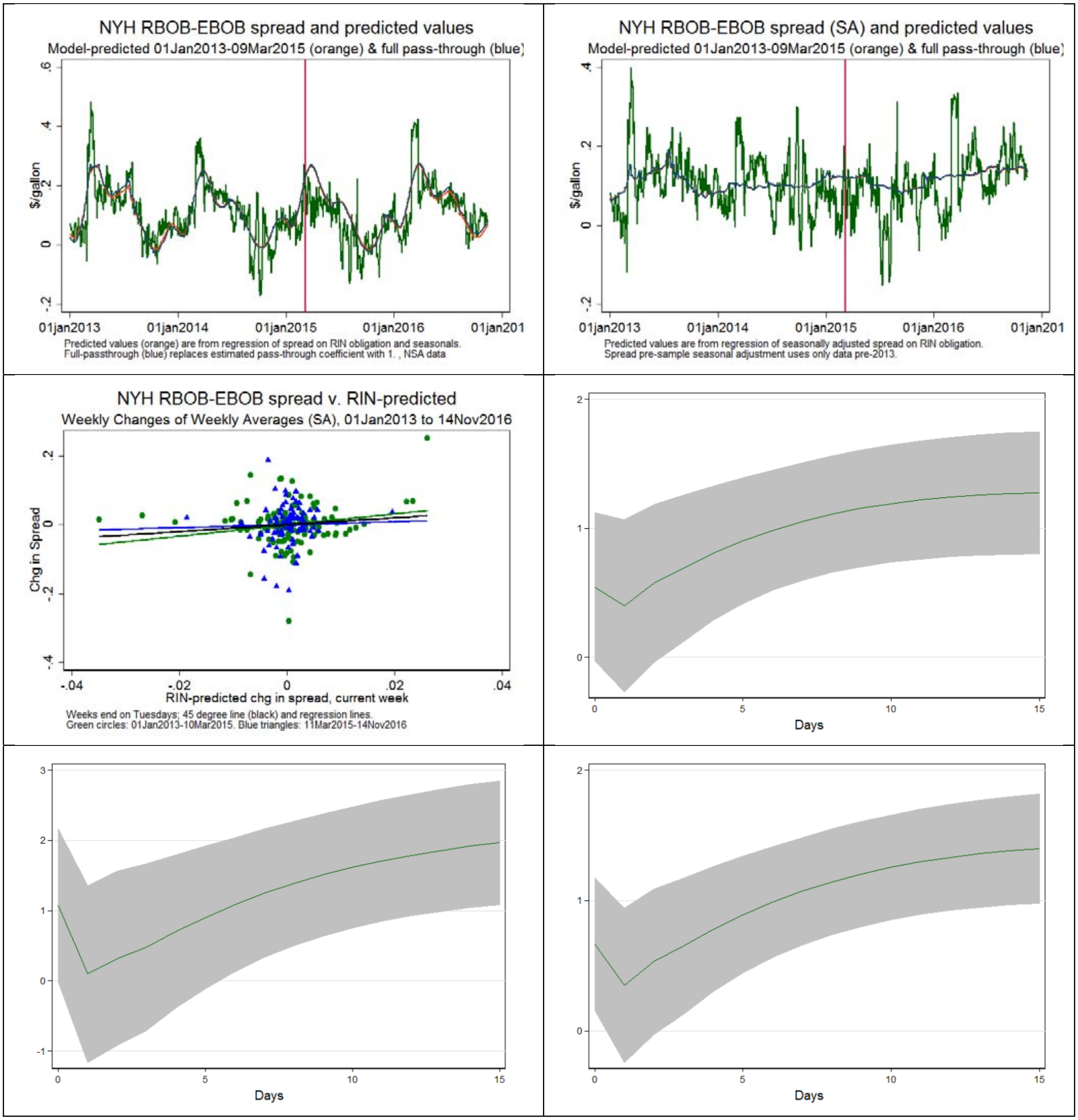
Notes: upper panels present spreads (green), KMS-sample predicted values (orange), and predicted under full pass through (blue), for seasonally unadjusted data/seasonals in model (left) and seasonally adjusted data (right). Middle left is scatterplot of weekly changes in spread on weekly changes in RIN obligation. Remaining panels are VAR impulse response presenting dynamic response of a change in the RIN obligation price on the spread, estimated using seasonally-adjusted data, in the KMS sample (middle-right), OOS (bottom-left), and full sample (bottom right).

