Policy Shocks and Market-Based Regulations:

Evidence from the Renewable Fuel Standard

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November 2016

Abstract

The Renewable Fuel Standard (RFS) mandates large increases in U.S. biofuel consumption and is implemented using tradable compliance credits known as RINs. In early 2013, RIN prices soared, causing the regulator to propose reducing future mandates. We estimate empirically the effect of three 'policy shocks' that reduced the expected mandates in 2013. We find that the largest of these shocks decreased the total cost of compliance in 2013 by $7 billion over three days. We then study the effects of the shocks on commodity markets and the market value of publicly traded biofuel firms. Results show that the burden of the mandate reductions fell primarily on advanced biofuel firms and commodity markets of the marginal compliance biofuel. We argue that the policy shocks reduced the incentive to invest in the technologies required to meet the future objectives of the RFS, and discuss alternative policy designs to address the problems that arose in 2013.

JEL Codes: Q42, Q50, H23

Keywords: tradable credits, policy design, quantity mechanisms, renewable fuel standard

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1 Introduction

Governments around the world have enacted legislation to increase renewable energy production in an effort to combat global climate change and address a host of adverse externalities associated with fossil energy production and consumption. Many of these policies come in the form of implicit or explicit renewable energy mandates that are ambitious both in the total amount of production envisioned as well as in the source of that production. For example, several U.S. states have passed renewable portfolio standards that seek to displace upwards of a quarter to half of fossil-based electricity generation with solar and wind energy by the end of the decade. Other policies such as California's Low Carbon Fuel Standard rely on the development and adoption of advanced, low-carbon transportation fuels, many of which are not commercially viable at present.

The largest and perhaps most ambitious such policy is the 2007 Renewable Fuel Standard (RFS), which mandated future U.S. biofuel consumption far beyond what was feasible with the technology and infrastructure available at the time. These technology and infrastructure constraints began to bind in 2013, causing the Environmental Protection Agency (EPA) initially to defer decisions about whether to enforce the mandate and eventually to propose future cuts. Announcements and rumors about future mandate cuts created what we call 'policy shocks.' In this paper, we show how such shocks to expected future mandate stringency affect current compliance costs.

We study the effects of three policy shock events in 2013 on the price of RFS tradeable compliance credits (known as RINs), commodity markets, and the value of publicly traded biofuel firms. The first policy shock was the release of the EPA's 2013 final rule in early August 2013. In the rule, the Agency indicated for the first time that it would likely reduce the 2014 mandates. Shortly after, a news article leaked a draft of the proposed cuts, our second event. The final event was the release of the 2014 proposed rule itself in November 2013 in which the EPA officially proposed cuts to the biofuel mandates.

To understand the mechanisms through which changes in expected future mandates affect RIN prices, we first develop a dynamic model of RFS compliance that incorporates many of the salient features of the policy including multiple compliance periods, banking and borrowing, and the nesting of mandates. Guided by our theory model, we then study abnormal returns to RIN prices around each policy event. We estimate that RIN prices decreased by nearly 50% over the three days following the release of the 2013 final rule, reducing the value of the 2013 RFS subsidy to the biofuel industry (or equivalently, the value of the fossil fuel industry's 2013 RIN tax obligation) by nearly \$7 billion. Smaller but significant losses were observed following the subsequent two events, with decreases on the order of \$300 million and \$700 million, respectively.

The RFS is a major source of demand for biofuels that substitute for gasoline and diesel as well as for their inputs. To better understand the impacts of the cuts, we first test whether commodity futures prices of ethanol, crude oil, soybean oil, corn, or sugar experience abnormal returns around each event. While most commodity prices did not experience abnormal returns, we find a 1.9% and 1.2% abnormal loss in soybean oil futures prices following the release of the leaked mandates and the 2014 proposed rule, respectively. Soybean oil is a major input to biodiesel, which we argue was the marginal biofuel over our sample. We also find significant abnormal losses in corn futures markets following the 2014 proposed rule. The findings suggest that the incidence of the cuts fell primarily on inputs for marginal compliance biofuels.

Last, we study the effects of the policy shocks on the value of publicly traded biofuel firms. We find large and statistically significant losses to all firms following the release of the 2014 proposed rule. We also find important heterogeneity in the effects of each event. Conventional firms experience small and statistically insignificant losses following the 2014 proposed rule and no discernible losses following the prior two events. Advanced biofuel firms experience large, statistically significant losses on the order or 7% following the release of the 2013 final rule, as well as losses around 6% following the 2014 proposed rule. Consistent with our findings in soybean oil markets, we find a statistically significant 3% loss in the valuation of biodiesel firms following the 2014 proposed rule.

The results suggest that the incidence of the cuts fell primarily on advanced biofuel and biodiesel producers. We argue that the events reduced the incentive to produce and invest in the very fuels the policy relies most on in the future. In addition, the actions created significant policy uncertainty regarding firms' compliance schedules for 2014 and beyond. Policy uncertainty, in turn, creates an option value to delaying investments in advanced fuel production capacity (Dixit and Pindyck, 1994). Although we are unable to separately identify the effects of the decrease in expected future stringency of the mandate from the increase in policy uncertainty, the increase in uncertainty likely further undermined the RFS efforts to increase the penetration of advanced biofuels. We, therefore, conclude by discussing policy mechanisms that would mitigate significant increases in compliance costs and foster greater policy certainty and transparency.

Our work contributes first to a large literature studying the RFS and similar biofuel mandates. Early work by de Gorter and Just (2009), Lapan and Moschini (2012), and Holland et al. (2009) examines the market effects and welfare outcomes under fuel mandates. The literature has been extended along a number of important dimensions, including comparing the efficiency of fuel mandates under a variety of forms of market competition to other policy instruments (Rajagopal et al., 2011; Rajagopal and Plevin, 2013; Lemoine, 2016; Bento et al., 2014; Lade and Lin Lawell, 2016), exploring unintended consequences of biofuel mandates (Khanna et al., 2008; Holland et al., 2014, 2015), and studying the impact of economic and policy uncertainty on the incentive for investments in new technologies (Miao et al., 2012; Clancy and Moschini, 2015). Our theoretical model builds on this previous work, developing a novel dynamic model of the RFS that incorporates many important design features of the policy.

We also contribute to a growing empirical literature studying market impacts of the RFS and related policies. A number of papers estimate the demand for high-blend ethanol fuels (Anderson, 2012; Du and Carriquiry, 2013; Salvo and Huse, 2013; Babcock and Pouliot, 2013; Pouliot and Babcock, 2014) as well as effects of public policy in spurring investments in fueling infrastructure and vehicles capable of using high-blend ethanol fuels (Corts, 2010; Anderson and Sallee, 2011). More recent work has exploited the considerable variation in RIN prices to study impacts of the RIN taxes and subsidies on downstream wholesale and retail fuel markets (Knittel et al., 2015; Lade and Bushnell, 2016). Bielen et al. (2016) use similar empirical techniques to our own to study the incidence of the U.S. ethanol blenders tax credit and find that the value of the subsidy was captured primarily by ethanol producers and downstream fuel blenders. We also build on work studying the impacts of the RFS mandates on commodity prices (Hausman et al., 2012; Roberts and Schlenker, 2013; Wright, 2014; Carter et al., 2016). Where previous work has examined longer-run effects, our work demonstrates that short-run cuts to mandates have more limited impacts on commodity prices.

Finally, we contribute to a large literature studying market-based mechanisms. Regulations that allow firms to trade compliance credits are less costly than corresponding command and control policies (Coase, 1960; Crocker, 1966; Dales, 1968). In competitive markets, economic theory predicts that trading credits will lead to an efficient market outcome in which marginal compliance costs are equalized across parties (Montgomery, 1972). Moreover, allowing parties to bank and borrow credits can smooth marginal compliance costs over time, further improving regulatory efficiency (Kling and Rubin, 1997). However, when parties are allowed to bank and borrow compliance credits, expected future compliance costs affect current compliance costs, which may lead to volatility in prices as uncertainty regarding future compliance obligations increases.

We highlight an example in which uncertainty regarding future mandates resulted in significant volatility in a compliance credit market.[1] The context is salient due both to the value of the swings observed over a few days as well as the feature that the proposals were at least in part affected by political pressure to minimize fuel market impacts of the policy. To the extent that parties act strategically in their lobbying to influence future mandates, we highlight an important channel through which expectations about the success of such lobbying efforts may affect current compliance costs and policy incentives. Among our proposed solutions, the use of price collars borrows directly from a large literature studying solutions to reducing allowance price uncertainty in tradeable credit markets (Roberts and Spence, 1976; Newell et al., 2005; Nemet, 2010; Fell et al., 2012; Fell, 2016, 2015).

The paper proceeds as follows. Section 2 provides a brief background on the Renewable Fuel Standard and RIN markets. Section 3 discusses our theory model and market clearing RIN prices in a dynamic model under alternative policy designs. Section 4 discusses historical RIN prices and other relevant data used in our analysis. Section 5 discusses our empirical strategy and presents our estimates of the effects of the three policy shocks on RIN prices, commodity markets, and biofuel company stock valuations. Section 6 discusses the alternative policy designs that may increase policy certainty and reduce compliance cost volatility, and concludes.

[1] In a study similar to our own, Hitaj and Stocking (2016) explore the effect of regulatory announcements on prices for sulfur dioxide allowances under the U.S. Acid Rain Program.

2 The RFS and the Market for RINs

2.1 Background

The Renewable Fuel Standard was created by the Energy Policy Act of 2005 and expanded under the Energy Independence and Security Act (EISA) of 2007. EISA established ambitious standards for biofuel consumption in the U.S., with the goal of expanding yearly biofuel use to 36 billion gallons (bgal), or approximately 25% of total fuel consumption, by 2022. EISA established separate mandates for various biofuels including (i) cellulosic biofuel, which is produced from wood, grasses, or the inedible parts of plants; (ii) biomass-based diesel, predominantly produced from soybeans or canola in the U.S.;[2] (iii) advanced biofuel, or fuels with life-cycle greenhouse gas emissions at least 50 percent below a threshold set by the law; and (iv) renewable fuel, including all previous categories as well as ethanol derived from corn. The mandates are nested so that cellulosic biofuel and biodiesel count toward the advanced biofuel mandate, and all biofuels count toward the overall renewable fuel mandate.

The RFS is designed so that compliance in early years could be met primarily with corn ethanol. For example, the total renewable fuel mandate in 2013 was set at 16.5 bgal, of which 13.8 bgal could be met with corn ethanol. In contrast, in 2022 the total renewable fuel mandate is 36 bgal, of which corn ethanol is limited to 15 bgal. The remaining mandate must be met with cellulosic and other advanced biofuels (Environmental Protection Agency, 2013b). Thus, the program relies on the speedy development of a large advanced biofuel industry.

To enforce the RFS, every gallon of approved renewable fuel produced in or imported into the U.S. is associated with a Renewable Identification Number (RIN). Whenever a gallon of renewable fuel is blended into the U.S. fuel supply, the RIN is 'detached' and available to be sold. Obligated parties, mostly oil refiners and importers, must turn in a quantity of RINs equal to their prorated portion of the mandate to the EPA each year. The EPA allows limited banking and borrowing of RINs across compliance years. Firms may use RINs generated in the previous compliance year to meet up to 20% of their compliance obligation in any year. In addition, firms may carry a deficit between compliance years, but may only do so once (Environmental Protection Agency, 2007). To enforce the nested mandates and the banking/borrowing restrictions, RINs are differentiated by fuel type and vintage year, where RIN 'types' correspond to the biofuel categories described above.[3]

The success of the RFS in expanding U.S. biofuel consumption faces two significant challenges: (i) the blend wall, and (ii) the lack of development of a commercial-scale advanced biofuel industry. Ethanol has

[2] Biomass-based diesel (BBD) includes biodiesel and renewable diesel. Little renewable diesel was blended into the U.S. fuel supply over our sample period. As such, we use the terms 'biodiesel' and 'biomass-based diesel' interchangeably when referring to the BBD portion of the RFS requirements.

[3] We do not consider cellulosic ethanol RINs in this paper because little cellulosic biofuel has been produced to date and a viable market for cellulosic RINs has not emerged.

Table 1: Statutory vs. Proposed Mandates: 2013-2014

	Statutory Volumes (bgals)		EPA Rule (bgals)	
	2013	2014	2013	2014(P)
Cellulosic Biofuel	1	1.75	0.006	0.017
Biomass-Based Diesel	>1	>1	1.28	1.28
Advanced Biofuel	2.75	3.75	2.75	2.20
Total Biofuel	16.55	18.15	16.55	15.21

Notes: The 'Statutory Volumes' are the EISA statutory mandates for 2013 and 2014. The 'EPA Rule' refers the EPA proposed mandates; 2013 refers to the final rule, and the 2014(P) refers to the 2014 proposed rule volumes from November 2013. (Source: EPA)

historically been blended with gasoline at two levels: 10% ethanol, referred to as E10; and 85% ethanol, called E85. E10 has been approved by the EPA for decades and makes up most of the ethanol-blended gasoline sales in the U.S.[4] To maintain compliance with the RFS beyond a 10% ethanol-gasoline blend, refiners must therefore either sell greater volumes of E85 or increase sales of biodiesel, for which blending constraints do not bind. Both options are costly and require high RIN prices. In addition to the blend wall, the levels of advanced biofuel production envisioned in EISA have yet to materialize. This is particularly the case for cellulosic biofuels.[5]

Due in large part to these issues, the EPA has failed to release a final rule in a timely manner since 2013. In addition, the Agency has vastly scaled back the total biofuel mandates for 2014 to 2016 (Environmental Protection Agency, 2015b). Delays first arose during the 2013 rulemaking process. The Agency did not release the 2013 proposed rule until the end of January 2013, and the final rule was not published until August of that year, eight months into the compliance year (Environmental Protection Agency, 2013a). In its following 2014 proposed rule, published in November 2013, the Agency called for a significant cut to the overall biofuel mandate. Table 1 compares the EISA statutory mandates for 2013 and 2014 with the EPA proposed mandates. As can be seen, the proposed mandates for 2014 represent a large decrease relative to the EISA statutory mandates, and the proposed total biofuel mandate is lower than its level in the 2013 mandate.[6]

[4]In 2010, the EPA granted a partial waiver for E15 blends, or gasoline containing up to 15% ethanol; however, little E15 has been sold to date (Energy Information Agency, 2016).

