Policy Shocks and Market-Based Regulations:

Evidence from the Renewable Fuel Standard

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Abstract

The Renewable Fuel Standard 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 value of the fuel industry's 2013 compliance obligation by $7 billion. 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.

Key words: policy design, quantity mechanisms, renewable fuel standard, tradable credits

JEL classification: H23, Q42, Q50

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Introduction

Governments around the world have enacted legislation to increase renewable energy production to combat global climate change and address a host of externalities associated with fossil energy use. 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 of their fossil-based electricity generation with solar and wind by the end of the decade. Others such as California's Low Carbon Fuel Standard rely on the development and adoption of low-carbon fuels that are not currently commercially available.

Among the largest of these policies is the Renewable Fuel Standard (RFS). The RFS mandates U.S. biofuel use far beyond what was feasible with the technology and infrastructure available at the time it was passed. These constraints came to the fore in early 2013, and the regulation garnered increased attention from policymakers, stakeholders, and other interested parties as the price of tradeable compliance credits (known as RINs) soared. The increase in RIN prices was followed by a prolonged delay in the Environmental Protection Agency's (EPA) implementation and enforcement of the mandates and eventually led to the Agency proposing large cuts to the total biofuel mandates set by the enacting legislation.

We study three events surrounding the proposed cuts to the RFS mandates for 2014 and beyond. The first event is the EPA's release of the 2013 final rule in August of 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 is the release of the 2014 proposed rule in November 2013 in which the EPA officially proposed cuts to the biofuel mandates. We show that these events led to significant and sudden changes in RIN values. As such, we label them 'policy shocks:' regulatory announcements, either formal or informal such as through leaked regulatory documents, that affect market expectations of current and future compliance costs. The purpose of this article is to quantify the importance of these shocks and to study their effects on markets. Given our application, we focus on markets most likely to be affected by changes in the RFS mandates: commodity markets and stock prices of biofuel firms.

All three of our policy shocks affected expectations of future mandates. As such, we begin by developing a dynamic model of RFS compliance to understand how changes in expected future mandates affect RIN prices. The model incorporates many of the salient features of the policy including multiple compliance periods, banking and borrowing, and nested mandates. Guided by our model, we then study abnormal returns to RIN prices around each 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 also followed the subsequent two events, with decreases on the order of \$300 million and \$700 million, respectively.

Quantifying changes in RINs values does not allow us to understand the distributional impacts of the policy shocks. For this, we use similar empirical methods to test for abnormal returns in markets that are most likely to be affected by changes in the RFS mandates. We first test whether bulk commodity futures prices for ethanol, crude oil, soybean oil, corn, or sugar experience abnormal returns around each event. Most commodity prices did not experience abnormal returns over this period. However, we find small but significant losses in soybean oil futures prices following the release of the leaked mandates and 2014 proposed rule, as well as in corn futures prices following the 2014 proposed rule. Next, we examine the returns of publicly traded biofuel firms around each event. When we consider all biofuel firms, the only large and statistically significant losses follow the 2014 proposed rule. However, when we allow for heterogeneous impacts of the events, we find that the firms that primarily produce corn ethanol did not experience significant losses, but advanced biofuel and biodiesel producers saw large and significant abnormal losses following the 2013 final rule and 2014 proposed rule. Taken together, our results suggest that the incidence of the EPA's actions fell primarily on inputs for marginal compliance biofuels (soybean oil and corn), advanced biofuel producers, and biodiesel producers.

The RFS has transformed U.S. fuel and agricultural markets. Nearly all U.S. gasoline now contains at least 10% ethanol, and more than 35% of the 2016-17 marketing year corn harvest went to ethanol production (Energy Information Agency 2016; USDA Economic Research Service 2017). However, meeting the long-run objectives of the policy will require yet another transformation of fuel markets, with dramatic increases and investments in advanced biofuel production capabilities. Although we are unable to quantify the impact of the events on policy uncertainty, the RIN price volatility induced by these policy shocks increases the option value to delaying advanced biofuel capital investments and undermines the policy's efforts to transform fuel markets further (Dixit and Pindyck 1994; Mason and Wilmot 2016). We therefore conclude with a brief discussion on mechanisms that would 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, Knittel, and Hughes (2009) examines the market effects and welfare outcomes under fuel mandates. The subsequent theoretical literature is massive and has been extended along many important dimensions. This includes, but is certainly not limited to, work that compares the efficiency of fuel mandates to other policy instruments under perfect and imperfect competition (Rajagopal, Hochman, and Zilberman 2011; Rajagopal and Plevin 2013; Lemoine 2017a; Bento, Klotz, and Landry 2014; Lade and Lin Lawell 2017); studies welfare outcomes under mandates in open and closed economies (Moschini, Lapan, and Kim 2017; Just 2017); explores unintended consequences of biofuel mandates (Khanna, Ando, and Taheripour 2008; Holland et al. 2014, 2015); and studies the impact of economic and policy uncertainty on the incentive for investments in new technologies (Miao, Hennessy, and Babcock 2012; Clancy and Moschini 2015). Thompson, Hoang, and Whistance (2016) provides a more comprehensive review of the literature on market impacts of the ethanol mandate.

More recent papers model important features of fuel markets to study short-run costs of meeting the mandates and explain historical RIN prices. For example, Pouliot and Babcock (2016) develop a static model of ethanol and gasoline markets that explicitly accounts for the blend wall constraint, an issue we discuss in further detail below. As part of their simulation exercise, the authors solve for RIN prices under varying mandate levels. Meiselman (2017) and Korting and Just (2017) construct similar models, incorporating richer features of fuel markets including multiple types of fuels (i.e., ethanol and biodiesel) and explicitly modeling the nested structure of the mandate. Common to all of these papers is the focus on static models with myopic economic agents. We build on this work by developing a dynamic model of RIN prices under uncertainty with forward-looking behavior. While we use the model to guide our empirical analysis, future work could build on the model to simulate counterfactual RIN prices in a dynamic, uncertain economic environment.

We also contribute to the large and growing empirical literature studying market impacts of the RFS. This literature includes papers that estimate the demand for high-blend ethanol fuels using both non-experimental and experimental methods (Anderson 2012; Du and Carriquiry 2013; Salvo and Huse 2013; Babcock and Pouliot 2013; Pouliot and Babcock 2014; Liao, Pouliot, and Babcock 2016), papers that analyze the effects of public policy in spurring investments in high-blend ethanol fueling infrastructure and vehicles capable of using high-blend ethanol fuels (Corts 2010; Anderson and Sallee 2011), and papers analyzing the effects of the RFS using structural econometric models of dynamic games (Thome and Lin Lawell 2017; Yi, Lin Lawell, and Thome 2017). More recent work has exploited the large historical variation in RIN prices to study impacts of the RIN taxes and subsidies on wholesale and retail fuel prices (Knittel, Meiselman, and Stock 2017; Lade and Bushnell 2016; Li and Stock 2017; Pouliot, Smith, and Stock 2017). Bielen, Newell, and Pizer (2016) use similar empirical techniques to our own to study the incidence of the U.S. ethanol blenders tax credit and find that ethanol producers and fuel blenders captured most of the subsidy. Finally, our work on the short-run commodity price impacts of the policy shocks is tangentially related to a much larger literature studying the long-run impacts of the RFS mandates on commodity prices (e.g., Hausman, Auffhammer, and Berck (2012); Roberts and Schlenker (2013); Wright (2014); Carter, Rausser, and Smith (2017); Baumeister, Ellwanger, and Kilian (2017)). Condon, Klemick, and Wolverton (2015) provides a relatively recent review of this literature.