Figure 2. Results for NYH diesel – Rotterdam diesel



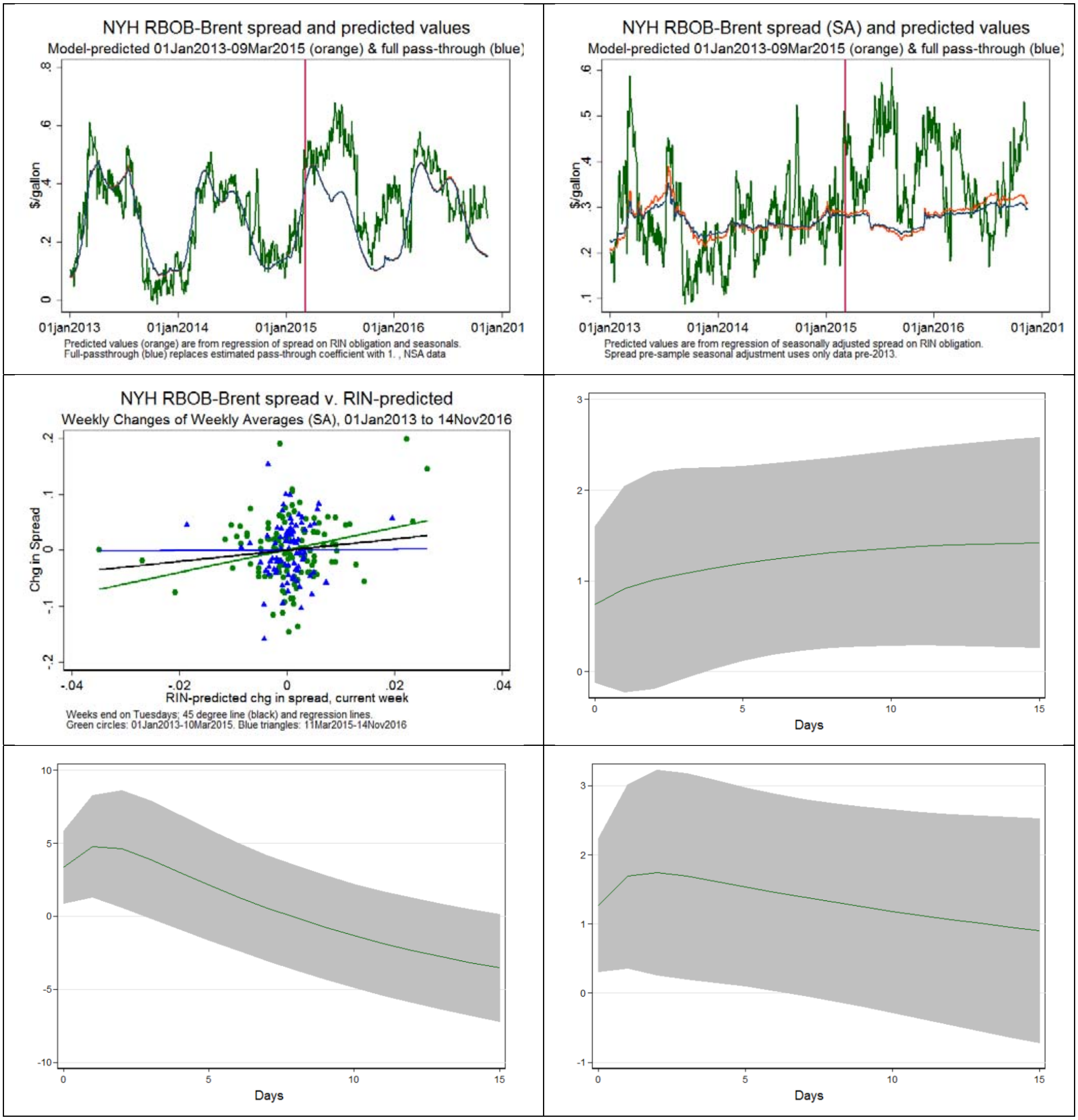
Notes: upper panels present spreads (green), KMS-sample predicted values (orange), and predicted under full pass through (blue), for seasonally unadjusted data/seasonals in model (left) and seasonally adjusted data (right). Middle left is scatterplot of weekly changes in spread on weekly changes in RIN obligation. Remaining panels are VAR impulse response presenting dynamic response of a change in the RIN obligation price on the spread, estimated using seasonally-adjusted data, in the KMS sample (middle-right), OOS (bottom-left), and full sample (bottom right).