[5]As of May 2014, six cellulosic biofuel plants were expected to produce fuel in 2014 (Adler et al., 2014), and little commercial-scale production has occurred as of 2016.

[6]A subsequent rule was not released until June 2015. The rule largely upheld the proposed cuts from 2014 and proposed similar large reductions to the 2015 and 2016 mandates. In November 2015, the EPA finalized the mandates for 2014-2016, slightly increasing mandates for all biofuels over the June rulemaking; however, the final mandates remain well below statutory levels (Environmental Protection Agency, 2015b). Given the importance of the original proposed cuts, our analysis focuses on rulemaking in 2013.

3 A Dynamic Model of Compliance

Most previous work studying the RFS and RIN prices are static. Static models omit three important features relevant to our study of RIN markets. First, regulated parties are uncertain about future fuel supply and prices, as well as future mandates. Second, the RFS is applied over many years, and firms are allowed to bank and borrow credits from one compliance year to the next. Third, the mandate has a nested structure, with certain biofuels counting towards compliance for sub-mandates and the total mandate.

To capture these features, we develop a dynamic model of RFS compliance under uncertainty. The model builds on both static models of compliance with mandates and intensity standards (de Gorter and Just, 2009; Lapan and Moschini, 2012; Holland et al., 2009; Lade and Lin Lawell, 2016), and dynamic models of compliance under cap and trade programs (Rubin, 1996; Kling and Rubin, 1997; Schennach, 2000; Holland and Moore, 2012, 2013). For ease of exposition, we describe here the important features of the model and market clearing RIN prices while relegating all derivations and a more detailed description of the model to Appendix A.

In a static model with no uncertainty in which firms produce a conventional fuel (q^c) and a renewable fuel (q^r), RIN prices (r) under a binding mandate reflect the weighted difference in marginal costs between the marginal renewable fuel and the marginal conventional fuel (Lade and Lin Lawell, 2016), i.e.,

$$r = C^{r'}(q^r) - P = \frac{C^{r'}(q^r) - C^{c'}(q^c)}{1+\alpha},$$

where $C^{r'}(q^r)$ and $C^{c'}(q^c)$ are aggregate (industry) marginal cost functions for renewable and conventional fuel, P is the market clearing blended fuel price, and α is the percent biofuel mandate. Thus, RINs 'bridge the gap' between higher marginal cost renewable fuels and lower cost conventional fuels.

In a dynamic setting with uncertainty where firms make production decisions in each production period t with a single future compliance period T, it can be shown that RIN prices are given by:

$$r_t = \beta^{(T-t)}\mathbb{E}_t[r_T], \tag{1}$$

where

$$r_T = \max[C_T^{r'}(q_T^r;\Theta_t) - P_T, 0] = \max\left[\frac{C_T^{r'}(q_T^r;\Theta_t) - C_T^{c'}(q_T^c;\Theta_t)}{1+\alpha}, 0\right], \tag{2}$$

where $C_T^{r'}(q_T^r;\Theta_t)$ and $C_T^{c'}(q_T^c;\Theta_t)$ are aggregate (industry) marginal cost functions for renewable and conventional fuels that depend on uncertain parameters Θ_t.

Equation (1) states that RINs in a dynamic setting follow Hotelling's rule and grow at the rate of interest in expectation. Equation (2) says that the fundamental value of RINs remains the same as in a static model. However, rather than reflecting current compliance costs, RIN prices reflect expected compliance costs in the final period T. Thus, if expectations regarding future compliance costs shift, RIN prices will respond immediately to incorporate changes in the expected future compliance costs.

Equations (1) and (2) are useful for interpreting a single RIN price series. However, at any given time, upwards of six different RIN series are trading due to the EPA's distinction between RINs generated in different compliance years and between RINs generated by different types of biofuel. To account for this, we consider two important extensions to our basic dynamic model to inform our empirics: (i) multiple compliance periods with limited banking and borrowing allowed between periods; and (ii) a nested mandate structure with sub-mandates for certain biofuels.

RIN prices with banking and borrowing. Because the EPA allows banking and borrowing, the price of RINs generated in any given year should be related to those produced in previous and future years as firms arbitrage expected differenced in compliance costs across compliance years. With unlimited banking and borrowing, equations (1) and (2) hold even with multiple compliance periods T_j. However, RIN prices between compliance years may differ from those predicted above when banking and borrow bind.

To study the implications of banking and borrowing restrictions on the relationship between RIN prices across compliance years (e.g., between conventional RINs generated in 2012 versus 2013), we consider a model with a single renewable and a single conventional fuel (q^c and q^r) and allow for two compliance periods T_1 and T_2. The price of RINs generated in the first compliance period are denoted $r_{1,t}$ and the price of RINs produced in the second period are denoted $r_{2,t}$.

Allowing for banking and borrowing in our dynamic model leads to RIN prices taking the following form:

$$r_{1,t} = \begin{cases} \beta^{(T_2-t)}\mathbb{E}_t\left[r_{2,T} - \Phi_2 + \beta^{(T_1-T_2)}\Phi_1\right] & \text{if } t \leq T_1 \\ \beta^{(T_2-t)}\mathbb{E}_t[r_{2,T} - \Phi_2] & \text{if } t > T_1 \end{cases} \tag{3}$$

$$r_{2,t} = \beta^{(T_2-t)}\mathbb{E}_t[r_{2,T}], \tag{4}$$

with

$$r_{2,T_2} = \max\left[C^{r'}_{T_2}(q^r_{T_2};\Theta_t) - P_{T_2}, 0\right],$$

where Φ_1 and Φ_2 denote the Lagrange multipliers on the borrowing and banking restrictions, respectively, and are positive when the respective restrictions bind. As before, $C^{r'}_{T_2}(q^r_{T_2};\Theta_t)$ is the aggregate marginal cost for renewable fuel in the second compliance period T_2.

Equation (3) demonstrates that binding expected banking and borrowing constraints drive a price wedge between the price of credits for the different compliance years. If neither constraint is expected to bind, $r_{1,t} = r_{2,t} = \beta^{(T_2-t)}\mathbb{E}_t[r_{2,T}]$ for all t. Thus, any difference between period 1 and period 2 RIN prices depends on whether the banking or borrowing constraints are expected to bind.

If the borrowing constraint is expected to bind and the banking constraint is not expected to bind ($\mathbb{E}_t[\Phi_1] > 0$ and $\mathbb{E}_t[\Phi_2] = 0$ for all t), then $r_{1,t} > r_{2,t}$ for all $t \leq T_1$. This situation would arise if, for example, firms expect the cost of generating RINs to decrease in the second period. In this case, firms defer to period 2 as much renewable fuel use as they are allowed; however, because of the borrowing constraint, they are unable to arbitrage the compliance cost differences fully.

A binding banking restriction arises if two conditions are satisfied. First, firms produce extra renewable fuel in period 1 in expectation that the cost of generating RINs will increase in period 2. Second, the expected increase in compliance costs eventuates, which makes it cheaper to use banked RINs than to use renewable fuel in period 2. If this occurs, firms are unable to fully arbitrage between lower compliance costs in the first period with higher compliance costs in the second period, and $r_{1,t} < r_{2,t}$ for all t.

RIN prices with nested mandates. In addition to observing multiple RIN vintages trading in any given period, we also observe different RIN prices for the various sub-mandates. For example, 2013 vintage RINs include separate series for conventional, advanced, and biodiesel RINs.

To better understand the relationship between these RIN prices, we develop a second model that allows for two types of renewable fuels ($q^r_{1,t}$ and $q^r_{2,t}$), one conventional fuel (q^c_t) and a single compliance period T. The policy includes an overall biofuel mandate for $q^r_{1,t}$ and $q^r_{2,t}$ as well as a sub-mandate for $q^r_{2,t}$. In this case, RIN prices for the overall mandate ($r_{1,t}$) and the nested mandate ($r_{2,t}$) are given by:[7]

$$\begin{aligned} r_{1,t} &= \beta^{(T-t)}\mathbb{E}_t[r_{1,T}] \\ r_{2,t} &= \beta^{(T-t)}\left(\mathbb{E}_t[r_{1,T}] + \mathbb{E}_t[\lambda_2]\right), \end{aligned}$$

with

$$\begin{aligned} r_{1,T} &= \max\left[C^{r'}_{1,T}(q^r_{1,T};\Theta_t) - P_T, 0\right] \\ r_{2,T} &= \max\left[C^{r'}_{2,T}(q^r_{2,T};\Theta_t) - P_T, 0\right] \\ \lambda_2 &= \max\left[C^{r'}_{2,T}(q^r_{2,T}) - \max\left[C^{r'}_{1,T}(q^r_{1,T}), P_T\right], 0\right], \end{aligned}$$

where λ_2 denotes the Lagrange multiplier on the sub-mandate, and is positive when the respective restrictions bind. As before, $C^{r'}_{j,T}(q^r_{j,T};\Theta_t)$ are aggregate marginal cost functions for renewable fuels $j = 1, 2$.

The results state that RIN prices for the nested biofuel sub-mandate $r_{2,t}$ can never be less valuable than RIN prices for the overall biofuel mandate $r_{1,t}$. This arises because $q^r_{i,2,t}$ is used for compliance towards both mandates. Furthermore, the price of credits for a binding sub-mandate reflects the difference in marginal cost between the marginal fuel used to meet the sub-mandate and the marginal cost of the renewable fuel used to meet the overall mandate. Thus, if RIN prices converge across RIN types such that $r_{1,t} = r_{2,t} > 0$, we can

[7]Note that subscripts now refer to the renewable fuel associated with the RIN rather than the period in which the RINs were generated as previously.

infer that the nested sub-mandate is not binding, and therefore that the biofuel industry is over-complying with the nested sub-mandate to meet the overall mandate. If the nested sub-mandate is not binding and the biofuel industry is over-complying with the nested sub-mandate to meet the overall mandate, this would suggest that the marginal compliance fuel is the fuel covered under the nested sub-mandate.

4 Data Summary and Stationarity Tests

This section discusses historical RIN prices as well as other data used in our analysis. Given our findings above, we use the relationship between prices of different RIN vintages and types to examine the historical importance of the EPA's banking and borrowing restrictions as well as the importance of each nested mandate. We then provide a more detailed discussion of the three policy shocks used in our event studies and summarize the futures market and stock price data used in our analysis. Last, we explore the statistical properties of all prices.

4.1 Historical RIN Prices

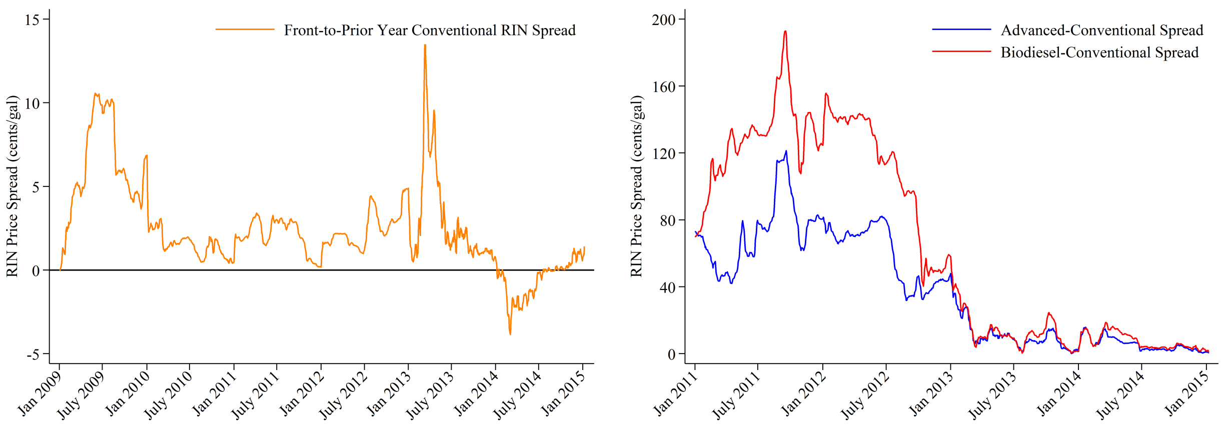
Oil Price Information Service (OPIS) is a major industry source of fuel market price data.[8] OPIS has recorded RIN price data through daily surveys of market participants since April 2008.[9] RIN prices are recorded for every biofuel category (conventional, advanced, and biodiesel) and vintage year (2008-2014). If neither the banking nor borrowing constraints imposed by the EPA bind, we would be able to aggregate RIN prices across vintage years by biofuel category to create three long time series for our analysis. However, if there were significant price differences between RIN vintages, aggregation may induce non-linearities in the time series and bias our results (Smith, 2005).