Beyond the biofuel literature, our work contributes to a large literature studying the design of 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. This may have the unintended consequence of increased volatility in compliance credit markets if prices are sensitive to changes in expectations of future compliance costs. Thus, similar to work by Hitaj and Stocking (2016) on the U.S. Acid Rain Program, our work provides a case study of the potential deleterious impacts of regulatory announcements on compliance costs in the absence of price-stabilizing mechanisms.

The article proceeds as follows. We first provide a brief background on the Renewable Fuel Standard and RIN markets. We next present our theoretical dynamic model of market clearing RIN prices under alternative policy designs. We then examine historical RIN prices and other relevant data used in our analysis. We discuss our empirical strategy and present our estimates of the effects of the three policy shocks on RIN prices, commodity markets, and biofuel company stock valuations. Finally, we discuss the alternative policy designs that may increase policy certainty and reduce compliance cost volatility, and conclude.

The RFS and the Market for RINs

In this section, we summarize the features of the RFS and RINs that are relevant to our study. We refer the reader to Schnepf and Yacobucci (2012) for a more comprehensive overview of the policy, Bracmort (2017) for a recent review of the EPA's waiver authority, and Thompson, Meyer, and Westhoff (2010) for a broader discussion of RINs markets. The Renewable Fuel Standard was created by the 2005 Energy Policy Act and expanded under the 2007 Energy Independence and Security Act (EISA).[1] EISA established ambitious standards for U.S. biofuel consumption, setting a goal of expanding yearly biofuel use to 36 billion gallons (bgals) by 2022. For perspective, according to the Energy Information Administration, U.S. consumption of finished motor gasoline in 2007 was around 142 bgals. Thus, if all mandated volumes were blended as ethanol into gasoline and total blended gasoline use remained constant, the RFS would displace roughly 25% of gasoline with ethanol.

EISA is also ambitious in the types of biofuels it mandates. The law established separate mandates for (i) cellulosic biofuel produced from wood, grasses, or the inedible parts of plants; (ii) biomass-based diesel (BBD) produced mostly from soybeans or canola over our study period; (iii) advanced biofuels that include cellulosic, BBD, and fuels such as sugarcane ethanol whose life-cycle greenhouse gas emissions at least 50 percent below a threshold set by the law; and (iv) renewable fuel, encompassing all previous categories as well as corn ethanol.[2,3] The mandates are nested so that cellulosic biofuel and biodiesel count toward the advanced biofuel mandate, and all biofuels count toward the renewable fuel mandate. Congress specified the mandates such that compliance in early years could be met primarily with corn ethanol. For example, the 2013 renewable fuel mandate was

16.5 bgal, of which corn ethanol could compose 13.8 bgal. In contrast, the 2022 total renewable fuel mandate is 36 bgal, of which corn ethanol can comprise only 15 bgal. The remaining volumes must be met with cellulosic and other advanced biofuels (Environmental Protection Agency January 2013).

To enforce the mandates, 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. Each year 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. RINs are differentiated by fuel type to enforce the nested mandates, where RIN ‘type’ corresponds to the mandate categories described above.[4] In this article, we refer to RINs that count only towards the renewable fuel mandate as ‘conventional’ RINs, those that count towards the advanced mandate as ‘advanced’ RINs, and those that count towards the BBD mandate as ‘biodiesel’ RINs.[5] RINs are also differentiated by vintage year as EISA gives firms some flexibility in meeting their yearly compliance obligations. Firms may use RINs generated in the previous compliance year to meet up to 20% of their compliance obligation in any year, a banking provision; and are allowed to carry a deficit between compliance years but may only do so once, a borrowing provision (Environmental Protection Agency 2007).

Achieving the mandates laid out in EISA requires overcoming (at least) two significant challenges: (i) the development of a commercial-scale advanced biofuel industry; and (ii) the blend wall. Lagging cellulosic production has plagued the program since its inception. EISA required cellulosic biofuel to increase from 100 mgals in 2010, to 3 bgals in 2015 and 16 bgals in 2022. Despite these aggressive targets and substantial federal support for the industry, large-scale production of liquid cellulosic biofuel has yet to materialize. In its 2017 final rulemaking, EPA projected that all cellulosic biofuel plants in the U.S. would produce just 13 million gallons in 2017 (Environmental Protection Agency 2016).

As a result, the EPA has exercised its authority under EISA to waive the cellulosic biofuel mandates. While the EPA administrator is granted authority to reduce the advanced and renewable fuel volumes by the same or lesser amount as the cellulosic waiver, the EPA did not take advantage of this provision before 2013 (Bracmort 2017). Instead, the Agency left the advanced and renewable volumes at EISA levels, requiring the fuel industry to meet the advanced mandate with other advanced biofuels such as biodiesel and imported sugarcane ethanol.

Our study focuses on a more controversial period in the regulation related to the Agency's general waiver authority. Understanding this issue first requires a basic understanding of the blend wall. Historically, ethanol has been blended with gasoline at two levels: 10% ethanol, referred to as E10; and E85, fuel containing up to 85% ethanol.[6] E10 now makes up most of the ethanol-blended gasoline sales in the U.S. However, the 2022 mandates require that ethanol far exceed a 10% blend in gasoline. 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.[7]

The blend wall came to the fore in 2013 as the total renewable fuel mandate began requiring more ethanol use than could be met with a national E10 blend. Under EISA, the EPA Administrator is allowed to waive the total renewable biofuel mandate only if there is inadequate domestic fuel supply or the mandates would cause severe economic or environmental harm (Bracmort 2017). In its delayed 2013 final rule, the EPA acknowledged for the first time challenges of overcoming the blend wall and suggested that it may alter the total biofuel mandates (Environmental Protection Agency 2013b). In its following 2014 proposed rule, published in November 2013, the Agency called for a significant cut to the renewable fuel mandates. Table 1 compares the EISA statutory mandates for 2013 and 2014 with the EPA's 2013 final mandates and 2014 proposed mandates. As can be seen, the proposed mandates for 2014 represent a substantial decrease relative to the EISA statutory mandates, and the proposed total biofuel mandate is lower than its level in the 2013 mandate. The proposed cuts to the renewable fuel volumes set off a prolonged delay in finalizing the mandates for 2014 and beyond as industry and other interested parties challenged the EPA's general waiver authority. The EPA did not release a subsequent rule until June 2015.[8]

A Dynamic Model of the RFS and RIN Prices

We present here a dynamic model under uncertainty of the RFS that incorporates two important features of RINs markets. First, regulated parties are uncertain about future fuel supply, prices, and mandate levels. Second, the RFS is applied over many years, and firms are allowed to bank and borrow credits from one compliance year to the next. The model builds on both static models of mandates and intensity standards (de Gorter and Just 2009; Lapan and Moschini 2012; Holland, Knittel, and Hughes 2009; Lade and Lin Lawell 2017) and dynamic models of compliance under cap and trade programs (Rubin 1996; Kling and Rubin 1997; Schennach 2000; Holland and Moore 2012, 2013). In addition, our model accounts for the nested nature of the mandates, and in this way is similar to more recent work by Meiselman (2017). For ease of exposition, we describe here the important features of the model and market clearing RIN prices and leave all derivations and a more detailed description of the model to the supplementary online appendix.