Figure 3. Results for Gulf diesel – Rotterdam diesel



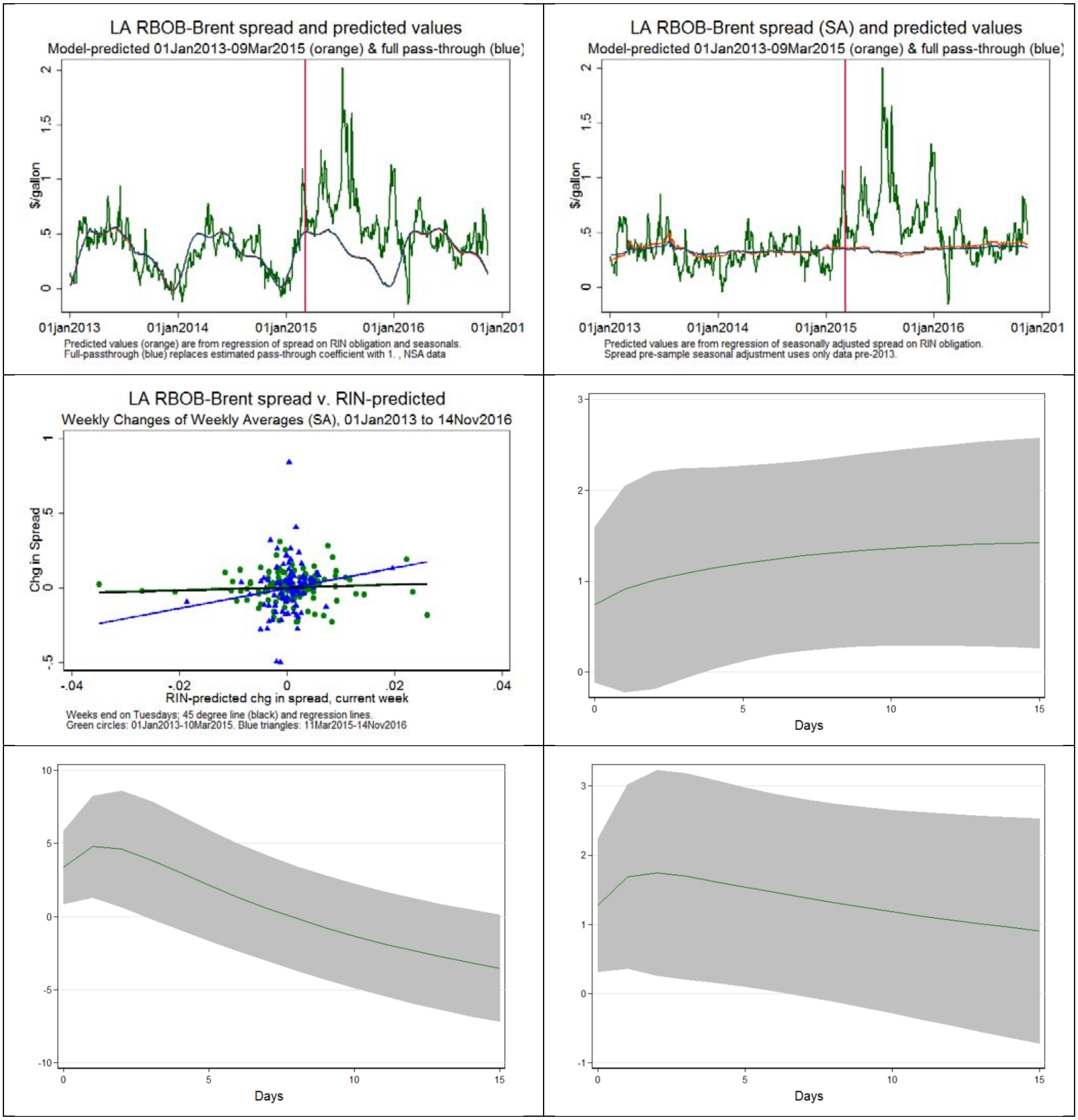
Notes: upper panels present spreads (green), KMS-sample predicted values (orange), and predicted under full pass through (blue), for seasonally unadjusted data/seasonals in model (left) and seasonally adjusted data (right). Middle left is scatterplot of weekly changes in spread on weekly changes in RIN obligation. Remaining panels are VAR impulse response presenting dynamic response of a change in the RIN obligation price on the spread, estimated using seasonally-adjusted data, in the KMS sample (middle-right), OOS (bottom-left), and full sample (bottom right).