The Importance of Banking and Borrowing Constraints. Figure 1a graphs a five-day moving average of the price spread between front-year and prior-year conventional RINs from 2009-2014. For example, in 2009 the figure graphs the average price spread between 2009 and 2008 conventional RINs. Until January 2014 the average price spread was \$0.03/gal with a high of \$0.14/gal, which from our theory model indicates that the banking constraints were binding over the period. From January through June 2014, front-year conventional RINs traded at a discount to prior-year RINs. This occurred as RIN prices spiked and suggests, based on our theory model, that the industry may have anticipated a binding borrowing constraint at the

[8] Conversations with an executive at a major oil refinery as well as employees at a large U.S. biodiesel producer confirm that OPIS is regularly used to determine market RIN values when making sales and purchases.

[9] OPIS has reported conventional RIN prices since April 2008, advanced RINs have been reported since January 2011, and biodiesel RINs have been reported since June 2009. For information on the methods used by OPIS to collect its data, see Oil Price Information Service (2015).

Figure 1: The Importance of Banking Constraints and Nested Mandates



(a) The Importance of Banking Constraints

(b) The Importance of Nested Mandates

Note: The left figure graphs the five-day moving average of the spread between front- and prior-year RINs from 2010-2014. Positive values indicate a binding banking constraint and negative values indicate a binding borrowing constraint. The right figure graphs the five-day moving average spread between front-year biodiesel and conventional RIN prices (red) and advanced and conventional RIN prices (blue). Positive values indicate the nested mandates bind while zero spreads indicate that firms over-comply with the nested mandate to comply with the overall mandate.

time. The negative values reversed themselves in a relatively short period, however, with front-year RINs trading at a slight premium over prior-year RINs by the end of 2014.

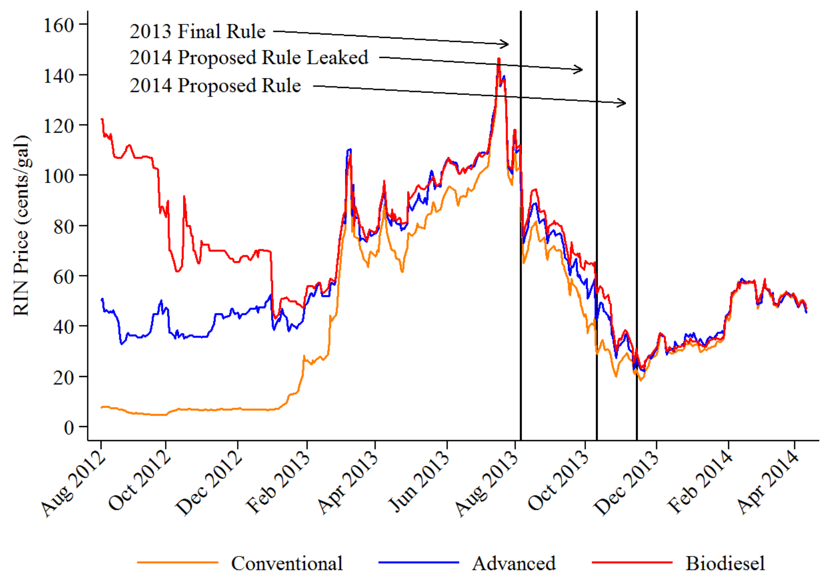
Overall, the findings suggest that the banking and borrowing constraints created important distortions in historical RIN prices. Moreover, the results indicate that the fuel industry would likely have produced more biofuels in earlier compliance periods had the banking restrictions not existed. This is consistent with Paulson (2012) who estimates the stock of RINs produced between 2007 and 2011 and finds that the banked volume of RINs equaled the 20% limit.

The Importance of Binding Nested Sub-Mandates. From our theory model, we know that if the nested mandates for advanced biofuels and biodiesel bind, advanced RINs should trade at a premium to conventional RINs and biodiesel RINs should trade at a premium to both advanced and conventional RINs.[10] Figure 1b graphs the advanced-conventional RIN and biodiesel-conventional spreads from 2011-2015. Before 2013, advanced and biodiesel RINs traded at a \$0.66/gal and \$1.17/gal average premium over conventional RINs, respectively. Thus, we can infer that the nested mandates were binding in earlier periods of the policy.

We also know from our theory model that if RIN prices converge across RIN types, we can infer that the nested sub-mandate is not binding, and therefore that the biofuel industry is over-complying with the nested

[10]This corresponds to $\lambda_2 > 0$ for both nested mandates in our theory model of RIN prices.

Figure 2: 2013 Vintage RIN Prices



Note: The figure graphs daily prices for 2013 vintage conventional (orange), advanced (blue), and biodiesel (red) RINs. The figure also indicates the timing of the key policy announcements.

sub-mandate to meet the overall mandate. If the nested sub-mandate is not binding and the biofuel industry is over-complying with the nested sub-mandate to meet the overall mandate, this would suggest that the marginal compliance fuel is the fuel covered under the nested sub-mandate. In 2013 and 2014, the average advanced and biodiesel premiums decreased to \$0.11/gal and \$0.14/gal, with a minimum of \$0.001/gal and \$0.004/gal. Thus, during our period of interest in 2013, when the RIN prices converged across RIN types, we can infer that the industry largely anticipated biodiesel playing an important role as a marginal compliance fuel.

2013 Vintage RIN Prices. Because the EPA's banking restrictions were binding for early conventional RIN vintages, aggregating RINs across vintage years may induce non-linearities in the series. As a result, we use 2013 vintage conventional, advanced, and biodiesel RINs for our main analysis. Table 2 summarizes the series and Figure 2 graphs the three series as well as indicates the timing of the three policy shocks.

Before 2013, conventional RIN prices were \$0.07/gal on average, reflecting that the industry was able to easily comply with the mandates by phasing fuel terminals from E0 to E10 across the country. Advanced and biodiesel RINs traded for \$0.42/gal and \$0.85/gal on average, respectively, consistent with binding mandates for the fuels' use. However, the advanced and biodiesel mandates were small at the time, and the total obligation associated with the two nested mandates was relatively low.

The 2013 statutory mandates began to push the blending mandates close to the blend wall, ahead of when the EPA originally anticipated this would occur (Thompson et al., 2012; Energy Information Agency,

Table 2: Summary Statistics for Price Data (cents/gal)

	Mean	Std. Dev.	Min	Max	N
Conventional RINs (cents/gal)	44.92	33.37	4.75	145.50	423
Advanced RINs (cents/gal)	59.89	26.52	22.00	146.50	423
Biodiesel RINs (cents/gal)	71.74	26.86	23.50	146.50	423
Oil Futures (cents/gal)	222.38	7.65	202.33	242.93	423
Ethanol Futures (cents/gal)	196.26	20.40	159.00	240.80	423
Soybean Oil Futures (cents/gal)	360.69	37.36	290.29	427.73	423
Corn Futures (cents/gal)	263.42	36.37	205.90	325.27	423
Sugar Futures (cents/gal)	260.63	21.85	213.92	304.92	423
S&P-GS Commodity Index	641.49	17.84	601.00	694.30	423
Russell 3000 Index	967.05	98.27	798.29	1137.17	423

Note: All RIN prices are shown for 2013 vintage series. Future prices are for July 2014 contracts.

2013). In response, all three RIN price series increased sharply in 2013 following the release of the 2013 proposed rules in January 2013 in which the EPA indicated it would enforce the statutory mandates. Prices continued to climb through July 2013, peaking around $1.45/gal in that month. At the same time, the prices of conventional, advanced, and biodiesel RINs converged. The observed RIN prices in 2013 were indicative of an industry that anticipated the mandates becoming increasingly costly the meet. Consistent with our discussion of the compliance opportunities beyond the blend wall, the convergence in RIN prices suggests that the industry anticipated biodiesel serving as the marginal compliance technology during this period.

After peaking in July 2013, RIN prices fell as precipitously as they had risen, particularly on a few key days. The high RIN prices led to increased pressure on the EPA to address the rising compliance costs as well as a number of congressional hearings (Irwin, 2013b). Three particular events, the focus of our empirical analysis, are graphed in Figure 2: (i) the release of the 2013 final rule; (ii) the publication of a news article leaking an early version of the 2014 proposed rule; and (iii) the release of the 2014 proposed rule. We next discuss each of these events in more detail.

4.2 Policy Announcements

Our analysis in the next section studies three 'policy shocks.' The first is the release of the 2013 final rule in August 2013. In the Rule, the EPA upheld the standards from the 2013 proposed rule; however, the

Agency acknowledged for the first time publicly the challenges with meeting the standards for 2014 and beyond, including the following language in the Rule:

> *[W]e recognize that...for 2014 the ability of the market to consume ethanol as E15 [and] E85 is constrained in a number of ways. We believe that it will be challenging for the market to consume sufficient quantities of ethanol...and to produce sufficient volumes of non-ethanol biofuels...to reach the mandated 18.15 bill gal for 2014.* ***Given these challenges, EPA anticipates that adjustments to the 2014 volume requirements are likely to be necessary based on the projected circumstances for 2014****...[emphasis added]*[11]

The August ruling was the first time that the EPA suggested it may change statutory mandates and was a strong signal that the mandates would be reduced later that year. In response, RIN prices fell precipitously in the days following the rule's release (Figure 2).

The second event is the publication of a news article in Reuters in October 2013 leaking an early version of EPA's 2014 proposed rule. To the authors' knowledge, and consistent with a discussion by Irwin (2013a), the news article was the first time that the EPA's draft rules were released to the general public. The article included the following discussion:

> ***In a leaked proposal that would significantly scale back biofuel blending requirements next year,*** *the U.S. Environmental Protection Agency (EPA) says the blend wall...is an "important reality"....according to an August 26 draft proposal seen by Reuters, the waiver has enabled the* ***EPA to cut the amount of corn-based ethanol that would be required in 2014 to 13 billion gallons. That is about 6 percent less than this year and well short of the 14.4 billion gallons required under the 2007 law****...* (Podkul, 2013) [emphasis added]

The article was the first insight into the EPA's impending cuts to the 2014 standard. It revealed that the EPA was considering reducing the overall standard not only below statutory levels, but below the 2013 mandate.

The final event is the release of the 2014 proposed rule in early November 2013 in which the EPA officially proposed reducing the 2014 biofuel mandates. The EPA proposed deep cuts to the mandates, reducing the overall biofuel mandate 2.94 bgals below the EISA mandates and 1.34 bgals below the 2013 level.

A number of other events could be included in our analysis. Morgenson and Gebeloff (2013) present a time series of RIN prices in 2013 along with the dates of industry events, congressional hearings, and news articles to highlight the volatility in RIN prices around key events. In this paper, we seek to study *policy* induced movements in RIN prices. As such, we have chosen a careful set of events that introduced new information from the EPA regarding the future mandates.

[11] 18.15 billion gallons refers to the overall biofuel mandate specified under EISA for 2014.

4.3 Commodity Futures and Stock Market Price Data

We collect data for various commodity futures prices as well as stock prices for two reasons. First, the effects of the three policy shocks on commodity prices for fuels and biofuel inputs is of direct interest. Second, each event study requires specifying variables to explain 'normal' returns. These variables control for movements in the RIN, commodity, or stock prices that are related to factors other than the policy shocks on each event day. For example, in event studies of stock market prices, most papers specify normal returns as a firm-specific mean daily return and returns due to the covariance of the firm's returns with a broad stock market index (MacKinlay, 1997).

RIN prices should reflect expected future compliance costs, which are a function of both expected future fuel costs and expectations regarding the future stringency of the policy. To control for expected future fuel costs in our RIN price event studies, we collect prices of July 2014 CME futures contracts for ethanol, soybean oil, and WTI crude oil contracts from Quandl.[12] We choose July 2014 contracts because the series traded over the entire observation period, and July contracts are typically among the most heavily traded. All prices are converted to a cents per gallon for ease of comparison.[13]

For our commodities market event studies, in addition to ethanol, soybean oil and WTI crude oil prices we collect July 2014 futures contract prices of CME No. 2 yellow corn and ICE No. 11 sugar from Quandl. Corn and sugar are important inputs to biofuel production in the U.S. and Brazil.[14] We use the CME S&P Goldman Sachs (S&P-GS) Commodity Index (a broad index of worldwide commodity prices) and the Russell 3000 (a broad index of the U.S. stock market) as our normal returns in our commodity market event studies. Both series are downloaded from Quandl. The variables capture movements in commodity prices due either to changes in demand for a broad class of commodities or shifts in the U.S. total stock market valuation.

Last, we collect stock prices for all publicly traded biofuel firms over our sample period. In total, we observe prices for 11 biofuel firms.[15] We classify each firm as a conventional ethanol, advanced ethanol, or biodiesel producer based on publicly available profiles of each firm's investments and production capabilities. Table 3 lists the firms as well as their classification. Most firms specialize in producing one type of biofuel. Exceptions are ADM, which produces both conventional ethanol and biodiesel; and Pacific Ethanol, which produces both conventional and advanced ethanol. In all stock price event studies, we specify normal returns

[12]Ideally, we would observe a futures price series for biodiesel; however, such a series is not currently trading on a major exchange. As a result, we use soybean oil, the dominant feedstock for biodiesel in the United States, to proxy for biodiesel costs.