In a static model with no uncertainty in which risk-neutral firms produce fossil fuel (q^f) and biofuel (q^b) and firms face a binding mandate for biofuel blending given by $q^b \geq \alpha q^f$, RIN prices (r) reflect the weighted difference in marginal costs between the marginal biofuel and the marginal fossil fuel (Lade and Lin Lawell 2017):

$$(1) \qquad r = C^{b'}(q^b) - P = \max\left[\frac{C^{b'}(q^b) - C^{f'}(q^f)}{1+\alpha}, 0\right],$$

where $C^{b'}(q^b)$ and $C^{f'}(q^f)$ are aggregate (industry) marginal cost functions for biofuel and fossil fuel, P is the market clearing blended fuel price, and α is the percent biofuel mandate.

Equation (1) states that RINs 'bridge the gap' between higher marginal cost biofuels and lower cost fossil fuels.

Consider an uncertain, dynamic setting in which risk-neutral firms make production decisions in periods t within a compliance period T and are allowed to bank and borrow compliance credits without limits. In this case, it can be shown that RIN prices are given by:

$$(2) \quad r_t = \beta^{(T-t)} \mathbb{E}_t [r_T],$$

where

$$(3) \quad r_T = \max[C_T^{b'}(q_t^b;\Theta_t) - P_T, 0] = \max\left[\frac{C_T^{b'}(q_t^b;\Theta_t) - C_T^{f'}(q_t^f;\Theta_t)}{1+\alpha}, 0\right],$$

where $C_T^{b'}(q_t^b;\Theta_t)$ and $C_T^{f'}(q_t^f;\Theta_t)$ are aggregate (industry) marginal cost functions for biofuel and fossil fuels that depend on uncertain parameters Θ_t, and β is the discount factor. Equation (2) states that in a dynamic setting, RINs follow Hotelling's rule and grow at the rate of interest in expectation. Equation (3) 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 compliance period T. Thus, changes in expectations of future compliance costs affect RIN prices for all $t \in T$. Equations (2) and (3) are useful for interpreting a single RIN price series. However, at any given time, upwards of six different RIN price 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 extensions to our basic model to inform our empirics: (i) multiple compliance periods with limited banking and borrowing; and (ii) a mandate with nested biofuel requirements.

RIN prices with banking and borrowing. Because the EPA allows banking and borrowing, the price of RINs generated in any year should be related to those produced in previous and future years as firms arbitrage expected differenced in compliance costs across years.

With unlimited banking and borrowing, equations (2) and (3) hold even with multiple compliance periods. However, prices may differ from those in (2) and (3) when banking and borrowing constraints bind. Thus, we develop a model with a single biofuel and a single fossil fuel (q^f and q^b) and allow for two compliance periods T^1 and T^2 in the supplementary online appendix. Firms make production decisions for each $t \in [1, \cdots, T^1, \cdots, T^2]$, and final compliance is due in $T^2 + 1$. In addition to a biofuel blending mandate, firms are constrained in the amount of credits from the first period that can be used towards their second period compliance obligation (a banking restriction), as well as in the amount of second period credits that they can use towards their first period compliance obligation (a borrowing restriction).

Let r_t^1 and r_t^2 denote RINs generated in the first and second compliance periods, respectively. In this model, it can be shown that RIN prices equal:

$$r_t^1 = \begin{cases} \beta^{(T^2-t)}\mathbb{E}_t\left[r_{T^2}^2 - \Phi^2 + \beta^{(T^1-T^2)}\Phi^1\right] & \text{if } t \leq T^1 \\ \beta^{(T^2-t)}\mathbb{E}_t[r_{T^2}^2 - \Phi^2] & \text{if } t > T^1 \end{cases} \tag{4}$$

$$r_t^2 = \beta^{(T^2-t)}\mathbb{E}_t[r_{T^2}^2], \tag{5}$$

with

$$r_{T^2}^2 = \max\left[C_{T^2}^{b'}(q_{T^2}^b; \Theta_t) - P_{T^2}, 0\right],$$

where Φ^1 and Φ^2 are the Lagrange multipliers on the borrowing and banking restrictions, respectively, and are positive when the respective restrictions bind. As before, $C_{T^2}^{b'}(q_{T^2}^b; \Theta_t)$ is the aggregate marginal cost for biofuel in the second compliance period T^2.

Equation (4) 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, $r_t^1 = r_t^2 = \beta^{(T^2-t)}\mathbb{E}_t[r_{T^2}^2]$ for all t. If the borrowing constraint is expected to bind and the banking constraint is not ($\mathbb{E}_t[\Phi^1] > 0$ and $\mathbb{E}_t[\Phi^2] = 0$ for all t), then $r_t^1 > r_t^2$ for all $t \leq T^1$. This situation would arise if, for example, all firms expect the cost of generating RINs to decrease in the second period. In this case, firms defer to period 2 as much biofuel 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 biofuel 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 biofuel 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 $r_t^1 < r_t^2$ for all t.

RIN prices with nested mandates. To better understand the relationship between RIN prices across nested mandates (e.g., the relationship between advanced and biodiesel RINs generated in 2013), we develop a second model in the supplementary online appendix that allows for two types of biofuels ($q_{1,t}^b$ and $q_{2,t}^b$), one fossil fuel (q_t^f) and a single compliance period T. The policy includes an overall biofuel mandate for $q_{1,t}^b$ and $q_{2,t}^b$ as well as a sub-mandate for $q_{2,t}^b$. In this case, it can be shown that RIN prices for the overall mandate ($r_{1,t}$) and the nested mandate ($r_{2,t}$) are given by:

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

with

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

where λ_2 denotes the Lagrange multiplier on the sub-mandate, and is positive when the respective restrictions bind. As before, $C_{j,T}^{b'}(q_{j,T}^b;\Theta_t)$ are aggregate marginal cost functions for biofuels $j = 1,2$.

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 $r_{1,t}$ because firms can use $q^b_{2,t}$ 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 biofuel 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 infer that, for example, the advanced biofuel sub-mandate is not binding, and therefore that the biofuel industry is over-complying with the advanced biofuel sub-mandate to meet the overall mandate. It follows that the marginal compliance fuel in this example is an advanced biofuel such as biodiesel.

Our model makes several simplifying assumptions that, while allowing us to derive intuitive and tractable analytic solutions, limit our ability to explain all features of RIN markets. For example, we consider multiple compliance periods and nested mandates separately, and therefore do not capture potential interactions between these constraints. Also, our model only allows for a single market for blended fuel, abstracting from the blend wall. Explicit consideration of the blend wall would require specifying separate demand functions for low- and high-blend ethanol fuels as well as for biodiesel as in Pouliot and Babcock (2016) and Meiselman (2017).[9] In addition, the model does not allow for market imperfections such as market power and transactions costs in RIN or commodity markets or consider other relevant dynamic issues such as firms only being able to borrow for one compliance period. Nonetheless, the insights derived above are useful in both studying historical RINs prices as well as in guiding our empirical work.