Figure 4. Results for NYH RBOB futures – Rotterdam EBOB



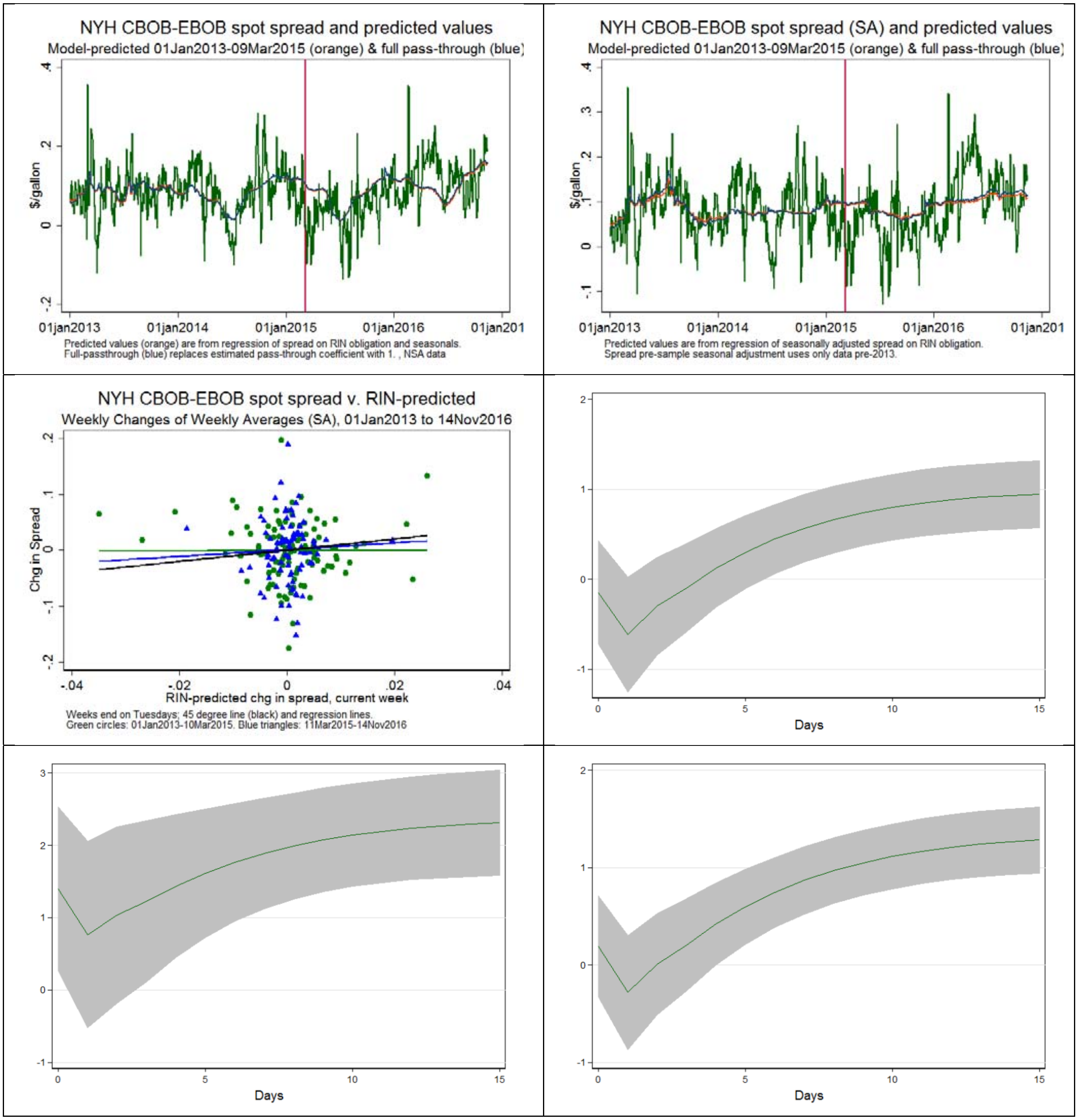
Notes: upper panels present spreads (green), KMS-sample predicted values (orange), and predicted under full pass through (blue), for seasonally unadjusted data/seasonals in model (left) and seasonally adjusted data (right). Middle left is scatterplot of weekly changes in spread on weekly changes in RIN obligation. Remaining panels are VAR impulse response presenting dynamic response of a change in the RIN obligation price on the spread, estimated using seasonally-adjusted data, in the KMS sample (middle-right), OOS (bottom-left), and full sample (bottom right).

Figure 5. Results for NYH RBOB futures – Brent



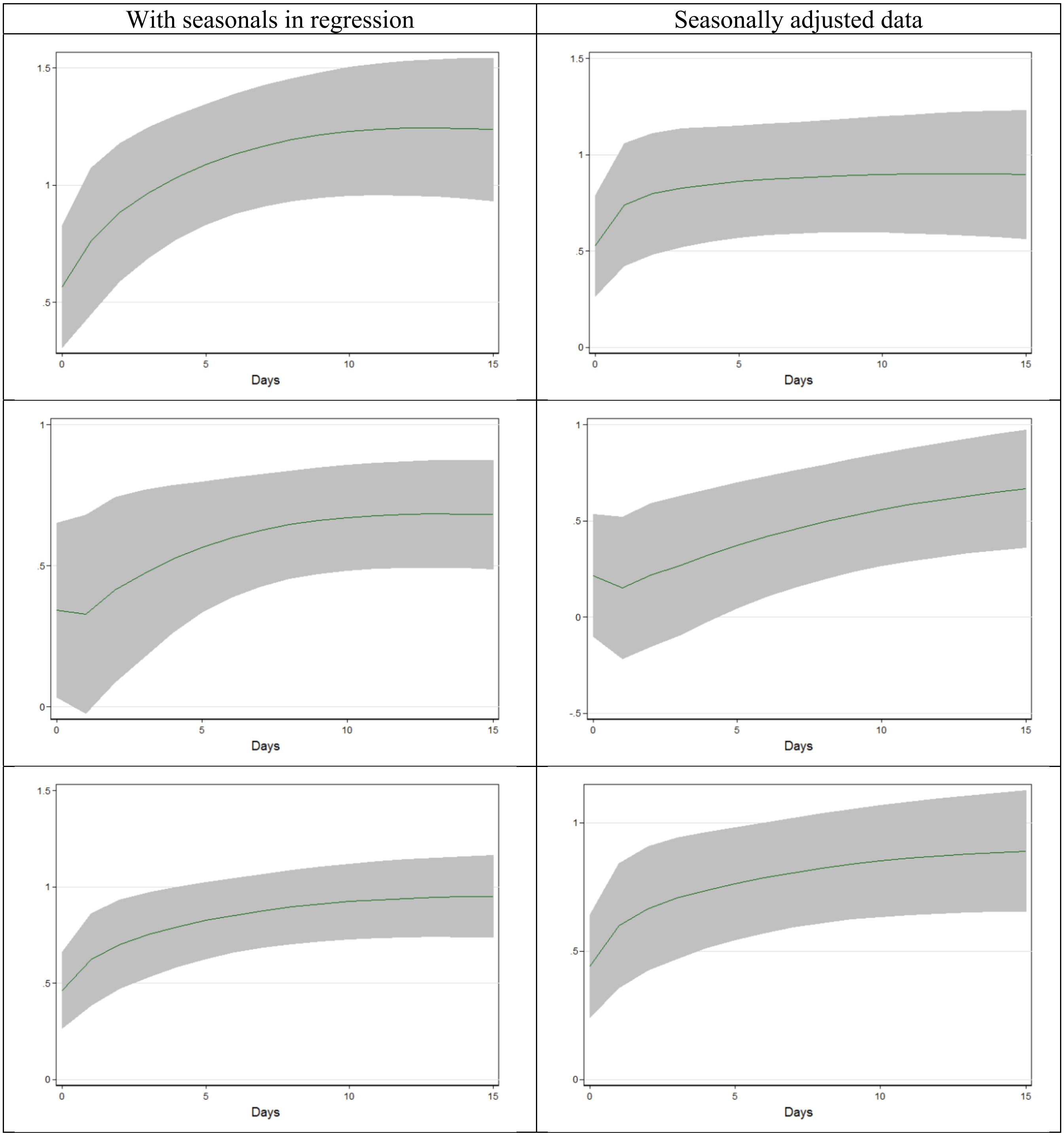
Notes: upper panels present spreads (green), KMS-sample predicted values (orange), and predicted under full pass through (blue), for seasonally unadjusted data/seasonals in model (left) and seasonally adjusted data (right). Middle left is scatterplot of weekly changes in spread on weekly changes in RIN obligation. Remaining panels are VAR impulse response presenting dynamic response of a change in the RIN obligation price on the spread, estimated using seasonally-adjusted data, in the KMS sample (middle-right), OOS (bottom-left), and full sample (bottom right).