[13]A conversion ratio of 1 pound of soybean oil to 7.7 gallons of biodiesel is assumed in converting soybean oil prices to $/gal (Sadaka, 2012).

[14]We convert corn prices to cents/gallon assuming a conversion rate of 2.77 gallons of ethanol per bushel and that 25% of those costs are offset from byproduct sales of distiller grains. We assume a conversion rate of 14 pounds of sugar per gallon of ethanol produced.

[15]There are more biofuel producers in the U.S., however, many are privately owned.

Table 3: Biofuel Producers and Categories

Firm	Ticker	Categories
Archer Daniels Midland	ADM	Conventional, Biodiesel
Andersons Inc.	ANDE	Conventional
Cosan, Ltd.	CZZ	Advanced
FutureFuel Corp	FF	Biodiesel
Gevo, Inc.	GEVO	Advanced
Green Plains Renewable Energy	GPRE	Conventional
Methes Energies International	MEIL	Biodiesel
Neste Oil	NTOIY	Biodiesel
Pacific Ethanol	PEIX	Conventional, Advanced
Renewable Energy Group, Inc.	REGI	Biodiesel
Solazyme, Inc.	SZYM	Biodiesel

Note: Categories reflect whether firms either produce or have significant investments in a particular technology.

as a function of a firm-specific daily return and the covariance of all firms' returns with the Russell 3000 index.

Table 2 summarizes the data. Oil futures prices fluctuated between \$2.02/gal and \$2.43/gal over the period, and ethanol futures prices traded \$0.25 lower than oil futures prices on average. Soybean oil futures prices fluctuated more widely over the period, ranging between \$2.90 and \$4.28/gal. Similar fluctuations are observed in corn futures prices as in ethanol markets. However, prices fluctuated more widely over the period, especially compared to our proxy for the cost of ethanol produced from sugar.

4.4 Stationarity and Cointegration Tests

Proper inference relies on the residuals from our econometric specifications to be stationary. Thus, we start by conducting unit root tests for each price series. Because we specify our variables in logs in our analysis, results are presented for the log of each series.

Panel A of Table 4 presents Dickey-Fuller GLS test statistics for each variable (Elliot et al., 1996). All test statistics allow for a linear trend in the series, and we present results including 1, 5, and 10 lags of the first-differenced dependent variable. We cannot reject the presence of a unit root for any RIN series, suggesting that the prices follow a random walk. The results are consistent with equation (1) of our theory model.[16] Of the remaining variables, the only series for which we can reject the null hypothesis of non-stationarity are WTI futures prices and our commodity and stock market indices. When we conduct similar tests using the first difference of each series, we find strong evidence supporting that the variables are all stationary.

[16] One may be concerned that, by causing large jumps in RIN prices, the policy events may drive our result that RIN prices follow a unit root (Perron, 1989). Unit root tests that flexibly allow for a break in the intercept of each RIN series yields similar results supporting the null hypothesis that the series are I(1) (Zivot and Andrews, 1992).

Table 4: Stationarity and Cointegration Test Results

	Lags		
Series	1	5	10
Panel A: Dickey-Fuller GLS Unit Root Test Statistics			
Conventional RINs	-0.87	-1.01	-1.19
Advanced RINs	-1.54	-1.47	-1.45
Biodiesel RINs	-1.82	-1.66	-1.56
Oil Futures	-3.03**	-2.84*	-2.77*
Ethanol Futures	-0.91	-0.82	-0.81
Soybean Oil Futures	-2.32	-2.33	-2.47
Corn Futures	-1.77	-1.26	-1.07
Sugar Futures	-1.94	-1.89	-2.38
S&P-GS Commodity Index	-3.18**	-3.12**	-3.39**
Russell 3000 Index	-3.25**	-2.93**	-3.02**
Panel B: Engle-Granger Cointegration Test Statistics			
Conventional RINs: Oil, Ethanol, Soybean Oil	-2.24	-2.20	-2.21
Advanced RINs: Oil, Ethanol, Soybean Oil	-2.10	-2.04	-2.15
Biodiesel RINs: Oil, Ethanol, Soybean Oil	-2.09	-2.04	-2.15
Oil Futures: Russell 3000 Index	-2.69	-2.86	-2.84
Ethanol Futures: Russell 3000 Index, SP-GS Index	-1.57	-1.36	-1.49
Soybean Oil Futures: Russell 3000 Index, SP-GS Index	-2.83	-2.61	-2.74
Corn Futures: Russell 3000 Index, SP-GS Index	-2.47	-1.78	-1.32
Sugar Futures: Russell 3000 Index, SP-GS Index	-2.50	-2.55	-3.03

Note: Panel A presents unit root test statistics for each series. Panel B presents Engle-Granger test statistics for cointegration between the first listed price and the prices listed after the colon. The null hypothesis under the DF-GLS test is that the series are non-stationary. The null hypothesis under the Engle-Granger test i sof no cointegrating relationship. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

While individual prices may be non-stationary, there may exist a stationary linear combination of the series. We test directly for cointegrating relationships between our primary variables of interest and the variables used as controls for ‘normal returns’ in each of our event studies in Panel B of Table 4. The table presents Engle-Granger test statistics where the null hypothesis is of no cointegration between the variables. As discussed previously, we use oil, ethanol, and soybean oil futures prices to control for normal returns to RIN prices. We use the commodity and stock market indices to control for normal returns in all commodity market event studies except for crude oil futures, where we control only for the stock market index. In all cases, we cannot reject the null hypothesis of no cointegration.

5 Empirical Strategy and Results

In this section, we discuss our empirical strategy to estimate the effect of the three policy shocks on our variables of interest. In all cases, we adopt an event study framework. Specifically, for each series we estimate 'abnormal' returns on days around when the policy shocks occurred. Similar methods have been used in a number of other studies of unexpected policy developments on stock and commodity markets (Linn, 2010; Lemoine, 2013; Bushnell et al., 2013). Identification rests on the assumption that on the event days, the returns to the prices of interest that cannot be explained by our control variables are attributable to the policy events. The identification strategy is facilitated by our use of high-frequency, daily prices.

5.1 RIN and Commodity Market Event Studies

We begin by studying the effect of the policy shocks on each RIN and commodity price series. Given our stationarity and cointegration test results, we specify each variable in their first differences. Our main specification for each RIN and commodity price is given by:

$$\Delta\log(r_t) = \beta_0 + \Delta\log(x_t)\beta + \sum_{m=1}^{3}\sum_{s\in S_m}\gamma_{m,s}\tau_{t,m,s} + \varepsilon_t, \tag{5}$$

where $\Delta\log(r_t)$ are the log differenced prices of interest, $\Delta\log(x_t)$ is a vector of log differenced prices for all control variables, $\tau_{t,m,s}$ is an indicator for day t being trading day s of event m, and S_m is the window of interest around event m. Because all variables are specified in logs, the dependent variable represents returns to each price series and β represent the covariance between returns to x_t and r_t.

Abnormal return estimates $\hat{\gamma}_{m,s}$ correspond to price changes for event m on day s that cannot be explained by changes in commodity and feedstock prices or the estimated average daily return. To see this, note that:

$$\hat{\gamma}_{m,s} = \Delta\log(r_t) - \hat{\beta}_0 - \Delta\log(x_t)\hat{\beta}$$

for all m and s. Abnormal returns are attributable to event m so long as no other events outside of movements in x_t affected r_t on the dates of interest. To control for other potential confounding factors, we include carefully chosen control variables x_t and include specifications with day-of-week and month-of-year fixed effects as well as a flexible polynomial of time to control for seasonality and time trends in the data.[17]

[17] We use a sixth order polynomial of time. More flexible functions do not change the results. The specifications with the time fixed effects and polynomial in time is analogous to a regression discontinuity design with time as the running variable that allows for multiple breaks.

Traditional inference regarding the hypothesis $H_0 : \gamma_{m,s} = 0$ may be inappropriate in event study settings (Conley and Taber, 2011; Gelbach et al., 2013). Because abnormal returns are estimated based on a single observation, asymptotic arguments do not apply, and t- and F- statistics may exhibit poor size and power properties. As a result, we use the sample quantile (SQ) test proposed by Gelbach et al. (2013) for inference on all estimated abnormal returns.[18] The test uses the distribution of $\hat{\varepsilon}_t$ for all non-event days to estimate empirical critical values from the density of the residuals. As long as the error process is stationary, the distribution of the residuals and empirical critical values converge to the true null distribution of abnormal returns as $T \to \infty$.

For our RIN market event studies, we specify normal returns as a mean daily return β_0 plus returns to due changes in expected future fuel costs $\Delta\log(x_t)$. Motivated by our model in Section 3, we include in x_t commodity futures prices for WTI crude oil, ethanol, and soybean oil.[19] We estimate equation (5) separately for conventional, advanced, and biodiesel RINs. This allows each event and energy and feedstock price shocks to have differential impacts on each series.[20] Because RIN markets may not fully internalize the change in expected future compliance costs on the event day, we estimate abnormal returns for the day that each event occurred as well as for the four subsequent trading days.

Two important factors affect the interpretation of $\hat{\gamma}_{m,s}$. First, if commodity markets were also affected by the events (a hypothesis that we test directly), the abnormal returns estimates include only returns beyond those due to adjustments in commodity market prices. These effects are of first-order interest and reflect the impact of the mandate cuts on expected future compliance costs above and beyond adjustments to changes in underlying commodity prices. Second, $\hat{\gamma}_{m,s}$ estimates only the unanticipated information due to each event. If market participants had a positive prior belief that the events would occur, the estimated impacts of the events are attenuated. In other applications, researchers scale their estimates using prior probabilities implied by predictive markets (Snowberg et al., 2011). We have no such prior information, so we interpret $\hat{\gamma}_{m,s}$ as the unanticipated information revealed by each event.

Our commodity market event studies estimate the impact of each policy shock on futures prices of crude oil, ethanol, soybean oil, corn, and sugar. We estimate equation (5) separately for each commodity. For all commodities except for crude oil, we specify $\Delta\log(x_t)$ as the Russell 3000 stock market index and the S&P Goldman Sachs (S&P-GS) Commodity Index. The S&P-GS index is composed of over twenty commodity futures, with heavy weights for energy futures contracts. The Russel 3000 index is a market capitalization-weighted index of the 3,000 largest stocks in the U.S. Thus, the abnormal return estimates correspond to

[18] Similar methods are used by Lemoine (2013) to study commodity market movements after negotiations for a comprehensive climate bill in the U.S. Senate ended unexpectedly.

[19] In Appendix B we explore specifications using other control variables. Results are not sensitive to the contract used.

[20] Alternatively, we could estimate a panel regression that pools the $\Delta\log(r_{j,t})$ for all RIN types j. Estimating equation (5) for each series is equivalent to estimating a panel model and allowing for β_j and $\gamma_{m,s,j}$ to vary by RIN type. We prefer this more flexible form over more restrictive forms such as assuming $\beta = \beta_j$ for each RIN type j.

those returns that cannot be explained by a commodity specific mean daily return and the co-movements of each series with worldwide commodity markets or the U.S. stock market. Given the importance of the RFS in driving demand for biofuel feedstocks, the events may have caused adjustments in multiple markets. To the extent that non-feedstock prices were also affected by the events, our estimates are attenuated. Because crude oil prices constitute a large share of the S&P-GS commodity index, we specify normal returns for WTI contracts as those due to a mean daily return and the co-movement with the Russell 3000 index only.

5.2 Biofuel Firm Stock Valuation Event Studies

To estimate the impact of each policy shock on the value of publicly traded biofuel firms, we could separately estimate equation (5) for each firm we observe and report results similar to those for RIN and commodity market. Instead, estimate a joint model of average abnormal returns for biofuel firms. Specifically, we estimate a panel data version of equation (5) of the following form:

$$\Delta\log(R_{it}) = \beta_{0i} + \Delta\log(x_t)\beta + \sum_{m=1}^{3}\sum_{s\in S_m}\gamma_{m,s}\tau_{i,t,m,s} + \varepsilon_{it}, \tag{6}$$

where $\Delta\log(R_{it})$ are log differenced stock prices for firm i on day t, and $\Delta\log(x_t)$ are log differenced prices for our control variables. The main difference between equations (6) and (5) are that the event indicators $\tau_{i,t,m,s}$ equal one for all firms if day t lies on trading day s of event m. Thus, the abnormal losses are averaged over all biofuel firms. We specify $\Delta\log(x_t)$ as the Russel 3000 index as in standard stock market event studies (MacKinlay, 1997). In order to draw more general inference regarding the incidence of the events, we estimate equation (6) separately for: (i) all biofuel firms; (ii) conventional biofuel producers; (iii) advanced biofuel producers, and (iii) biodiesel producers.

5.3 Results: RIN Markets

Table 5 presents our results for 2013 conventional, advanced, and biodiesel RINs. We present results for both normal and abnormal returns. The normal return estimates reflect the relative importance of the underlying commodity prices on RINs over our sample period,[21] while the abnormal return estimates represent those returns around each event that cannot be explained by movements in commodity prices.