Data Summary and Stationarity Tests

This section discusses our historical RIN price data as well as other data used in our analysis. Given our findings above, we first study 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 our data.

Historical RIN Prices

RIN price data are from the Oil Price Information Service (OPIS), a fuel industry source of market data.[10] Here, we take advantage of the insights derived from our model to highlight the historical importance of the EPA's banking and borrowing constraints as well as whether the nested mandates were binding. We focus on data for conventional, advanced, and biodiesel RINs from January 2012 through May 2014, our period of interest.

2013 Vintage RIN Prices. We use 2013 vintage conventional, advanced, and biodiesel RINs as our dependent variables in our main analysis. We choose these series because they traded over our entire period of interest and 2013 RINs are the most relevant series for when we value the changes in the 2013 renewable volume obligation (RVO) after each event. OPIS first reported prices for 2013 RINs on August 6, 2012, five months before the large run-up in RIN prices, and we include data through May 15, 2015, six months after the release of the 2014 Proposed Rule.[11] Table 2 summarizes the series, and Figure 1 graphs the three RIN series, indicating 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. Prices for all three RINs increased sharply in January 2013 as the statutory mandates began to push closer to the blend wall. They especially increased after the 2013 proposed rule upheld the statutory renewable fuel mandate (Thompson, Meyer, and Westhoff 2012). Prices continued to climb through July 2013, peaking at around $1.45/gal. At the same time, the prices of conventional, advanced, and biodiesel RINs converged, suggesting that the fuel industry anticipated biodiesel serving as the marginal compliance fuel. After peaking in July, RIN prices fell as precipitously as they had risen as the high prices garnered increased pressure on the EPA and Congress held hearings on the subject (Irwin 2013). The prices fell particularly sharply around three events: (1) the release of the 2013 final rule; (2) a news leak of an early version of the 2014 proposed rule; and (3) the release of the 2014 proposed rule.

The Importance of Banking and Borrowing Constraints. Our dynamic theory model shows that if the EPA's banking constraint binds, RINs generated in past years should trade for lower prices than RINs generated in more recent years. The opposite should hold if the borrowing constraint binds. Subject to the caveats described above regarding the direct applicability of our model, it is useful to explore historical RIN price spreads to study whether these constraints have been relevant historically. Figure 2a graphs the ten-day moving average of the price spread between front-year and prior-year conventional, advanced, and biodiesel RINs.[12,13] The spreads show a sustained, positive value between vintages for all three RIN types over most of 2012 and 2013.[14] Positive spreads continue to be seen for advanced and biodiesel RINs through 2014, while the front-to-prior-year spread for conventional RINs fell and even traded at negative prices. While noisy, the figure suggests that the banking restrictions were the most relevant constraint on the industry historically. This is consistent with, and complementary to, findings by Nick Paulson's regular RIN generation updates (Paulson 2012, 2014).

The Importance of Binding Nested Sub-Mandates. Our model shows that if the both nested mandates 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.[15] Figure 2b graphs the advanced-conventional RIN and biodiesel-conventional spreads for 2012-2014. In 2012, advanced and biodiesel RINs traded at a $0.59/gal and $1.09/gal premium over conventional RINs on average, respectively. This suggests that the sub-mandates were binding over this period. However, after the large run-up in RIN prices in 2013, advanced and biodiesel RINs traded on average at a \$0.08/gal and \$0.10/gal premium only, and at times both series traded for less than a one cent premium. The near-convergence in the RIN price series suggests that the nested mandates were less important in 2013 and 2014, and that at times may not have been binding. The finding is consistent with the fuel industry anticipating biodiesel playing a more important role as a marginal compliance fuel.

2013 Policy Shocks

Our first policy shock is the release of the 2013 final rule in August 2013. While the EPA upheld its earlier proposed 2013 mandates, it also acknowledged for the first time challenges to maintaining the EISA standards in 2014 and beyond. The rule included the following passage, sending a strong signal of the comings reductions to the renewable fuel mandate:[16]

> *[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****...* (Environmental Protection Agency 2013b) [emphasis added]

Our 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 (2013), the news article was the first time that the EPA's draft rules were released to the general public.[17] It revealed that the EPA was considering reducing the overall standard not only below statutory levels, but below the 2013 mandate:

> ***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 2013a) [emphasis added]

Our 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 (Table 1).[18]

Commodity Futures and Stock Market Price Data

We collect data for various commodity futures prices and biofuel firm stock prices for two reasons. First, the effects of the three policy shocks on commodity prices and biofuel firms are of direct interest. Second, our event study empirical strategy requires specifying variables to explain 'normal' market returns. We therefore also use different combinations of these variables to control for movements in RIN, commodity, and stock prices that are not directly related to the policy shocks.

From our model, we know that RIN prices should reflect expected future compliance costs, which are a function of both expected future fuel costs and expectations of the future stringency of the policy. To control for fuel costs in our RIN price event studies, we collect prices of July 2014 Chicago Mercantile Exchange (CME) futures contracts for ethanol, soybean oil, and WTI crude oil contracts from Quandl.[19] 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.[20]

For our commodities market event studies, in addition to ethanol, soybean oil and 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. 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 to control for 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 from Yahoo! Finance. We observe prices for the eleven firms listed in Table 3.[21] While the number of firms we observe is relatively small, the firms in Table 3 own a relatively large share of biofuel production capacity in the U.S. According to data from the Renewable Fuel Association and Biodiesel Magazine, as of May 2017 these firms owned 26% and 24% of U.S. ethanol and biodiesel production capacity, respectively (Renewable Fuels Association 2017; Biodiesel Magazine 2017). We classify each firm as a conventional ethanol, advanced ethanol, or biodiesel producer based on publicly available profiles of their investments and production capabilities. While most firms produce only one type of biofuel, some such as ADM produce both ethanol and biodiesel while other such as Pacific Ethanol produce both conventional and advanced ethanol. In all stock price event studies, we specify normal returns as a function of a firm-specific daily return and the covariance of all firms' returns with the Russell 3000 index.

Table 2 summarizes these data. There is substantial variation in most future prices and indices over this period, reflecting a relatively volatile period in commodities prices during this time. For example, oil futures trade between \$2.02/gal and \$2.45/gal. While ethanol futures prices traded \$0.25 lower than oil price on average, they ranged between \$1.59 and \$2.40 per gallon. Soybean oil futures prices fluctuated even more widely, ranging between \$2.90 and \$4.28/gal.

Stationarity and Cointegration Tests

Our theory suggests that there should be a long-run relationship between RIN prices and futures prices of relevant renewable and fossil fuels. This implies that our data may be cointegrated. To test for this, we start by conducting unit root tests for each series used in our subsequent analysis. We then test for cointegration between RIN prices and the variables that we specify as normal returns. We also test for cointegration between each our other primary variables of interest and the variables used as controls for ‘normal returns’ in each of our subsequent event studies.