Figure 6. Results for LA RBOB spot – Brent



Notes: upper panels present spreads (green), KMS-sample predicted values (orange), and predicted under full pass through (blue), for seasonally unadjusted data/seasonals in model (left) and seasonally adjusted data (right). Middle left is scatterplot of weekly changes in spread on weekly changes in RIN obligation. Remaining panels are VAR impulse response presenting dynamic response of a change in the RIN obligation price on the spread, estimated using seasonally-adjusted data, in the KMS sample (middle-right), OOS (bottom-left), and full sample (bottom right).

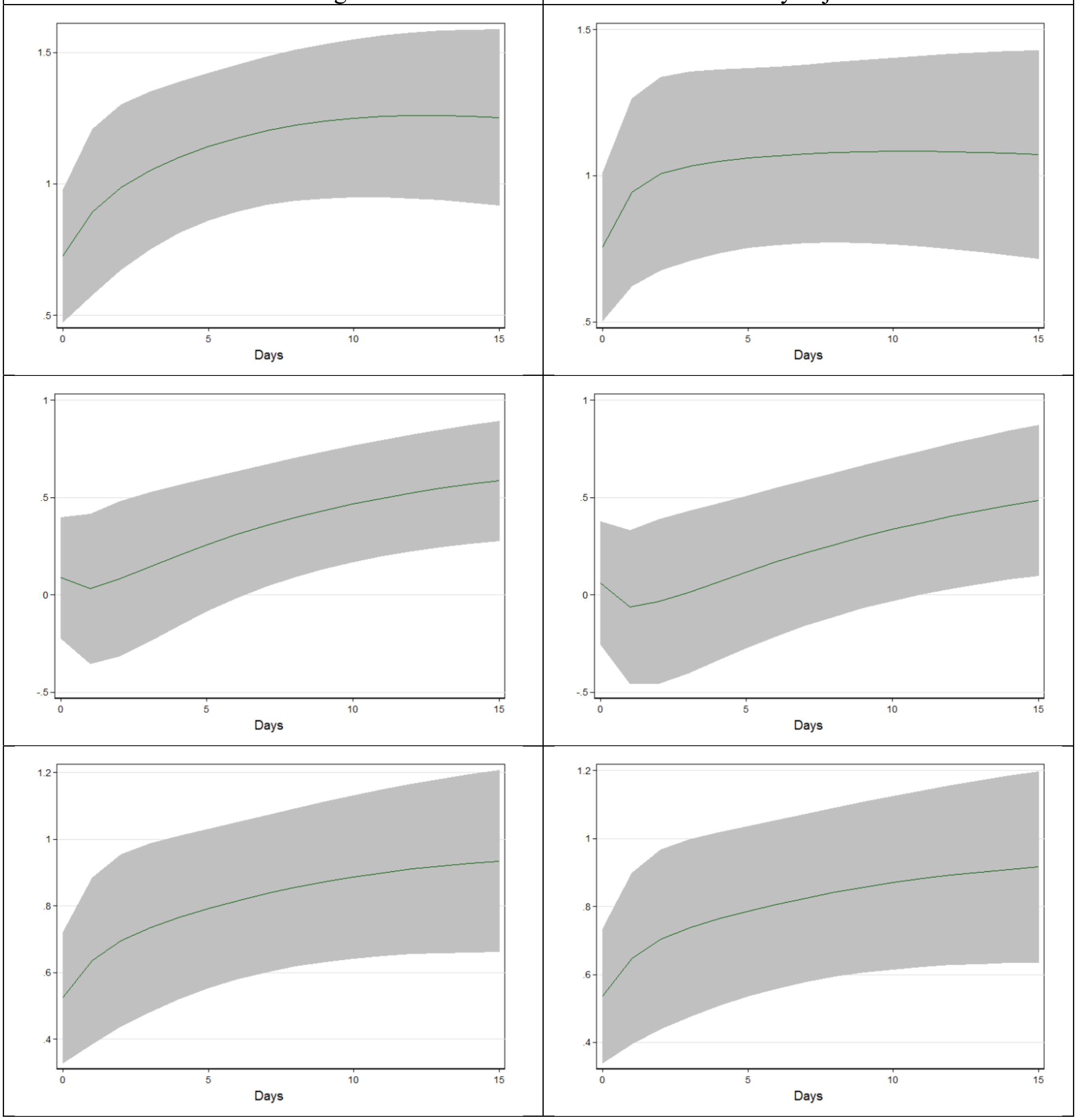
Figure 7. Results for NYH CBOB spot – Rotterdam EBOB