All normal return point estimates are consistent with our theoretical model. The estimates suggest that increases in WTI prices decrease RIN prices and that increases in ethanol and soybean oil prices increase RIN prices. The only statistically significant normal return estimates are associated with soybean oil futures prices, which are statistically significant for both conventional and biodiesel RINs. The finding is consistent with our discussion in Section 4.1 where we found that biodiesel was the marginal compliance fuel over much of the estimation period.

[21] All normal return standard errors are Newey-West standard errors allowing for arbitrary autocorrelation up to five lags.

Table 5: RIN Event Study Regression Results

(Dependent Variable: Log Differenced 2013 RIN Prices)

		Conventional RINs		Advanced RINs		Biodiesel RINs	
		(1)	(2)	(3)	(4)	(5)	(6)
Normal Returns							
Oil Futures		-0.429	-0.412	-0.288	-0.269	-0.280	-0.264
		(0.354)	(0.346)	(0.343)	(0.345)	(0.332)	(0.333)
Ethanol Futures		0.183	0.128	-0.016	-0.080	0.165	0.099
		(0.215)	(0.234)	(0.261)	(0.273)	(0.231)	(0.243)
Soybean Oil Futures		0.570*	0.595*	0.283	0.367	0.724*	0.759**
		(0.340)	(0.343)	(0.393)	(0.386)	(0.385)	(0.381)
Abnormal Returns							
2013 Final Rule:	Day 0	-0.136**	-0.116**	-0.131**	-0.114**	-0.062*	-0.055*
	Day 1	-0.143**	-0.128**	-0.132**	-0.119**	-0.133**	-0.130**
	Day 2	-0.197***	-0.175***	-0.155**	-0.132**	-0.181**	-0.165**
	Day 3	0.029	0.046	0.036	0.045	0.056*	0.060*
	Day 4	0.050	0.060*	0.047	0.049	0.030	0.036
Leaked 2014 Rule:	Day 0	-0.145**	-0.129**	-0.020	0.011	-0.048*	-0.030
	Day 1	0.091**	0.099**	0.151***	0.173***	0.053*	0.071*
	Day 2	0.047	0.065*	-0.004	0.028	-0.017	0.001
	Day 3	0.001	0.015	-0.023	0.006	-0.029	-0.014
	Day 4	-0.061*	-0.040	-0.057*	-0.018	-0.046	-0.019
2014 Proposed Rule:	Day 0	-0.042	-0.034	-0.036	-0.037	-0.048*	-0.053*
	Day 1	-0.193***	-0.192***	-0.124**	-0.133**	-0.216***	-0.221***
	Day 2	0.061	0.071*	-0.023	-0.022	0.002	-0.004
	Day 3	-0.015	-0.007	-0.002	-0.003	0.033	0.026
	Day 4	0.020	0.033	-0.027	-0.021	-0.059*	-0.055*
SQ 10%	Lower Bound	-0.058	-0.053	-0.051	-0.055	-0.047	-0.046
	Upper Bound	0.063	0.059	0.059	0.060	0.051	0.049
SQ 5%	Lower Bound	-0.083	-0.078	-0.098	-0.10	-0.068	-0.073
	Upper Bound	0.087	0.090	0.083	0.077	0.080	0.076
SQ 1%	Lower Bound	-0.18	-0.17	-0.26	-0.25	-0.21	-0.22
	Upper Bound	0.18	0.17	0.14	0.13	0.14	0.13
Observations		422	422	422	422	422	422
Time Controls		No	Yes	No	Yes	No	Yes

Note: Normal return standard errors in parentheses are Newey-West errors with 5 lags. Inference for abnormal returns are based on SQ critical values given at the bottom of the table. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

Table 6: Change in Value of the 2013 Renewable Volume Obligation

		Change in 2013 RVO	Lower Bound	Upper Bound
2013 Final Rule:	Event Day Loss	-1.97***	-2.14	-1.79
	3 Day Loss	-7.05***	-7.49	-6.61
	5 Day Loss	-5.82***	-6.43	-5.21
Leaked 2014 Rule:	Event Day Loss	-0.63***	-0.71	-0.55
	3 Day Loss	0.04	-0.08	0.16
	5 Day Loss	-0.30***	-0.49	-0.10
2014 Proposed Rule:	Event Day Loss	-0.16**	-0.20	-0.12
	3 Day Loss	-0.70***	-0.80	-0.59
	5 Day Loss	-0.70***	-0.86	-0.54

Note: The table presents the change in the value of the 2013 Renewable Volume Obligation (RVO) due to each event. Lower and upper bounds represent 95% confidence intervals. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

Abnormal return estimates are large and statistically significant for all RIN series around the three events. On the day the 2013 final rule was released, conventional RIN prices experienced an 11%-13.5% abnormal loss, with similar losses to advanced RINs on that day. Biodiesel RINs experienced smaller losses of 5.5%-6%. All three series continued to fall 13%-20% on the two subsequent trading days before recovering slightly. Abnormal losses following the leaked 2014 proposed rule are largest for conventional RINs (≈13%); however, biodiesel RINs also experience statistically significant abnormal losses. All series experience small and mostly insignificant abnormal losses following the release of the 2014 proposed rule, with large losses of 12%-22% on the day following the rule's release. This is likely due to the rule being released on a Friday afternoon.

To put the losses into context, we estimate the resulting change in the value of the RFS subsidy to the biofuel industry for 2013. This also equals the change in the value of refiners' tax obligation under the policy. To calculate this value, we first estimate a fully interacted panel analog of equation (5). We then calculate the cumulative abnormal returns over different horizons by multiplying the RIN price on each day by the estimated abnormal return and summing them. Last, we multiply the losses for each event and horizon by the 2013 mandates.

Table 6 presents the results.[22] On the day the 2013 Final Rule was released, the estimated abnormal return corresponds to a decrease in the value of the 2013 RVO of $2 billion. The estimated losses increase to around $7 billion over the subsequent two trading days. Event day losses following the leaked 2014 rule

[22]Standard errors are clustered at the month to allow for arbitrary serial correlation and correlation across RIN types.

were on the order of \$600 million. The losses recover over a two-day horizon but fall again to around \$300 million over a five-day horizon. Following the release of the 2014 final rule, event day losses are \$160 million, and increase over a two- and five-day horizon to around \$700 million.

5.4 Results: Commodity Markets

The findings above demonstrate that the policy shocks led to significant, sudden shifts in the value of the RFS. Table 7 presents results from our tests of whether the announcements led to corresponding adjustments in commodity markets. The table presents abnormal return estimates for WTI crude oil, ethanol, soybean oil, corn, and sugar futures contracts. Because commodity futures markets are highly liquid, we focus on abnormal returns only on the day of each event and the subsequent two trading days.

Overall, little movement is observed in most commodity markets, particularly on the event dates. WTI, ethanol, and sugar contracts did not experience statistically significant abnormal returns on any of the event days. Sugar prices experienced positive abnormal returns following the release of the 2013 proposed rule and negative abnormal returns two days after the publication of the leaked 2014 rule; however, given their timing, it is hard to attribute these movements to the policy shocks.

We find significant abnormal losses surrounding the events in soybean oil and corn markets. Soybean oil contracts experience a significant 1.9% abnormal loss on the day the 2014 rule was leaked, and a 1.2%-1.4% loss following the release of the 2014 proposed rule. Corn prices decreased by 1.4% on the day the 2014 proposed rule was published and an additional 2% on the following day. The findings can be rationalized by recalling that the leaked rule revealed for the first time that the mandate would be set below 2013 levels, and therefore below the blend wall. Before the release of the 2013 final rule, the convergence in RIN prices across biofuel types indicated that biodiesel was the marginal compliance fuel for the overall biofuel mandate (Irwin, 2014a,b). Thus, both the leaked and proposed 2014 rules were effectively negative demand shocks to biodiesel. Given the size of the proposed cuts, the rule also likely served as a negative demand shock to corn ethanol.

Table 7: Commodity Market Abnormal Return Estimates

(Dependent Variable: Log Differenced Commodity Prices)

		WTI		Ethanol		Soybean Oil		Corn		Sugar	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
2013 Final Rule:	Day 0	-0.006	-0.008	0.006	0.007	-0.008	-0.011	-0.000	-0.002	0.001	0.002
	Day 1	-0.002	-0.004	-0.008	-0.006	-0.006	-0.011	-0.001	-0.000	0.016*	0.018**
	Day 2	-0.008	-0.012*	0.002	0.006	0.001	-0.002	0.007	0.009	-0.001	-0.000
Leaked 2014 Rule:	Day 0	-0.006	-0.005	-0.008	-0.009	-0.019***	-0.019***	-0.008	-0.006	0.011*	0.010
	Day 1	0.000	0.001	0.001	-0.001	0.003	0.003	0.007	0.006	0.005	0.004
	Day 2	-0.003	-0.001	0.012	0.011	0.009	0.008	0.015*	0.015*	-0.014**	-0.014*
2014 Proposed Rule:	Day 0	-0.003	-0.003	-0.006	-0.008	-0.014*	-0.012*	-0.014	-0.014	-0.000	-0.001
	Day 1	-0.007	-0.008	0.004	0.002	-0.006	-0.005	-0.020**	-0.022**	0.010	0.010
	Day 2	-0.000	0.000	-0.001	-0.003	-0.001	-0.001	0.013	0.010	-0.001	-0.000
Observations		423	423	422	422	422	422	422	422	422	422
Time Controls		No	Yes	No	Yes	No	Yes	No	Yes	No	Yes
SQ 10% Lower Bound		-0.010	-0.010	-0.013	-0.014	-0.010	-0.010	-0.015	-0.014	-0.011	-0.011
SQ 10% Upper Bound		0.0090	0.0094	0.014	0.013	0.012	0.011	0.013	0.013	0.011	0.011
SQ 5% Lower Bound		-0.015	-0.014	-0.017	-0.017	-0.013	-0.013	-0.020	-0.018	-0.014	-0.015
SQ 5% Upper Bound		0.013	0.013	0.018	0.017	0.015	0.014	0.018	0.018	0.017	0.015
SQ 1% Lower Bound		-0.022	-0.023	-0.029	-0.028	-0.019	-0.019	-0.033	-0.033	-0.020	-0.024
SQ 1% Upper Bound		0.024	0.023	0.030	0.030	0.024	0.024	0.038	0.039	0.024	0.022

Note: SQ test critical values are estimated from the empirical residual distribution excluding event days. Abnormal returns represent those that cannot be explained by corresponding movements in the S&P-GS Commodity Index, the Russel 3000 Index, and a daily mean return. WTI regressions exclude the S&P-GS Commodity Index. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

5.5 Results: Biofuel Firm Values

Table 8 presents abnormal return estimates for publicly traded biofuel firms. As with the commodity market results, we estimate abnormal returns on the event day and the two subsequent trading days. Results are presented for specifications including all biofuel firms as well as for conventional, advanced, and biodiesel producers.

All biofuel firms experienced average abnormal losses of 1.1%-1.9% following the release of the 2013 final rule; however, the losses are not statistically significant. Average stock values did not change significantly following the leaked proposed rule. The only statistically significant abnormal losses follow the release of the 2014 proposed rule. On the day that the rule was published, we estimate a 2% statistically insignificant gain; however, as discussed previously the rule was published on a Friday afternoon. On the subsequent trading day, biofuel firms experienced a 3.8%-4.3% statistically significant average abnormal loss.

Columns (3)-(8) decompose the average losses by type of biofuel producer. Conventional ethanol producers experienced small but statistically insignificant losses following the release of the 2013 final rule and 2014 proposed rule. In contrast, advanced biofuel and biodiesel producers' stock values were volatile following the 2013 final and 2014 proposed rules. Advanced biofuel firms experience over 2% abnormal losses on the day the 2013 final rule was released and a 5% abnormal losses on the subsequent day. The largest losses to advanced biofuel firms came on the day after the 2014 proposed rule was published, where they lost 5%-6% of their value on average.[23] Biodiesel producers did not experience substantial losses following the publication of the 2013 final rule. However, they experienced significant losses on the order of 3.5% following the release of the 2014 proposed rule.

Our findings suggest that the incidence of the cuts to the RFS mandates fell disproportionately on advanced and biodiesel firms. The latter results are consistent with the losses observed in soybean oil markets, suggesting that the 2014 proposed rule caused an adverse demand shock to biodiesel markets.[24] Interestingly, while the release of the 2013 final rule was associated with the most significant losses in RIN markets, except for advanced biofuel companies, the largest losses in biofuel firm values came after the 2014 proposed rule. The findings suggest that markets did price fully price the mandate cuts until the EPA officially proposed them.

[23] On the day the 2014 proposed rule was released advanced producers experienced a 12% abnormal gain. As discussed previously, the rule was released on a Friday afternoon. We argue, therefore, that the more relevant abnormal returns are on the day following the release of the rule.

[24] The results are also consistent with the work of Bielen et al. (2016), who find that the incidence of an earlier ethanol blending subsidy was captured primarily by ethanol producers. Our results are more nuanced in that we find limited impacts of a decrease in the RIN subsidy on corn ethanol producers and a much larger incidence on advanced and biodiesel firms.