Panel A of Table 4 presents Dickey-Fuller GLS test statistics for each variable (Elliot, Rothenberg, and Stock 1996). All test statistics allow for a linear trend, 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 (2) of our theoretical model and findings by Mason and Wilmot (2016).[22] Similar to previous work, we find that of the remaining prices 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 (e.g., Trujillo-Barrera, Mallory, and Garcia (2012); Mallory, Irwin, and Hayes (2012)). When we apply similar tests to the first difference of each series, we reject the unit root null hypothesis in all cases.

Panel B of Table 4 reports the results from our Engle-Granger cointegration tests. In all cases, we cannot reject the null hypothesis of no cointegration. 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. The results for RIN prices conflict with the predictions of our model and those for energy price series conflict in part with previous work by, for example, Mallory, Irwin, and Hayes (2012). However, this finding is likely due to the short and relatively volatile sample period. The results may differ in a longer sample.

Empirical Strategy and Results

In this section, we present 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. Event studies are popular tools for evaluating the economic impacts of events ranging from macroeconomic announcements, to changes in regulatory environments, to celebrity scandals (McQueen and Rolley 1993; Schwert 1981; Knittel and Stango 2014).[23] Although event studies have historically focused on stock prices, these tools are increasingly popular in evaluating the economic impacts of changes in environmental regulations on broader financial markets including commodity markets (Linn 2010; Lemoine 2017b; Bushnell, Chong, and Mansur 2013; Meng 2017).

For each event study, we must first specify control variables that constitute each dependent variable's 'normal' returns. We use relevant commodity prices for all price RIN specifications, guided by our theoretical model. For our commodity market and stock market event studies, we follow standard practice and specify our normal returns using broad macroeconomic variables including the Russell 3000 stock market index and the S&P-Goldman Sachs commodity market price index. After determining our normal returns, we estimate abnormal returns to each dependent variable on and shortly after each of our events of interest. This estimation strategy amounts to attributing all unexplained returns on the event date to the impact of the event. Identification, therefore, relies on (i) correctly specifying variables that explain normal price movements in our dependent variable and (ii) controlling for all relevant factors on the event date. For example, if other news impacting RIN markets occurred on the same day as the released its 2013 final rule and we did not control for this, we would attribute the combined effect of the news story and the EPA's rulemaking to the latter. This identification strategy is facilitated by the high frequency of our daily price data, and we explore the robustness of our abnormal return estimates to the inclusion of rich time controls as well as alternative specifications of normal returns.

RIN and Commodity Market Event Studies

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

$$(6) \quad \Delta\log(r_t) = \beta_0 + \Delta\log(x_t)\beta + \sum_{m=1}^{3}\sum_{s\in S_m} \gamma_{m,s}\tau_{t,m,s} + \varepsilon_t,$$

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 (or normal returns), $\tau_{t,m,s}$ 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.[24]

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.[25]

Traditional inference of the hypothesis $H_0 : \gamma_{m,s} = 0$ may be inappropriate in event study settings (Conley and Taber 2011; Gelbach, Helland, and Klick 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, Helland, and Klick (2013) for inference on all estimated abnormal returns. 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 dynamic theory model, we include in x_t commodity futures prices for WTI crude oil, ethanol, and soybean oil. We estimate equation (6) separately for conventional, advanced, and biodiesel RINs to allow each event, energy price, and feedstock price to have differential impacts on each RIN series.[26] 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 four subsequent trading days.

Two important factors influence our interpretation of $\hat{\gamma}_{m,s}$ in our RIN event studies. 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. Second, $\hat{\gamma}_{m,s}$ estimates only the unanticipated information due to each event.[27] Thus, our abnormal returns estimate the impact of unexpected information revealed by each event above and beyond those due to adjustments in commodity markets.[28] We argue that these effects are of first-order interest as they reflect the unanticipated impact of each event on expected future compliance costs above and beyond adjustments to changes in underlying commodity prices.

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 (6) 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 Russell 3000 index is a market capitalizationweighted index of the 3,000 largest stocks in the U.S. Thus, the abnormal return estimates correspond to 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.

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 (6) 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 analogue of equation (6) given by:

$$(7) \quad \Delta\log(R_{it}) = \beta_{0i} + \Delta\log(x_t)\beta + \sum_{m=1}^{3}\sum_{s\in S_m}\gamma_{m,s}\tau_{i,t,m,s} + \varepsilon_{it},$$

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 (7) and (6) 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 Russell 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 (7) separately for (i) all biofuel firms; (ii) conventional biofuel producers; (iii) advanced biofuel producers, and (iii) biodiesel producers.

Results: RIN Markets

Table 5 presents our results for 2013 conventional, advanced, and biodiesel RINs.[29] 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, while the abnormal return estimates represent those returns around each event that cannot be explained by movements in commodity prices.[30]

The normal return coefficients are imprecisely estimated, but their estimated impact on RIN returns is consistent with our theoretical model. RIN prices decrease in WTI prices and increase in ethanol and soybean oil prices. The only statistically significant normal return factor is soybean oil futures prices, which are statistically significant for both conventional and biodiesel RINs. The finding is consistent with our discussion in Section where we found suggestive evidence that biodiesel was the marginal compliance fuel at least for some time during our estimation window.[31]

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 a 12%-13% abnormal loss, with similar losses to advanced RINs on that day. Biodiesel RINs experienced smaller losses of 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 ($\approx$13%); however, biodiesel RINs also experience statistically significant abnormal losses on that day. 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, likely due to the EPA releasing the rule on a Friday afternoon.

To put the size of our estimated abnormal returns into context, we estimate the resulting change in the value of the 2013 RVO. This is equivalent to the change in value of the 2013 subsidy for the biofuel industry, or the change in value of the tax obligation for all obligated parties. To calculate this, we multiply the 2013 ethanol-equivalent mandate volumes from

Table 1 by the estimated abnormal returns for each RIN series, converted to dollars per gallon, over various event windows, and sum the change in each RIN type obligation.[32] To compute our standards, we estimate a fully interacted panel analog of equation (6) and cluster our standard errors at the month to allow for arbitrary serial correlation and correlation across RIN types.

Table 6 presents the results. 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 nearly 2 billion dollars. The estimated losses increase to over $7 billion over the subsequent two trading days. Event day losses following the leaked 2014 rule 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. While the estimated change in the value of the 2013 RVO is large, we are unable to the determine the incidence of these changes on the fuel industry.[33] To gain better insight into the incidence of the policy shocks, we now turn to their effects on commodity markets and the price of publicly traded biofuel firms.

Results: Commodity Markets

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 only the subsequent two trading days.

We observe little movement 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 is suggestive 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.

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 EPA published the rule, we estimate a 2% statistically insignificant gain. However, the rule was released on a Friday afternoon, and on the following Monday, we estimate that firms experienced a 3.8%-4.3% 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. 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.[34] 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.

Conclusions

We document important impacts of three 'policy shocks' on the value of RFS compliance credit prices. Furthermore, we study distributional effects of these shocks, and show that they mostly fell on advanced biofuel firms and commodity markets of the marginal compliance fuels. These findings highlight the role of bankable compliance credits in translating changes in expectations about future compliance costs into changes in current compliance costs, a key prediction of our theory model.