Notes: Left: with seasonals in VAR (left panel) Right: Seasonally-adjusted data
Top: KMS sample; Middle: post-09March2015. Bottom: full sample. *Note that the vertical scales vary across panels*.

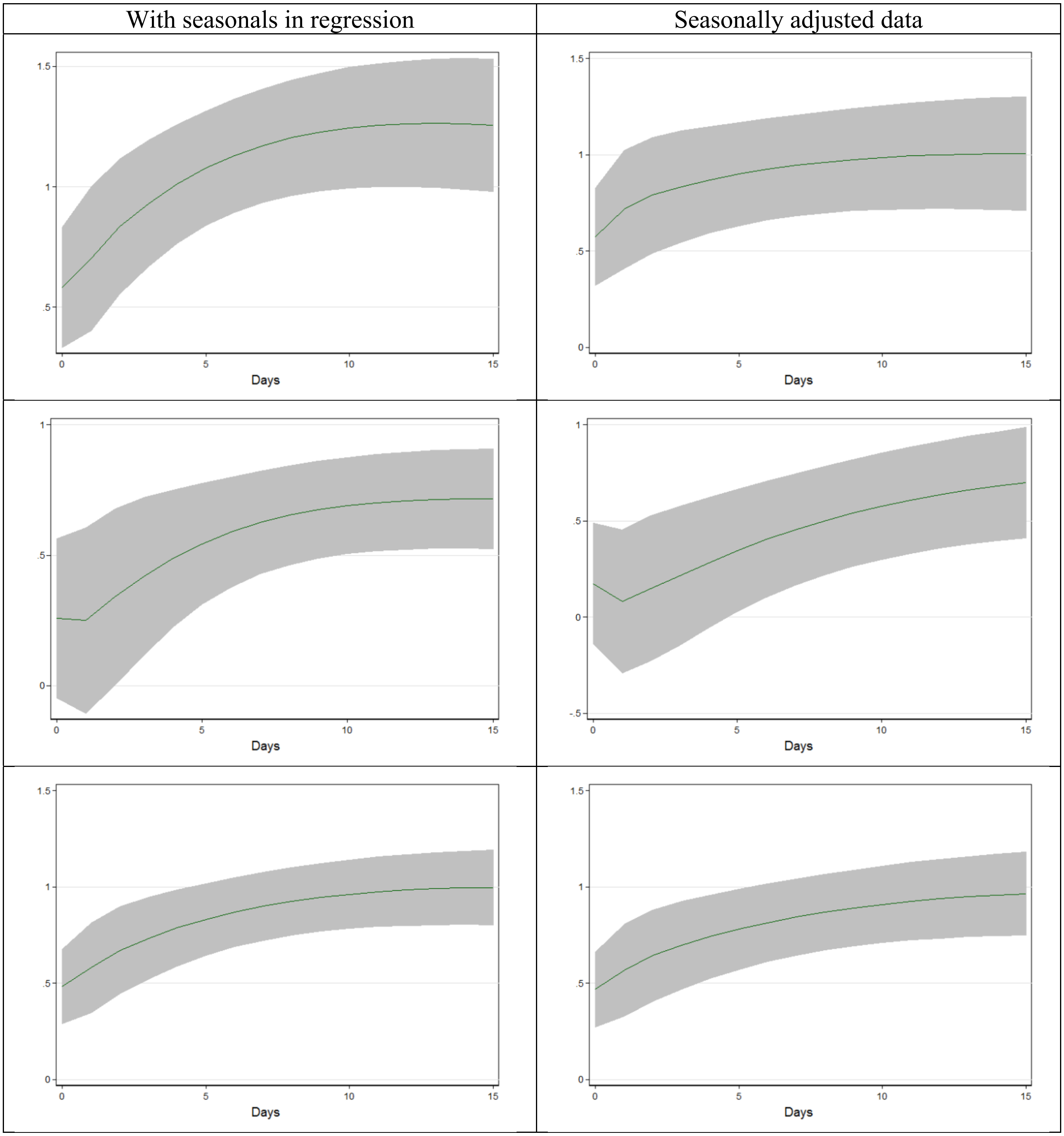
Figure 8. Pooled impulse response functions: Diesel spreads

With seasonals in regression	Seasonally adjusted data



Notes: Left: with seasonals in VAR (left panel) Right: Seasonally-adjusted data
Top: KMS sample; Middle: post-09March2015. Bottom: full sample. *Note that the vertical scales vary across panels*.