Table 8: Biofuel Firm Abnormal Return Estimates
(Dependent Variable: Log Biofuel Firm Stock Prices)

		All Biofuel Firms		Conventional Firms		Advanced Firms		Biodiesel Firms	
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2013 Final Rule:	Day 0	-0.011	-0.014	-0.009	-0.011	-0.022	-0.027	-0.009	-0.011
	Day 1	-0.019	-0.019	-0.012	-0.008	-0.050**	-0.050*	-0.011	-0.014
	Day 2	0.022	0.020	0.010	0.014	0.006	0.003	0.029	0.027
Leaked 2014 Rule:	Day 0	-0.008	-0.006	-0.012	-0.006	-0.012	-0.006	-0.011	-0.010
	Day 1	-0.004	0.000	-0.001	0.003	0.002	0.008	-0.009	-0.003
	Day 2	-0.007	-0.006	-0.005	-0.008	0.001	0.000	-0.011	-0.008
2014 Proposed Rule:	Day 0	0.021	0.024	0.005	0.012	0.112***	0.122***	-0.008	-0.008
	Day 1	-0.043*	-0.038*	-0.029	-0.025	-0.059**	-0.049*	-0.036*	-0.032*
	Day 2	-0.016	-0.014	-0.018	-0.020	-0.018	-0.014	-0.014	-0.012
Observations		4,585	4,585	1,688	1,688	1,266	1,266	2,475	2,475
Time Controls		No	Yes	No	No	No	No	No	Yes
SQ 10% Lower Bound		-0.029	-0.029	-0.031	-0.034	-0.030	-0.035	-0.029	-0.029
SQ 10% Upper Bound		0.029	0.030	0.029	0.029	0.032	0.033	0.030	0.030
SQ 5% Lower Bound		-0.046	-0.046	-0.047	-0.049	-0.046	-0.051	-0.045	-0.044
SQ 5% Upper Bound		0.047	0.045	0.046	0.047	0.049	0.049	0.048	0.048
SQ 1% Lower Bound		-0.099	-0.098	-0.099	-0.099	-0.098	-0.101	-0.094	-0.094
SQ 1% Upper Bound		0.106	0.108	0.106	0.108	0.106	0.107	0.106	0.106

Note: Results are presented for all firms, advanced biofuel firms, and biodiesel firms. All regressions include controls for returns due to changes in the Russell 3000 index and the S&P-GS commodity index. Inference for abnormal returns are based on SQ critical values given at the bottom of the table. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

6 Conclusions

The three policy shocks in 2013 had a number of effects on RIN and commodity markets, as well as on regulated parties. First, we estimate that the events caused significant and sudden shifts in the value of the RFS. In addition, the announcements increased uncertainty regarding future RFS compliance schedules. This paper provides evidence that the events adversely affected advanced biofuel firms and commodity markets of the marginal compliance fuel, namely biodiesel and soybean oil.

Our results highlight the role of bankable compliance credits in translating changes in expectations about future compliance costs into changes in current compliance costs. Cost uncertainty is a well-known drawback of quantity-based regulations like the RFS (Weitzman, 1974; Roberts and Spence, 1976). As currently designed, the EPA was left with few options with which it could respond to high RIN prices other than to reduce the statutory mandates. Our findings suggest that the RFS would benefit from alternative policy designs aimed specifically at addressing situations in which compliance costs increase to levels deemed untenable or where compliance becomes infeasible given market conditions such as the slow development of new production technologies and fuel distribution networks.

We suggest three mechanisms in particular. First, similar to Hitaj and Stocking (2016), our results suggest that policies implemented using tradeable credits would be better served by more coordinated, frequent, and transparent communication policies between regulators, obligated parties, and stakeholders. This could involve multi-year rulemaking processes rather than the year-by-year process used by the EPA. Multi-year rulemaking would have a number of benefits. First, they would provide a clear signal to regulated entities regarding future compliance schedules. Second, they would provide affected parties and stakeholders with an opportunity to comment on proposed rule well in advance of when the mandates would affect them. For example, a multi-year rulemaking process in 2012 or 2013 would likely have spurred a broader discussion of the challenges with meeting the 2014 statutory mandates and allowed the EPA to proposed its course of action to address the blend wall well before July 2013.

Second, the level of compliance cost uncertainty can depend on whether the regulation is specified in terms of total volume (e.g., a required number of gallons of biofuel) or a rate (e.g., a required proportion of blended biofuel in gasoline and diesel). Designing the RFS as a rate standard would likely have been more efficient than the chosen volume standard because short-run marginal compliance cost curve becomes steep at an ethanol-gasoline blend rate of 10%. Specifying a volume standard for biofuels generates high compliance cost uncertainty because variation in gasoline and diesel consumption causes the implicit blend mandate to vary. This finding illustrates the importance for regulators to understand key barriers to achieving policy goals, and to set policies in ways that can create greater certainty regarding future compliance costs.

Last, the regulation could significantly decrease compliance cost uncertainty by instituting price collars for RIN prices. Roberts and Spence (1976) first proposed such a mechanism whereby a regulator supplements a tradable permit program with a fixed abatement subsidy and non-compliance penalty. Such hybrid policies ensure compliance costs remain in a given range and reduce the expected social cost of a policy. Similar hybrid policies have since been studied by several authors who find that the mechanisms have desirable efficiency properties (Pizer, 2002; Newell et al., 2005; Burtraw et al., 2010; Lade and Lin Lawell, 2016).

Our findings have implications for policies beyond RFS. Several states have passed low carbon fuel standards and renewable portfolio standards that require substantial increases in the share of low carbon fuel and renewable electricity, respectively (National Low Carbon Fuel Standard Project, 2012; Department of Energy, 2015). In addition, the EPA's proposed Clean Power Plan requires states to institute either a mass-based or rate-based carbon emissions standard for fossil-fuel fired electric generation plants (Environmental Protection Agency, 2015a). Given important capacity and production constraints that are inherent in energy markets, these policies will likely face similar challenges as those faced by the EPA in 2013. As such, anticipating these issues and designing the policies in a manner that allows the regulator to address them better is imperative.

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A Dynamic Model of RFS Compliance and RIN Prices

In this appendix we derive market clearing RIN prices under two mandate specifications. First, we examine a market with a single renewable fuel and two compliance periods to analyze the impacts of banking and borrowing restrictions on the relationship between RIN prices across vintage years for the same RIN type. Second, we consider a market with two renewable fuels, a single compliance period, and a nested mandate to derive the relationship between RIN prices for different biofuel types due to the nested structure of the RFS mandate.

Both models posit a competitive industry that must comply with a biofuel mandate. Firms use two types of inputs in the production of fuel Q: (i) a cheap and abundant conventional input q^c and (ii) costly renewable inputs $\mathbf{q}^r$. Total fuel production in period t is given by:

$$Q_t = \sum_i \left(q_{i,t}^c + \sum_j q_{i,j,t}^r \right),$$

where t denotes the time period in production days, i denotes the firm, and j denotes the renewable fuel. Under a fuel mandate, renewable fuels generate a vector of a compliance credits denoted by $\mathbf{w}$ that can be purchased or sold at market clearing prices $\mathbf{r}$.

Uncertainty enters the model through several avenues. Each day, firms may experience a common price (demand) shock θ_t^p; a cost (supply) shock θ_t^c for conventional fuel; cost (supply) shocks θ_t^r for renewable fuels; and a policy shock θ_t^α. The tuple of shocks is denoted by $\Theta_t = (\theta_t^p, \theta_t^c, \theta_t^r, \theta_t^\alpha)$. All shocks are realized before firms make their period t production decisions. We assume every firm knows the distribution of possible future shocks conditional on current and past shocks, and is able to form consistent, rational expectations given a realized history of shocks.

In all cases, consumers are assumed to have have quasilinear preferences for fuel with aggregate inverse demand $P(Q; \Theta_t)$. Renewable and conventional fuels are specified in units so that they are perfect substitutes in production and consumption.[25] All cost functions are assumed to be separable, increasing, and strictly convex such that:

$$C_{i,t}(q_{i,t}^c, \mathbf{q}_{i,t}^r; \Theta_t) = C_{i,t}^c(q_{i,t}^c; \Theta_t) + \sum_j C_{i,j,t}^r(q_{i,j,t}^r; \Theta_t),$$

where $C_{i,t}^c(\cdot; \Theta_t)$ is the cost function for conventional fuel and $C_{i,j,t}^r(\cdot; \Theta_t)$ is the cost function for renewable fuel j, with $C_{i,t}^{c'}(\cdot; \Theta_t) > 0$ and $C_{i,t}^{c''}(\cdot; \Theta_t) > 0$ for all i and t. Similar conditions hold for $C_{i,j,t}^r(\cdot; \Theta_t)$.

In deriving RIN prices under each scenario, we first consider each firm's problem to demonstrate the importance of tradeable credit prices in equalizing marginal compliance costs across all firms. We then solve a 'representative' or aggregate firm's problem in order to solve for market clearing RIN prices.

[25] Energy content differences across fuels are accommodated by assuming the fuels units are specified in equivalent units such as gasoline gallon equivalents (GGE).

A.1 Two Compliance Periods and One Renewable Fuel

First consider a market with one conventional and one renewable fuel, and suppose there are two compliance periods. The first compliance period occurs for days $t \in [1, T_1]$ with mandate α_1, and the second compliance period occurs for $t \in [T_1+1, T_2]$ with mandate α_2, which does not necessarily equal α_1. Denote a compliance credit generated in compliance period τ and purchased by firm i on day t as $w_{i,\tau,t}$ for $\tau = 1, 2$. The stock of period 1 and 2 compliance credits evolves as follows:

$$\begin{aligned} B_{i,1,t+1} &= B_{i,1,t} + \left(q^r_{i,t} - \alpha_1 q^c_{i,t}\right) \mathbf{1}(t \leq T_1) + w_{i,1,t} \\ B_{i,2,t+1} &= B_{i,2,t} + \left(q^r_{i,t} - \alpha_2 q^c_{i,t}\right) \mathbf{1}(t > T_1) + w_{i,2,t}, \end{aligned}$$

where $B_{i,1,t}$ is the stock of period 1 compliance credits held by firm i on day t, $B_{i,2,t}$ is the stock of period 2 compliance credits held by firm i on day t, $\mathbf{1}(\cdot)$ denotes the indicator function, and $B_{i,1,0} = B_{i,2,0} = 0$. We allow a forward market for period 2 compliance credits, which means that firms can trade them in period 1 even though none get generated until period 2. The policy constraint over both compliance periods is:

$$B_{i,1,T_2+1} + B_{i,2,T_2+1} \geq 0,$$

i.e., the aggregate stock of credits must be non-negative at the end of the second compliance period.

Firms may over- or under-comply with their renewable volume obligations in each compliance period, but are limited in the extent to which they may do so. A firm cannot meet more than a proportion γ_1 of its period 1 obligation with credits generated in period 2, a borrowing restriction. In addition, it cannot meet more than a proportion γ_2 of its period 2 obligation with credits generated in period 1, a banking restriction. We write the borrowing and banking restrictions, respectively, as:

$$\begin{aligned} B_{i,1,T_2+1} &\geq -\gamma_1 \sum_{t=1}^{T_1} \alpha_1 q^c_{i,t} \\ B_{i,2,T_2+1} &\geq -\gamma_2 \sum_{t=T_1+1}^{T_2} \alpha_2 q^c_{i,t}. \end{aligned}$$

The constraints state that the bank of credits in either period may be negative, but not too negative. Any deficit in the bank of credits in one period must be made up by credits generated in the other period.

Given this setup, each firm's Bellman equation is given by:

$$\begin{aligned} V_{i,t}(B_{i,t}; \Theta_t) = \max_{\substack{q^c_{i,t}, q^r_{i,t} \geq 0, \\ w_{i,1,t}, w_{i,2,t}}} & P_t(Q_t; \Theta_t) Q_{i,t} - C^c_{i,t}(q^c_{i,t}; \Theta_t) - C^r_{i,t}(q^r_{i,t}; \Theta_t) - r_{1,t} w_{i,1,t} - r_{2,t} w_{i,2,t} \\ & + \beta \mathbb{E}_t[V_{i,t+1}(B_{i,t+1}; \Theta_{t+1})] \end{aligned}$$

$$
\begin{aligned}
\text{subject to} \qquad\qquad B_{i,1,t+1} &= B_{i,1,t} + \left(q^r_{i,t} - \alpha_1 q^c_{i,t}\right) \mathbf{1}(t \le T_1) + w_{i,1,t} \\
B_{i,2,t+1} &= B_{i,2,t} + \left(q^r_{i,t} - \alpha_2 q^c_{i,t}\right) \mathbf{1}(t > T_1) + w_{i,2,t} \\
B_{i,1,T_1+1} &\ge -\gamma_1 \textstyle\sum_{t=1}^{T_1} \alpha_1 q^c_{i,t} \\
B_{i,2,T_2+1} &\ge -\gamma_2 \textstyle\sum_{t=T_1+1}^{T_2} \alpha_2 q^c_{i,t} \\
B_{i,1,T_2+1} + B_{i,2,T_2+1} &\ge 0 \\
B_{i,1,0} = B_{i,2,0} &= 0.
\end{aligned}
$$

The third and fourth constraints are the borrowing and banking restrictions, respectively, and the fifth constraint is the policy constraint.