Examples of other policy shocks abound. As highlighted in the supplementary online appendix, RINs markets were again subject to 'policy shocks' following the release of the EPA's next three proposed and final rules in 2015 and 2016. Outside the RFS, the price of tradeable credits for California's Low Carbon Fuel Standard (a similarly structured fuel mandate) has experienced similar volatility following major court decisions and policy announcements (Yeh et al. 2016). If these other policy shocks also have detrimental impacts on markets as we found in this study, they may undermine the objectives of these other policies.

What lessons can we draw from this work? We offer two observations and recommendations that may alleviate at least some of the problems that led to the events studied in this article. First, while cost uncertainty is a well-known drawback of quantity-based regulations like the RFS (Weitzman 1974; Roberts and Spence 1976), we demonstrate that when combined with uncertainty in future mandates, compliance cost uncertainty can lead to especially volatile compliance credit markets and that this volatility impacts regulated parties. Thus, similar to Hitaj and Stocking (2016), our results suggest that policies implemented using tradeable credits may be better served by more coordinated, frequent, and transparent communication policies between regulators, obligated parties, and stakeholders.

Second, price collars would substantially reduce compliance cost uncertainty by bounding RIN prices. Roberts and Spence (1976) first proposed such a mechanism whereby a regulator supplements a tradeable credit 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 policies. Many papers have since studied hybrid policy mechanisms and have shown that they have desirable efficiency properties in many contexts (Pizer 2002; Newell, Pizer, and Zhang 2005; Burtraw, Palmer, and Kahn 2010; Lade and Lin Lawell 2017).[35]

Our work is, of course, limited and subject to important caveats. For example, our theoretical model could be extended along several dimensions to better represent additional real-world features of RINs markets. However, further extending the model would likely come at the cost of having to forgo analytic solutions. Also, while our reduced form empirical strategy estimates the ex-post impacts of the policy shocks on RINs, commodity, and stock markets, we are unable to quantify the welfare effects of these events or describe their effects on important outcomes such as investments in advanced biofuel infrastructure. Also, we are only able to quantify the impact of the events on the level of prices and cannot quantify their effects on market participants' perceptions regarding future policy uncertainty.

Notes

[1] The initial iteration of the law is therefore often referred to as the RFS1, and the EISA version as the RFS2.

[2] Biomass-based diesel includes biodiesel and renewable diesel. Little renewable diesel blending occurred in the U.S. in our sample. As such, we use the terms 'biodiesel' and 'biomass-based diesel' interchangeably when referring to the BBD portion of the RFS requirements. Other fuels such as renewable jet fuel also generate RINs, but played a negligible compliance role before 2013.

[3] BBD has a higher energy content than ethanol. To account for this, the EPA specifies mandates in 'ethanol-equivalent' units. For example, one gallon of corn ethanol generates one RIN, while one gallon of biodiesel produces 1.5 ethanol-equivalent RINs due to its higher energy content.

[4] We do not study cellulosic ethanol RINs in this article as little cellulosic biofuel was produced.

[5] These are also known as D6, D5, and D4 RINs, respectively.

[6] E85 can contain between 51% and 83% ethanol blend. Blends vary by time of year and region to meet relevant fuel standards.

[7] The blendwall could also be overcome with a large increase in E15 sales (fuel containing 15% ethanol). In 2010, the EPA granted a partial waiver for E15 blends (Energy Information Agency 2016). However, the fuel is still not allowed to be sold in summer months, and almost no E15 was sold over our study period.

[8] In the supplementary online appendix, we discuss the more recent rules for the 2014-2017 mandates, and conduct a similar empirical analysis for these events.

[9] Our model would permit, for example, $C^b(q^b)$ to increase sharply beyond a certain level of q^b. This would generate similar RIN price characteristics as with a blend wall whereby RIN prices increase suddenly around a certain level of ethanol blending.

[10] OPIS records RIN price data through daily surveys of market participants, and is a highly cited source for RIN price data in the biofuel industry.

[11] Our supplementary online appendix includes robustness checks of the sensitivity of our results to using alternative time periods as well as an aggregate RIN price for each type.

[12] We use a ten-day moving average to smooth noise in the daily data.

[13] For example, in 2012 the figure graphs the average price spread between 2012 and 2011 RINs for each RIN type.

[14] The 2012 biodiesel RINs traded at a large premium to 2011 RINs during the first half of 2012, after which the spread fell quickly and followed conventional and advanced RIN spreads for much of the rest of the sample. During that time, biodiesel RIN prices were volatile due to uncertainty in a whether a blending tax credit for the fuel would be reinstated. Irwin (2014b) provides a more descriptive discussion of biodiesel RIN pricing over this period. Also, early in each year the front-year RIN market may be illiquid as few RINs have been generated. This may cause some noise early in each year.

[15] This corresponds to $\lambda_2 > 0$ for both nested mandates in our theoretical model of RIN prices. The same caveats hold regarding transactions costs and other potential market frictions in RINs markets as before.

[16] 18.15 billion gallons refers to the overall biofuel mandate specified under EISA for 2014.

[17] Several other news outlets and organizations refer to the same article in stories and press releases following the leaked rule. For example, the Reuters article was referenced by news articles and press releases from AAA, Biomass Magazine, Scientific American, CNBC, and E&E News (Podkul 2013b; Green 2013; Voegele 2013; Amanda Peterka 2014). The article was also cited in a letter discussing, among other things, the leaked proposals that was submitted to the EPA Docket by the Biotechnology Innovation Organization, a large biotechnology trade association, in January 2015 (Erickson 2014).

[18] We could include a number of other events 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 article, 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.

[19] Ideally, we would observe a futures price series for biodiesel; however, such a series was not available. Instead, we use soybean oil futures as soybeans were the dominant feedstock for biodiesel in the U.S. over this period.

[20] We assume a conversion ratio of 1 pound of soybean oil to 7.7 gallons of biodiesel (Sadaka 2012).

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

[22] 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).

[23] MacKinlay (1997) provides a more comprehensive overview on the historical use of event studies.

[24] Mason and Wilmot (2016) find that modeling RIN returns as a geometric Brownian motion with time-vary volatility and discontinuous 'jumps' substantially improves the statistical fit of their model. The authors' data include a similar period to our own, and therefore the jumps in their data include our events of interest. Thus, our study here can be thought of as quantifying the importance of the policy announcements in driving large 'jumps' in RIN prices.

[25] 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 are analogous to a regression discontinuity design with time as the running variable that allows for multiple breaks.

[26] Alternatively, we could estimate a panel regression that pools the $\Delta \log(r_{j,t})$ for all RIN types j. Estimating equation (6) 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.

[27] In other applications, researchers scale their estimated abnormal returns using prior probabilities implied by predictive markets (Snowberg, Wolfers, and Zitzewitz 2011). We have no such prior information, so we interpret $\hat{\gamma}_{m,s}$ as the unanticipated information revealed by each event.

[28] The second issue is also relevant in interpreting our commodity and stock price event studies. However, it is difficult to argue that the EPA's actions affected broader classes or world commodity prices or U.S. stock prices.