Figure 9. Pooled impulse response functions: Diesel spreads + KMS original BOB spreads



Notes: Left: with seasonals in VAR (left panel) Right: Seasonally-adjusted data
Top: KMS sample; Middle: post-09March2015. Bottom: full sample. *Note that the vertical scales vary across panels*.

Figure 10. Pooled impulse response functions: Diesel spreads, NYH RBOB futures – EBOB, and NYH CBOB spot - EBOB

Table 1. Extended Sample: Estimated pass-through coefficients from levels fuel spread regressions (wholesale petroleum fuels only)

	Original KMS wholesale petroleum fuel spreads						Additional
Regression coefficients (standard errors):	**Gulf diesel– Gulf jet fuel**	**NYH diesel– Rott. diesel**	**Gulf diesel– Rott. diesel**	**NYH RBOB Fut –EBOB**	**NYH RBOB Fut –Brent**	**LA RBOB Spot –Brent**	**NYH CBOB Spot –EBOB**
01Jan2013-10Mar2015							
(1a) OLS, seasonals	1.159	1.565	0.818	0.682	1.086	0.711	0.903
	(0.154)	(0.424)	(0.142)	(0.332)	(0.310)	(0.701)	(0.278)
(2a) DOLS, seasonals	1.199	1.650	0.836	0.579	1.031	0.744	0.984
	(0.156)	(0.454)	(0.159)	(0.311)	(0.326)	(0.725)	(0.318)
(4a) OLS, SA data	1.059	0.628	0.603^^	0.952	1.436	1.906	0.799
	(0.225)	(0.469)	(0.185)	(0.353)	(0.477)	(0.749)	(0.181)
11Mar2015-14Nov2016							
(1b) OLS, seasonals	0.446^^^	1.045	1.834^^^	1.939^^^	-1.219^^	-7.007^^^	1.763^^
	(0.145)	(0.051)	(0.088)	(0.229)	(1.021)	(2.442)	(0.301)
(2b) DOLS, seasonals	0.466^^^	1.030	1.848^^^	2.018^^^	-1.225^^	-7.351^^^	1.748^^
	(0.149)	(0.052)	(0.093)	(0.253)	(1.030)	(2.460)	(0.312)
(4b) OLS, SA data	0.488^^	0.947	1.628	1.733	-1.282^^	-7.039^^^	1.750^
	(0.231)	(0.223)	(0.421)	(0.565)	(1.059)	(2.839)	(0.404)
01Jan2013-14Nov2016							
(1c) OLS, seasonals	0.800	1.158	1.408^^	1.152	0.951	-0.705	1.096
	(0.156)	(0.277)	(0.193)	(0.259)	(0.702)	(1.895)	(0.210)
(2c) DOLS, seasonals	0.828	1.179	1.428^^	1.145	0.887	-0.949	1.131
	(0.169)	(0.297)	(0.195)	(0.266)	(0.745)	(2.009)	(0.226)
(4c) OLS, SA data	0.943	0.731	1.117	1.129	1.102	0.305	1.075
	(0.152)	(0.310)	(0.268)	(0.280)	(0.574)	(1.322)	(0.203)
t-test for break (SA data)	-1.774*	0.610	2.238**	1.173	-2.347**	-3.054***	2.159**
Engle-Granger ADF test for cointegration	-4.232***	-4.526***	-4.592***	-5.646***	-3.054*	-3.983***	-7.019***

Notes: Regressions 1, 2, and 4 are regressions 1, 2, and 4 in KMS, Table 2. The *t*-tests in the final block test the hypothesis that the coefficients on the net RIN obligation are the same before and after 10Mar2015, maintaining constancy of the other coefficients in the regression. The final row reports the Engle-Granger Augmented Dickey-Fuller test for cointegration, computed over the full sample (rejection indicates cointegration). SA data are full-sample (through final series availability date) seasonally adjusted. Reported regression coefficients are significantly different from 1 at the ^10% ^^5% ^^^1% significance level. *t*-statistics reject the null at the ***1%, **5%, *10% significance level. See the notes to Table 2 of KMS.