The relevant firm-level optimality conditions necessary to derive RIN prices relate to $w_{i,1,t}$ and $w_{i,2,t}$, and are given by:

$$
r_{1,t} = \begin{cases} \beta^{(T_2-t)}\mathbb{E}_t[\lambda_i] + \beta^{(T_1-t)}\mathbb{E}_t[\Phi_{i,1}] & \text{if } t \le T_1 \\ \beta^{(T_2-t)}\mathbb{E}_t[\lambda_i] & \textit{if } t > T_1 \end{cases} \tag{7}
$$

$$
r_{2,t} = \beta^{(T_2-t)}\mathbb{E}_t[\lambda_i + \Phi_{i,2}], \tag{8}
$$

where λ_i is the firm's Lagrange multiplier on the policy constraint, and $\Phi_{i,1}$ and $\Phi_{i,2}$ are the Lagrange multipliers on the borrowing and banking constraints, respectively. Equations (7) and (8) state that firms buy and sell compliance credits until their marginal compliance costs net of the banking and borrowing constraints are equalized.

To solve for market clearing RIN prices, we consider a representative, aggregate firm's problem. On each day, the aggregate firm's Bellman equation is given by:

$$
V_t(B_t;\Theta_t) = \max_{q^c_t, q^r_t \ge 0} P_t(Q_t;\Theta_t)Q_t - C^c_t(q^c_t;\Theta_t) - C^r_t(q^r_t;\Theta_t) + \beta\mathbb{E}_t[V_{t+1}(B_{t+1};\Theta_{t+1})]
$$

$$
\begin{aligned}
\text{subject to} \qquad\qquad B_{1,T_1+1} &\ge -\gamma_1 \textstyle\sum_{t=1}^{T_1} \alpha_1 q^c_t \\
B_{2,T_2+1} &\ge -\gamma_2 \textstyle\sum_{t=T_1+1}^{T_2} \alpha_2 q^c_t \\
B_{1,T_2+1} + B_{2,T_2+1} &\ge 0 \\
B_{1,0} = B_{2,0} &= 0.
\end{aligned}
$$

Interior optimality conditions for q^c_t and q^r_t for $t \in \{t, ..., T_1\}$ are, respectively:

$$
P_t = C^{c'}_t(q^c_t) + \alpha_1\beta^{(T_2-t)}\mathbb{E}_t[\lambda] + \alpha_1(1-\gamma_1)\beta^{(T_1-t)}\mathbb{E}_t[\Phi_1] \tag{9}
$$

$$
P_t = C^{r'}_t(q^r_t) - \beta^{(T_2-t)}\mathbb{E}_t[\lambda] - \beta^{(T_1-t)}\mathbb{E}_t[\Phi_1], \tag{10}
$$

where λ denotes the Lagrange multiplier on the aggregate policy constraint and Φ_1 denotes the Lagrange multiplier on the aggregate borrowing restriction. Interior optimality conditions for $t \in \{T_1+1, ..., T_2\}$ for each fuel are given by:

$$
P_t = C^{c'}_t(q^c_t) + \alpha_2\beta^{(T_2-t)}\mathbb{E}_t[\lambda + (1-\gamma_2)\Phi_2] \tag{11}
$$

$$P_t = C_t^{r'}(q_t^r) - \beta^{(T_2-t)}\mathbb{E}_t[\lambda + \Phi_2], \tag{12}$$

where Φ_2 denotes the Lagrange multiplier on the aggregate banking restriction.

Consider the solution on the terminal date $t = T_2$. From equations (7) and (8), RIN prices are:

$$\begin{aligned} r_{1,T_2} &= \lambda \\ r_{2,T_2} &= \lambda + \Phi_2. \end{aligned}$$

Thus, any difference between RIN prices on day T_2 is driven solely by a binding banking constraint.

We have three scenarios to consider on day T_2. First, if none of the policy constraints bind, both credit prices are zero. Second, if the total mandate binds but the banking constraint does not bind ($\Phi_2 = 0$ and $\lambda > 0$), then equations (11) and (12) implies that the RIN prices are equal and given by:

$$r_{1,T_2} = r_{2,T_2} = \lambda = C_{T_2}^{r'}(q_{T_2}^r) - P_{T_2} = \frac{C_{T_2}^{r'}(q_{T_2}^r) - C_{T_2}^{c'}(q_{T_2}^c)}{1+\alpha_2} > 0.$$

Third, if the banking constraint binds ($\Phi_2 > 0$), then there are surplus period 1 credits that the firm would like to use towards its period 2 compliance obligation, but the banking restriction prevents it from fully doing so. These surplus period 1 credits therefore have no value on the margin, i.e., $r_{1,T_2} = 0$. From (7), this implies that $\lambda = 0$, i.e., the total mandate is not binding. Solving for the period 2 RIN price using equations (11) and (12) yields:

$$\begin{aligned} r_{1,T_2} &= 0 \\ r_{2,T_2} &= \Phi_2 = C_{T_2}^{r'}(q_{T_2}^r) - P_{T_2} = \frac{C_{T_2}^{r'}(q_{T_2}^r) - C_{T_2}^{c'}(q_{T_2}^c)}{1+\alpha_2(1-\gamma_2)} > 0. \end{aligned}$$

Now, consider the borrowing constraint. A binding borrowing constraint means there are no period 1 RINs available for trade in period 2. On date T_1, the market resolves whether the borrowing constraint binds, so if the constraint is binding, then this is the last day a market exists for both RINs. From equations (7), (9) and (10), the period 1 RIN price on day T_1 is given by:

$$r_{1,T_1} = \beta^{(T_2-T_1)}\mathbb{E}_{T_1}[\lambda] + \Phi_1 = C_{T_1}^{r'}(q_{T_1}^r) - P_{T_1} = \frac{C_{T_1}^{r'}(q_{T_1}^r) - C_{T_1}^{c'}(q_{T_1}^c)}{1+\alpha_1} + \frac{\alpha_1\gamma_1}{1+\alpha_1}\Phi_1 > 0.$$

Using (7) and (8), and the fact that a binding borrowing constraint means that the banking constraint will not bind ($\Phi_2 = 0$), the difference between RIN prices on day T_1 is therefore:

$$\begin{aligned} \Phi_1 &= r_{1,T_1} - r_{2,T_1} \\ &= \left(C_{T_1}^{r'}(q_{T_1}^r) - P_{T_1}\right) - \beta^{(T_2-T_1)}E_{T_1}\left[\max\left[C_{T_2}^{r'}(q_{T_2}^r) - P_{T_2}, 0\right]\right]. \end{aligned}$$

Thus, the Lagrange multiplier on the borrowing constraint reflects the discounted difference in marginal compliance costs between the costlier first compliance period T_1 and the second compliance period T_2.

Using equations (9)-(12), we can solve further to obtain:

$$\begin{aligned}\Phi_1 &= \frac{C_{T_1}^{r'}(q_{T_1}^r) - C_{T_1}^{c'}(q_{T_1}^c)}{1+\alpha_1} + \frac{\alpha_1\gamma_1}{1+\alpha_1}\Phi_1 - r_{2,T_1} \\ &= \frac{C_{T_1}^{r'}(q_{T_1}^r) - C_{T_1}^{c'}(q_{T_1}^c)}{1+\alpha_1(1-\gamma_1)} - \frac{1+\alpha_1}{1+\alpha_1(1-\gamma_1)}r_{2,T_1}.\end{aligned}$$

Substituting into the expression for the period 1 RIN price and simplifying yields:

$$r_{1,T_1} = \frac{C_{T_1}^{r'}(q_{T_1}^r) - C_{T_1}^{c'}(q_{T_1}^c)}{1+\alpha_1(1-\gamma_1)} - \frac{\alpha_1\gamma_1}{1+\alpha_1(1-\gamma_1)}r_{2,T_1}.$$

In sum, on any day t, we have:

$$\begin{aligned}r_{1,t} &= \begin{cases}\beta^{(T_2-t)}\mathbb{E}_t\left[r_{2,T} - \Phi_2 + \beta^{(T_1-T_2)}\Phi_1\right] & \text{if } t \leq T_1 \\ \beta^{(T_2-t)}\mathbb{E}_t[\lambda_i] & \text{if } t > T_1\end{cases}, \\ r_{2,t} &= \beta^{(T_2-t)}\mathbb{E}_t[r_{2,T}] = \beta^{(T_2-t)}\mathbb{E}_t\left[\max\left[C_{T_2}^{r'}(q_{T_2}^r) - P_{T_2}, 0\right]\right].\end{aligned}$$

On the last day T_1 of the first compliance period, if the borrowing constraint binds ($\Phi_1 > 0$), then the banking constraint does not bind ($\Phi_2 = 0$) and RIN prices are given by:

$$\begin{aligned}r_{1,T_1} &= C_{T_1}^{r'}(q_{T_1}^r) - P_{T_1} \\ &= \frac{C_{T_1}^{r'}(q_{T_1}^r) - C_{T_1}^{c'}(q_{T_1}^c)}{1+\alpha_1(1-\gamma_1)} - \frac{\alpha_1\gamma_1}{1+\alpha_1(1-\gamma_1)}r_{2,T_1} > 0 \\ r_{2,T_1} &= \beta^{(T_2-T_1)}E_{T_1}\left[\max\left[C_{T_2}^{r'}(q_{T_2}^r) - P_{T_2}, 0\right]\right] \\ &= \beta^{(T_2-T_1)}E_{T_1}\left[\max\left[\frac{C_{T_2}^{r'}(q_{T_2}^r) - C_{T_2}^{c'}(q_{T_2}^c)}{1+\alpha_2}, 0\right]\right] < r_{1,T_1}.\end{aligned}$$

On the last day T_2 of the second compliance period, if the banking constraint binds ($\Phi_2 > 0$), then the borrowing constraint does not bind ($\Phi_1 = 0$) and RIN prices are given by:

$$\begin{aligned}r_{1,T_2} &= 0 \\ r_{2,T_2} &= C_{T_2}^{r'}(q_{T_2}^r) - P_{T_2} = \frac{C_{T_2}^{r'}(q_{T_2}^r) - C_{T_2}^{c'}(q_{T_2}^c)}{1+\alpha_2(1-\gamma_2)} > 0.\end{aligned}$$

A.2 Single Compliance Period and Two Renewable Fuels

Now consider a market with two renewable fuels $q_{i,j,t}^r$, where $j \in 1, 2$ denotes the type of renewable fuel. Each gallon of renewable fuel j generates a credit $w_{i,j,t}$ that can be sold at price $r_{j,t}$. Assume that there is only one compliance period for $t \in [1, T]$. Suppose firms face two policy constraints: (i) a mandate on total renewable fuel production with blend requirement α_1; and (ii) a sub-mandate for $q_{i,2,t}^r$ with blend mandate

α_2. The policy constraints are given by:

$$\sum_{t=1}^{T}\left(q^r_{i,1,t} + w_{i,1,t} + q^r_{i,2,t} + w_{i,2,t}\right) \geq \alpha_1 \sum_{t=1}^{T} q^c_{i,t}$$

$$\sum_{t=1}^{T}\left(q^r_{i,2,t} + w_{i,2,t}\right) \geq \alpha_2 \sum_{t=1}^{T} q^c_{i,t}.$$

The constraints are written in compact form by defining the amount of banked credits $B^r_{i,1,t}$ and $B^r_{i,2,t}$ as:

$$\begin{aligned}
B^r_{i,1,t+1} &= B^r_{i,1,t} + q^r_{i,1,t} + w_{i,1,t} + q^r_{i,2,t} + w_{i,2,t} - \alpha^r_1 q^c_{i,t} \\
B^r_{i,2,t+1} &= B^r_{i,2,t} + q^r_{i,2,t} + w_{i,2,t} - \alpha^r_2 q^c_{i,t}.
\end{aligned}$$

Thus, the policy constraints for the two mandates can be written as:

$$B^r_{i,1,T+1} \geq 0$$

$$B^r_{i,2,T+1} \geq 0.$$

Given this setup, each firm's maximization problem in period t is:

$$\begin{aligned}
V_{i,t}(B^r_{i,1,t}, B^r_{i,2,t}; \Theta_t) = \max_{\substack{q^c_{i,t}, q^r_{i,1,t}, q^r_{i,2,t} \geq 0, \\ w_{i,1,t}, w_{i,2,t}}} & P_t(Q_t; \Theta_t) Q_{i,t} - C^c_t(q^c_{i,t}; \Theta_t) - \sum_j C^r_{i,j,t}(q^r_{i,j,t}; \Theta_t) - \sum_j r_{j,t} w_{i,j,t} \\
& + \beta \mathbb{E}_t V_{i,t+1}(B^r_{i,1,t+1}, B^r_{i,2,t+1}; \Theta_{t+1})
\end{aligned}$$

$$\begin{aligned}
\text{subject to} \quad B^r_{i,1,t+1} &= B^r_{i,1,t} + q^r_{i,1,t} + w_{i,1,t} + q^r_{i,2,t} + w_{i,2,t} - \alpha^r_1 q^c_{i,t} \\
B^r_{i,2,t+1} &= B^r_{i,2,t} + q^r_{i,2,t} + w_{i,2,t} - \alpha^r_2 q^c_{i,t} \\
B^r_{i,1,T+1} &\geq 0, B^r_{i,2,T+1} \geq 0, \\
B^r_{i,1,1} &= 0, B^r_{i,2,1} = 0.
\end{aligned}$$