[29] In the supplementary online appendix we explore the robustness of our results to using alternative control variables, estimating equation (6) over different time periods, and specifying all variables in levels rather than logs. While our normal return estimates vary slightly depending on the specification, all abnormal return estimates are largely similar to those in Table 5.

[30] All normal return standard errors are Newey-West standard errors allowing for arbitrary autocorrelation up to five trading days. Standard errors are similar, and in many cases less conservative, when using the optimal lag selection criterion from Newey and West (1994).

[31] Interestingly, soybean oil futures are not statistically significant predictors or advanced RIN price returns. When we include sugar futures prices in our normal return specification (Table B.1 in the supplementary online appendix), they appear to play a larger role in explaining advanced RINs, suggesting that advanced RINs may have been driven more by sugarcane ethanol prices than biodiesel prices over this period. However, as in Table 5, all estimated normal returns are noisy and we are unable to draw any statistically valid conclusions based on our results.

[32] Specifically, we calculate the RVO losses for event m over horizon S_m as:

$$\begin{aligned}\Delta\widehat{\mathrm{RVO}} = &\left[\sum_{s\in S_m} \hat{\gamma}_{m,s}^{D4} \times r_{m0}^{D4} \times \mathrm{RVO}_{\mathrm{EE}}^{\mathrm{D4}}\right] + \left[\sum_{s\in S_m} \hat{\gamma}_{m,s}^{D5} \times r_{m0}^{D5} \times \left(\mathrm{RVO}_{\mathrm{EE}}^{\mathrm{D5}} - \mathrm{RVO}_{\mathrm{EE}}^{\mathrm{D4}}\right)\right] \\ &+ \left[\sum_{s\in S_m} \hat{\gamma}_{m,s}^{D6} \times r_{m0}^{D6} \times \left(\mathrm{RVO}_{\mathrm{EE}}^{\mathrm{D6}} - \mathrm{RVO}_{\mathrm{EE}}^{\mathrm{D5}}\right)\right],\end{aligned}$$

where $\hat{\gamma}_{m,s}^{D4}$ is the estimated abnormal return for D4 RINs on day s of event m, r_{i0}^{D4} is the initial level of D4 RIN prices in dollars per gallon on day 0 of event m, and $\text{RVO}_{\text{EE}}^{\text{D4}}$ is the 2013 biodiesel RVO in ethanol-equivalent units (1.5 times the volumetric units from Table 1). Similar notation is used to calculate the change in the value of the D5 and D6 RVO. We adjust the D5 and D6 RVOs to account for the nested nature of the mandates, and do not include the 6 mgals of cellulosic biofuel.

[33] To illustrate this, consider two extreme cases: a refiner that acquired all RINs to meet its firm's 2013 RVO in July 2013 and a refiner that had not yet purchased any RINs as of July 2013. The former would be harmed by this change while the latter would benefit significantly from the EPA's announcements.

[34] The results are also consistent with the work of Bielen, Newell, and Pizer (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.

[35] This option may be challenging to implement from a political economy perspective as it requires the EPA to both collect revenue should the price cap bind as well as to subsidize firms if RINs prices fall below the price floor.

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

	2013(M)	2013(F)	2014(M)	2014(P)
Cellulosic Biofuel	1	0.006	1.75	0.017
Biomass-Based Diesel	>1	1.28	>1	1.28
Advanced Biofuel	2.75	2.75	3.75	2.20
Total Biofuel	16.55	16.55	18.15	15.21

Notes: The table compares volumes from the statutory mandates passed under EISA to volumes from the EPA's 2013 final rule and 2014 proposed rule. Statutory mandates are denoted by (M); 2013(F) denotes volumes from the 2013 final rule; and 2014(P) are volumes from the 2014 proposed rule. All volumes are specified ethanol-equivalent volumes except for biomass-based diesel which is physical gallons. (Sources: Environmental Protection Agency (2010, 2013a,b))

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

	Mean	Std. Dev.	Min	Max	N
Conventional RINs (cents/gal)	44.86	32.50	4.75	145.50	446
Advanced RINs (cents/gal)	59.01	26.10	22.00	146.50	446
Biodiesel RINs (cents/gal)	70.31	26.87	23.50	146.50	446
Oil Futures (cents/gal)	223.26	8.38	202.33	244.62	446
Ethanol Futures (cents/gal)	196.89	20.08	159.00	240.80	446
Soybean Oil Futures (cents/gal)	358.81	37.30	290.29	427.73	446
Corn Futures (cents/gal)	262.42	35.69	205.90	325.27	446
Sugar Futures (cents/gal)	259.89	21.53	213.92	304.92	446
S&P-GS Commodity Index	641.49	17.84	601.00	694.30	423
Russell 3000 Index	974.93	101.52	798.29	1137.17	446

Notes: All RIN prices are shown for 2013 vintage series. Future prices are for July 2014 contracts. Summary statistics are include data from 8/6/2012 to 5/15/2014.

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

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

Table 4. Stationarity and Cointegration Test Results

	Lags		
Series	1	5	10
Panel A: Dickey-Fuller GLS Unit Root Test Statistics			
Conventional RINs	-0.91	-1.05	-1.26
Advanced RINs	-1.60	-1.52	-1.52
Biodiesel RINs	-1.86	-1.70	-1.61
Oil Futures	-3.09**	-2.91**	-2.80*
Ethanol Futures	-1.21	-0.96	-0.90
Soybean Oil Futures	-2.43	-2.43	-2.58*
Corn Futures	-1.88	-1.40	-1.24
Sugar Futures	-1.61	-1.54	-1.87
S&P-GS Commodity Index	-3.18**	-3.12**	-3.39**
Russell 3000 Index	-3.42**	-3.01**	-3.07**
Panel B: Engle-Granger Cointegration Test Statistics			
Conventional RINs: Oil, Ethanol, Soybean Oil	-2.28	-2.25	-2.11
Advanced RINs: Oil, Ethanol, Soybean Oil	-2.16	-2.10	-2.13
Biodiesel RINs: Oil, Ethanol, Soybean Oil	-2.06	-2.10	-2.13
Oil Futures: Russell 3000 Index	-3.55*	-3.34	-3.40
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

Notes: 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 is of no cointegrating relationship. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