Table 2. Pooled levels regressions for wholesale spreads

Regression coefficients (SEs):	Diesel	Gasoline	Diesel and Gasoline	Five Refined Product Spread
01Jan2013-09Mar2015				
(1) OLS, seasonals	1.181	0.826	1.003	1.026
	(0.154)	(0.268)	(0.114)	(0.109)
(2) DOLS, seasonals	1.228	0.785	1.007	1.049
	(0.164)	(0.283)	(0.121)	(0.113)
(4) OLS, seasonally adjusted data	0.764	1.431	1.098	0.808
	(0.211)	(0.305)	(0.158)	(0.149)
10Mar2015-14Nov2016				
(1) OLS, seasonals	1.108^^	-2.096^^	-0.494^^	1.406^^
	(0.055)	(1.074)	(0.554)	(0.088)
(2) DOLS, seasonals	1.115^	-2.186^^	-0.536^^	1.422^^
	(0.059)	(1.061)	(0.549)	(0.095)
(4) OLS, seasonally adjusted data	1.021	-2.196^^	-0.588^^	1.309
	(0.190)	(1.135)	(0.565)	(0.229)
01Jan2013-14Nov2016				
(1) OLS, seasonals	1.122	0.466	0.794	1.123
	(0.144)	(0.799)	(0.433)	(0.093)
(2) DOLS, seasonals	1.145	0.361	0.753	1.142
	(0.150)	(0.844)	(0.456)	(0.095)
(4) OLS, seasonally adjusted data	0.930	0.845	0.888	0.999
	(0.178)	(0.585)	(0.314)	(0.140)

Notes: This table extends regressions 1, 2, and 4 in KMS table 3 to the two new sample periods. All regressions are of the form of the spread in levels against its net RIN obligation in levels, with additional regressors. The diesel regressions pool three diesel spreads, the gasoline regressions pool three gasoline spreads, and the diesel and gasoline regressions pool all six spreads. The coefficient on the levels is constrained to be the same for the pooled spreads, but the other coefficients are allowed to differ across spreads. Standard errors are Newey-West with 30 lags and allow both for own- and cross-serial correlation in the errors. Reported regression coefficients are significantly different from 1 at the ^10%, ^^5%, and ^^^1% significance level. See the notes to Table 1.

Table 3. Pooled VARs: Cumulative structural impulse response functions, wholesale spreads

(a) Diesel spreads

	KMS data set (Jan. 1, 2013-March 9, 2015)				Full data set (Jan. 1, 2013-Nov. 14, 2016)			
	seasonals in VAR		seasonally adjusted data		seasonals in VAR		seasonally adjusted data	
Lag								
0	0.567	(0.266)	0.527^	(0.270)	0.464	(0.204)	0.441^^^	(0.206)
1	0.762	(0.319)	0.741	(0.328)	0.623	(0.244)	0.600	(0.248)
2	0.882	*(0.302)*	0.798	(0.324)	0.702	(0.236)	0.666	(0.247)
3	0.967	*(0.286)*	0.828	(0.316)	0.753	(0.225)	0.706	(0.241)
4	1.034	(0.271)	0.846	(0.305)	0.793	(0.212)	0.737	(0.232)
5	1.089	(0.263)	0.861	(0.298)	0.826	(0.203)	0.763	(0.225)
6	1.133	(0.261)	0.872	(0.295)	0.853	(0.198)	0.786	(0.220)
7	1.167	(0.264)	0.881	(0.295)	0.876	(0.195)	0.806	(0.218)
8	1.194	(0.268)	0.888	(0.298)	0.896	(0.195)	0.823	(0.218)
9	1.214	(0.274)	0.894	(0.303)	0.911	(0.197)	0.838	(0.219)
10	1.228	(0.280)	0.898	(0.309)	0.924	(0.199)	0.851	(0.222)

(a) Five refined product spreads

	KMS data set (Jan. 1, 2013-March 9, 2015)				Full data set (Jan. 1, 2013-Nov. 14, 2016)			
	seasonals in VAR		seasonally adjusted data		seasonals in VAR		seasonally adjusted data	
Lag								
0	0.583	(0.255)	0.574^	(0.259)	0.484	(0.198)	0.468^^^	(0.200)
1	0.702	(0.307)	0.717	(0.315)	0.581	(0.240)	0.566^	(0.244)
2	0.834	(0.288)	0.791	(0.309)	0.671	(0.232)	0.644	(0.243)
3	0.931	(0.269)	0.836	(0.298)	0.734	(0.217)	0.696	(0.234)
4	1.012	(0.253)	0.871	(0.284)	0.787	(0.202)	0.741	(0.222)
5	1.077	(0.244)	0.900	(0.275)	0.831	(0.191)	0.780	(0.213)
6	1.130	(0.241)	0.924	(0.270)	0.869	(0.184)	0.814	(0.207)
7	1.171	(0.243)	0.945	(0.269)	0.899	(0.181)	0.843	(0.204)
8	1.204	(0.246)	0.962	(0.270)	0.925	(0.180)	0.869	(0.203)
9	1.228	(0.251)	0.975	(0.273)	0.946	(0.181)	0.891	(0.203)
10	1.245	(0.257)	0.986	(0.277)	0.962	(0.183)	0.910	(0.205)

Notes: Entries are impulse responses, with standard errors in parentheses. VARs for all indicated spreads are constrained to have the same coefficients, including the same impact coefficient. All VARs have 2 daily lags and are estimated in levels. All spreads have the same net RIN obligation. The impulse response functions are identified by ordering the RIN obligation ordered first in a Cholesky factorization. Coefficients are statistically different from 1 at the ^10% ^^5% ^^^1% level.