Let $\lambda_{i,j}$ denote the Lagrange Multipliers for each policy constraint $j = \{1, 2\}$. The firm's optimality conditions are:

$$\begin{aligned}
q^c_{i,t} \geq 0 \quad &\perp \quad P_t - C^{c'}_{i,t}(q^c_{i,t}) - \beta^{(T-t)}\left(\alpha_1 \mathbb{E}_t[\lambda_{i,1}] + \alpha_2 \mathbb{E}_t[\lambda_{i,2}]\right) \leq 0 \\
q^r_{i,1,t} \geq 0 \quad &\perp \quad P_t - C^{r'}_{i,1,t}(q^r_{i,1,t}) + \beta^{(T-t)} \mathbb{E}_t[\lambda_{i,1}] \leq 0 \\
q^r_{i,2,t} \geq 0 \quad &\perp \quad P_t - C^{r'}_{i,2,t}(q^r_{i,2,t}) + \beta^{(T-t)}\left(\mathbb{E}_t[\lambda_{i,1}] + \mathbb{E}_t[\lambda_{i,2}]\right) \leq 0
\end{aligned}$$

$$r_{1,t} = \beta^{(T-t)} \mathbb{E}_t[\lambda_{i,1}] \tag{13}$$

$$r_{2,t} = \beta^{(T-t)}\left(\mathbb{E}_t[\lambda_{i,1}] + \mathbb{E}_t[\lambda_{i,2}]\right) \tag{14}$$

$$B^r_{i,1,T+1}\lambda_{i,1} = 0, \quad B^r_{i,2,T+1}\lambda_{i,2} = 0.$$

Equations (13) and (14) state the firms produce where their individual compliance costs equal the market clearing RIN price. With tradable credits, it therefore follows that:

$$\begin{aligned}
r_{1,T} &= \lambda_1 \\
r_{2,T} &= \lambda_1 + \lambda_2 = r_{1,T} + \lambda_2,
\end{aligned}$$

where λ_j is the Lagrange multiplier for policy constraint j in the aggregate firm's problem. Using a similar argument as previously and writing the problem in the final period using a representative firm, it can be shown that:

$$\begin{aligned}
r_{1,T} &= \max\left[C^{r'}_{1,T}(q^r_{1,T}) - P_T, 0\right] \\
r_{2,T} &= \max\left[C^{r'}_{2,T}(q^r_{2,T}) - P_T, 0\right] \\
\lambda_2 &= \max\left[C^{r'}_{2,T}(q^r_{2,T}) - \max\left[C^{r'}_{1,T}(q^r_{1,T}), P_T\right], 0\right].
\end{aligned}$$

From this and the firm optimality conditions, it follows that:

$$\begin{aligned}
r_{1,t} &= \beta^{(T-t)}\mathbb{E}_t[\lambda_1] = \beta^{(T-t)}\mathbb{E}_t[r_{1,T}], \\
r_{2,t} &= \beta^{(T-t)}\mathbb{E}_t[\lambda_1 + \lambda_2] = \beta^{(T-t)}\mathbb{E}_t[r_{1,T} + \lambda_2].
\end{aligned}$$

B Robustness Checks

B.1 RIN Abnormal Returns

Section 5 specifies normal returns for RINs as a function of log price changes of WTI, ethanol and soybean oil futures contracts. Here, we consider alternative specifications using commodity prices that more directly reflect ethanol and biodiesel production costs. For conventional and advanced RINs, we specify normal returns as a function of reformulated gasoline (RBOB), yellow No. 2 corn, No. 11 sugar, soybean oil, and Henry Hub natural gas futures prices. For biodiesel RINs we use New York Harbor ultra low sulfur diesel (ULSD) futures prices instead of gasoline futures prices. All futures prices are for July 2014 contracts and are downloaded from Quandl. Results are presented in Table C.1. All normal return estimates have the expected signs, with increases in RBOB and ULSD decreasing RIN prices and increases in the cost of biofuel inputs increasing RIN prices. All estimates are noisier than our more sparse, preferred specifications and no normal return variables are statistically significant. All abnormal return estimates, however, remain statistically significant and are very similar to those in Table 5.

B.2 Commodity Market Abnormal Returns

To ensure the commodities market results from Section 5.5 are not driven by our selection of July 2014 future contracts, we conduct event studies for eleven futures contracts that were trading at the time of the events for each commodity.[26] Tables C.2 and C.3 present the abnormal return estimates for the event day and subsequent trading day. Significant abnormal returns are determined by estimating SQ critical values for each series. Consistent with our findings in the paper, no systematic significant abnormal returns are observed in WTI crude oil, ethanol, or No. 11 sugar futures contracts. The only significant abnormal returns are observed in soybean oil and corn futures contracts. All soybean oil contracts experienced abnormal losses between 1.3% and 1.7% following the release of the 2013 final rule, 1.9%-2.3% following the leaked 2014 rule, and 1.0%-1.7% following the 2014 proposed rule. Similar to our main results, corn markets experienced 1.5%-2.6% losses following the 2014 proposed rule.

[26]Futures contracts are only observed for March, May, July and October for No. 11 sugar futures contracts.

Table C.1: RIN Even Study Regression Results
(Dependent Variable: Log Differenced 2013 RIN Prices)

		Conventional RINs		Advanced RINs		Biodiesel RINs	
		(1)	(2)	(3)	(4)	(5)	(6)
Normal Returns							
RBOB Futures		-0.245	-0.233	-0.436	-0.355	–	–
		(0.338)	(0.333)	(0.354)	(0.364)	–	–
ULSD Futures		–	–	–	–	-0.310	-0.291
		–	–	–	–	(0.430)	(0.418)
Corn Futures		0.158	0.138	0.201	0.153	0.152	0.097
		(0.185)	(0.176)	(0.235)	(0.231)	(0.218)	(0.216)
Sugar Futures		0.193	0.204	0.264	0.213	0.375	0.405
		(0.311)	(0.315)	(0.296)	(0.317)	(0.278)	(0.292)
Soybean Oil Futures		0.512	0.516	0.165	0.234	0.684	0.713
		(0.359)	(0.355)	(0.436)	(0.433)	(0.440)	(0.438)
Natural Gas Futures		0.058	0.079	0.191	0.201	0.055	0.047
		(0.215)	(0.222)	(0.219)	(0.230)	(0.198)	(0.201)
Abnormal Returns							
2013 Final Rule:	Day 0	-0.135**	-0.115**	-0.134**	-0.117**	-0.061*	-0.055*
	Day 1	-0.147**	-0.133**	-0.136**	-0.123**	-0.141**	-0.139**
	Day 2	-0.197***	-0.175***	-0.159**	-0.137**	-0.181**	-0.165**
	Day 3	0.022	0.040	0.041	0.050	0.049	0.053*
	Day 4	0.045	0.056	0.041	0.044	0.025	0.031
Leaked 2014 Rule:	Day 0	-0.149**	-0.135**	-0.026	0.004	-0.054*	-0.037
	Day 1	0.088*	0.095**	0.146***	0.169***	0.048	0.066*
	Day 2	0.052	0.070	-0.001	0.032	-0.010	0.008
	Day 3	0.001	0.013	-0.021	0.006	-0.030	-0.018
	Day 4	-0.059	-0.039	-0.059*	-0.019	-0.047	-0.020
2014 Proposed Rule:	Day 0	-0.043	-0.035	-0.037	-0.040	-0.047	-0.053*
	Day 1	-0.188***	-0.188***	-0.121**	-0.129**	-0.215***	-0.222***
	Day 2	0.059	0.070*	-0.024	-0.022	-0.000	-0.006
	Day 3	-0.009	-0.005	-0.004	-0.008	0.038	0.028
	Day 4	0.020	0.033	-0.023	-0.019	-0.059*	-0.055*
Observations		422	422	422	422	422	422
Time Controls		No	Yes	No	Yes	No	Yes
SQ 10% Lower Bound		-0.061	-0.054	-0.053	-0.055	-0.048	-0.044
SQ 10% Upper Bound		0.063	0.060	0.057	0.058	0.052	0.050
SQ 5% Lower Bound		-0.077	-0.077	-0.100	-0.090	-0.068	-0.074
SQ 5% Upper Bound		0.089	0.089	0.077	0.076	0.081	0.075
SQ 1% Lower Bound		-0.175	-0.165	-0.252	-0.234	-0.209	-0.215
SQ 1% Upper Bound		0.183	0.168	0.138	0.130	0.136	0.136

Note: Normal return standard errors in parentheses are Newey-West errors with 5 lags. Inference for abnormal returns are based on SQ critical values given at the bottom of the table. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

Table C.2: Commodity Market Abnormal Returns: All Traded Contracts

		2013 Final Rule		Leaked 2014 Rule		2014 Proposed Rule	
	Contract	Day 0	Day 1	Day 0	Day 1	Day 0	Day 1
WTI Crude	December-13	-0.009	-0.006	-0.009	0.004	0.002	-0.003
	March-14	-0.009	-0.004	-0.005	0.002	-0.000	-0.005
	May-14	-0.008	-0.003	-0.006	0.001	-0.002	-0.007
	July-14	-0.008	-0.003	-0.005	0.001	-0.003	-0.008
	September-14	-0.007	-0.002	-0.004	0.001	-0.003	-0.008
	December-14	-0.007	-0.001	-0.002	0.001	-0.003	-0.007
	March-15	-0.007	-0.000	-0.001	0.000	-0.002	-0.007
	May-15	-0.006	0.000	-0.001	-0.000	-0.002	-0.007
	July-15	-0.006	0.001	-0.001	-0.001	-0.001	-0.006
	September-15	-0.005	0.002	-0.000	-0.001	-0.001	-0.006
	December-15	-0.005	0.002	0.000	-0.001	-0.000	-0.006
Ethanol	December-13	0.013	-0.007	-0.012	0.006	-0.017**	-0.001
	March-14	0.005	-0.008	-0.012	0.005	-0.008	-0.013*
	May-14	0.005	-0.007	-0.012	-0.000	-0.009	-0.014*
	July-14	0.005	-0.008	-0.011	0.000	-0.008	0.002
	September-14	0.004	-0.008	-0.011	0.001	-0.008	0.003
	December-14	0.004	-0.009	-0.010	0.000	-0.007	0.003
	March-15	0.005	-0.009	-0.011	0.000	-0.007	0.003
	May-15	0.005	-0.009	-0.011	0.000	-0.007	0.003
	July-15	0.005	-0.009	-0.011	0.000	-0.007	0.003
	September-15	0.005	-0.008	-0.011	0.000	-0.007	0.003
	December-15	0.005	-0.008	-0.010	-0.001	-0.007	0.002

Note: SQ test critical values for each contract is given in Table 7. All specifications include flexible time controls. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

Table C.3: Commodity Market Abnormal Returns: All Traded Contracts

		2013 Final Rule		Leaked 2014 Rule		2014 Proposed Rule	
	Contract	Day 0	Day 1	Day 0	Day 1	Day 0	Day 1
Soybean Oil	December-13	-0.017**	-0.016**	-0.023***	0.003	-0.010*	-0.006
	March-14	-0.016**	-0.015**	-0.022***	0.003	-0.010*	-0.005
	May-14	-0.015**	-0.013*	-0.021***	0.004	-0.011*	-0.004
	July-14	-0.014**	-0.013*	-0.021***	0.004	-0.012*	-0.004
	September-14	-0.013*	-0.013*	-0.020***	0.004	-0.012*	-0.005
	December-14	-0.014**	-0.013*	-0.018**	0.006	-0.015**	-0.004
	March-15	-0.013*	-0.009	-0.019***	0.003	-0.016**	-0.006
	May-15	-0.013*	-0.006	-0.019***	0.003	-0.016**	-0.004
	July-15	-0.014**	-0.006	-0.019***	0.009	-0.015**	-0.003
	September-15	-0.013*	-0.001	-0.021***	0.003	-0.017**	-0.003
	December-15	-0.014**	-0.002	-0.019***	0.000	-0.009	-0.007
Corn	December-13	-0.004	-0.004	-0.009	0.008	-0.009	-0.026**
	March-14	-0.003	-0.003	-0.008	0.008	-0.013	-0.023**
	May-14	-0.003	-0.001	-0.009	0.008	-0.014	-0.023**
	July-14	-0.004	-0.003	-0.009	0.007	-0.014	-0.022**
	September-14	-0.003	-0.003	-0.008	0.006	-0.014	-0.021**
	December-14	-0.001	-0.003	-0.008	0.007	-0.013	-0.020**
	March-15	-0.002	-0.002	-0.007	0.004	-0.013	-0.020**
	May-15	-0.002	-0.001	-0.006	0.003	-0.014	-0.019*
	July-15	-0.001	-0.001	-0.005	0.005	-0.014	-0.017*
	September-15	-0.002	-0.001	-0.002	0.003	-0.014	-0.018*
	December-15	0.004	-0.004	-0.004	0.010	-0.014	-0.015*
Sugar	March-14	0.001	0.016*	0.010	0.006	-0.005	0.014*
	May-14	0.002	0.017**	0.010	0.006	-0.003	0.011*
	July-14	0.001	0.016*	0.009	0.006	-0.001	0.010
	September-14	0.000	0.015*	0.008	0.005	0.002	0.009
	March-15	-0.000	0.013*	0.007	0.005	0.003	0.009
	May-15	0.000	0.013*	0.006	0.004	0.003	0.008
	July-15	0.000	0.014*	0.004	0.004	0.004	0.007
	September-15	0.002	0.015*	0.003	0.004	0.004	0.007

Note: SQ test critical values for each contract is given in Table 7. All specifications include flexible time controls. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.