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		-0.410	-0.417	-0.291	-0.315	-0.256	-0.276
		(0.341)	(0.332)	(0.332)	(0.330)	(0.321)	(0.317)
Ethanol Futures		0.145	0.087	0.013	-0.027	0.148	0.095
		(0.193)	(0.206)	(0.231)	(0.237)	(0.206)	(0.214)
Soybean Oil Futures		0.511	0.543*	0.212	0.280	0.641*	0.664*
		(0.318)	(0.320)	(0.369)	(0.363)	(0.360)	(0.360)
Abnormal Returns							
2013 Final Rule:	Day 0	-0.136**	-0.118**	-0.132**	-0.117**	-0.062*	-0.057*
	Day 1	-0.144**	-0.129**	-0.132**	-0.120**	-0.134**	-0.131**
	Day 2	-0.197***	-0.175***	-0.155**	-0.133**	-0.181**	-0.167**
	Day 3	0.028	0.045	0.037	0.048	0.055*	0.060**
	Day 4	0.052	0.061*	0.048	0.050	0.032	0.037
Leaked 2014 Rule:	Day 0	-0.147**	-0.131**	-0.021	0.008	-0.050*	-0.033
	Day 1	0.091**	0.099**	0.151***	0.171***	0.053*	0.069*
	Day 2	0.048	0.065*	-0.004	0.025	-0.016	-0.000
	Day 3	0.003	0.016	-0.023	0.004	-0.027	-0.014
	Day 4	-0.061*	-0.041	-0.058*	-0.020	-0.046*	-0.022
2014 Proposed Rule:	Day 0	-0.043	-0.034	-0.036	-0.037	-0.049*	-0.053*
	Day 1	-0.193***	-0.192***	-0.125**	-0.133**	-0.217***	-0.221***
	Day 2	0.061*	0.071*	-0.023	-0.022	0.002	-0.004
	Day 3	-0.013	-0.005	-0.003	-0.003	0.034	0.028
	Day 4	0.022	0.035	-0.026	-0.017	-0.057*	-0.052*
SQ 10% Lower Bound		-0.057	-0.050	-0.050	-0.053	-0.046	-0.043
SQ 10% Upper Bound		0.060	0.058	0.057	0.056	0.050	0.049
SQ 5% Lower Bound		-0.077	-0.074	-0.097	-0.090	-0.068	-0.068
SQ 5% Upper Bound		0.087	0.089	0.076	0.080	0.080	0.077
SQ 1% Lower Bound		-0.177	-0.168	-0.255	-0.247	-0.213	-0.217
SQ 1% Upper Bound		0.180	0.168	0.137	0.133	0.139	0.140
Observations		445	445	445	445	445	445
Time Controls		No	Yes	No	Yes	No	Yes

Notes: Normal return standard errors in parentheses are Newey-West errors with 5 lags. Inference for abnormal returns are based on sample quantile critical values given at the bottom of the table (Gelbach, Helland, and Klick 2013). *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

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

		Δ 2013 RVO	Lower Bound	Upper Bound
2013 Final Rule:	Event Day	-1.93***	-2.10	-1.77
	3 Day	-7.05***	-7.47	-6.64
	5 Day	-5.82***	-6.40	-5.24
Leaked 2014 Rule:	Event Day	-0.65***	-0.72	-0.57
	3 Day	0.00	-0.12	0.12
	5 Day	-0.33***	-0.52	-0.15
2014 Proposed Rule:	Event Day	-0.17***	-0.21	-0.13
	3 Day	-0.72***	-0.82	-0.62
	5 Day	-0.71***	-0.86	-0.56

Notes: 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.

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		446	446	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	0.022	0.030	0.030	0.024	0.024	0.038	0.039	0.024	0.022

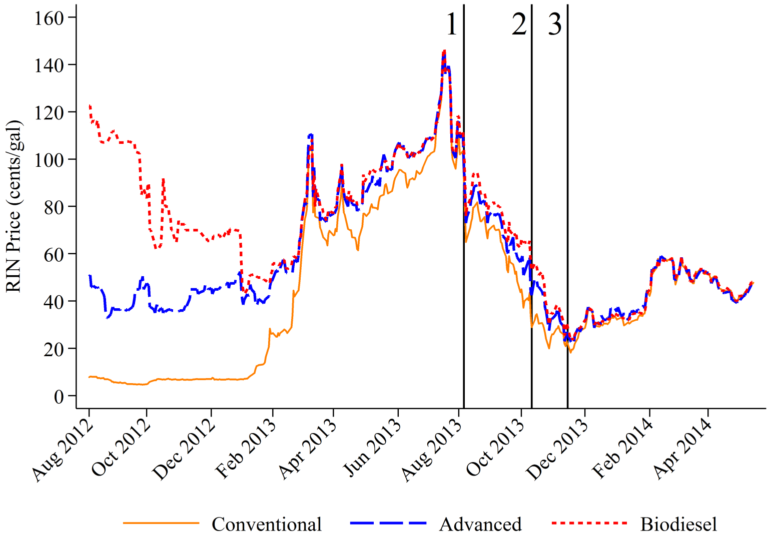
Notes: Sample Quantile test critical values are estimated from the empirical residual distribution excluding event days (Gelbach, Helland, and Klick 2013). Abnormal returns represent those that cannot be explained by corresponding movements in the S&P-GS Commodity Index, the Russell 3000 Index, and a daily mean return. WTI regressions exclude the S&P-GS Commodity Index. *, **, and *** denote significance at the 10%, 5%, and 1% confidence levels, respectively.

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
Firms		11	11	4	4	3	3	6	6
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

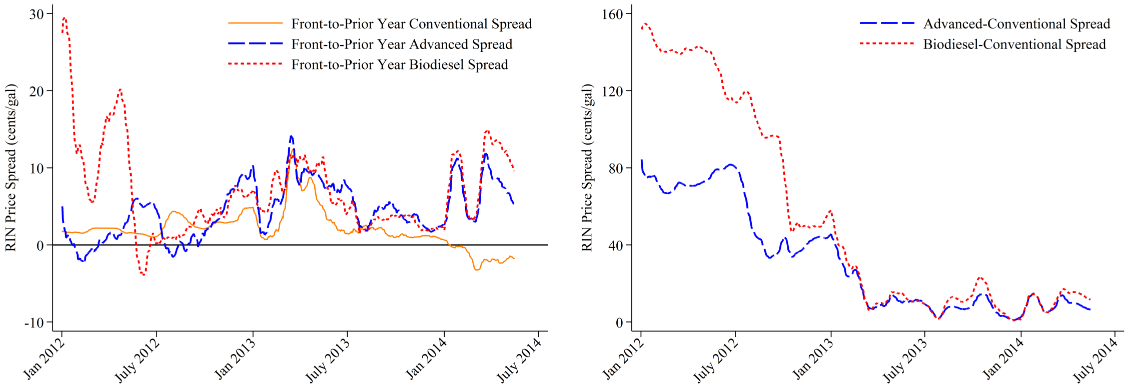
Notes: Results are presented for all firms, advanced biofuel firms, and biodiesel firms. All regressions include controls for returns due to changes in the Russell 3000 index and the S&P-GS commodity index. Inference for abnormal returns are based on SQ critical values given at the bottom of the table.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

Figure 1. 2013 Vintage RIN Prices



Notes: The figure graphs daily prices for 2013 vintage conventional (orange), advanced (blue), and biodiesel (red) RINs from 8/6/2012-5/15/2014. The figure also indicates the timing of the key policy announcements. Event 1 is the release of the 2013 Final Rule, 2 is the leaked 2014 Proposed Rule, and 3 is the 2014 Proposed Rule.

Figure 2. The Importance of Banking Constraints and Nested Mandates



(a) The Importance of Banking Constraints **(b) The Importance of Nested Mandates**

Notes: The left figure graphs the ten-day moving average of the spread between front- and prior-year RINs from 2012-2014. Positive (negative) values are suggestive of a binding banking (borrowing) constraint. The right figure graphs the ten-day moving average spread between front-year biodiesel and conventional RIN prices (red) and advanced and conventional RIN prices (blue). Positive values suggest that the nested mandate is binding, while zero values suggest that firms are over-complying with the nested mandate.