Designing Climate Policy:
Lessons from the Renewable Fuel Standard and the Blend Wall[1]

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Abstract

Many climate policies mandate renewable energy production to combat global climate change. These policies often differ significantly from first-best policy prescriptions. The largest such policy to date is the Renewable Fuel Standard (RFS), which mandates biofuel consumption far beyond what is feasible with current technology and infrastructure. In this paper, we critically review the methods used by the Environmental Protection Agency to project near- and long-term compliance costs under the RFS, as well as draw lessons from the RFS experience to date that would have improved the program's efficiency. The lessons are meant to inform both future RFS rulemaking and the design of future climate policies. We draw two lessons specific to the RFS rulemaking. (1) *Incorporate uncertainty into rulemaking.* Make, implement, and analyze policy with a view towards what might happen, rather than a projection of what will happen. (2) *Implement multi-year rules.* Multi-year rulemaking allows for longer periods between major regulatory decisions and sends greater certainty to markets. We also make two more general recommendations. (3) *Tie waiver authority to compliance costs or include cost containment provisions*. Explicit and transparent cost containment mechanisms send a more stable policy signal to markets. (4) *Fund research and development of new technologies directly rather than mandating them*. Future technological advancement is uncertain, and mandating new technologies has proven to be largely ineffective to date, particularly in fuel markets.

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1. Introduction

The year 2016 was the warmest year on record since at least 1880. The same was true about the previous two years, and six of the warmest recorded years since 1880 have occurred in the past decade (NASA, 2017). If continued unabated, the world is on target to warm by about 2 degrees Celsius in less than 40 years, pushing the climate to a regime unlike any witnessed in the last million years (Ramanathan et al., 2016). Alarmed by the scientific consensus that carbon emissions from burning fossil fuels are the leading cause of climate change, many governments have enacted policies to promote alternative fuels and to reduce fossil fuel use.

Most economists recommend using a carbon tax or cap-and-trade program to address climate change externalities (Auffhammer et al., 2016). Such incentive-based instruments price carbon emissions, impacting energy demand in two ways. First, it raises fuel costs, reducing demand for energy. Second, it reduces the relative price of low-carbon intensity fuels, making renewable fuels more competitive in the marketplace. In addition to pricing externalities, many economists also recommend subsidizing basic research into climate change mitigation technologies because the private rate of research and development (R&D) may be lower than the socially optimal rate of R&D. Firms may under-invest in R&D because there are positive spillovers involved: when a firm invents a new climate change mitigation technology, other firms can free ride on the invention and may even imitate the invention without having paid for the R&D efforts. Even with patent protection, these spillovers reduce the payoff to investing in R&D (Corderi and Lin, 2011; Corderi Novoa and Lin Lawell, 2017).

Instead of pursuing first-best policies in the transportation fuel sector, governments have generally enacted policies that subsidize renewable fuels. For example, the European Union has a consumption target of 10% biofuel by 2020, with an additional requirement that fuel providers reduce the greenhouse gas intensity of their fuels by 6%. In California, the Low Carbon Fuel Standard establishes aggressive carbon intensity standards, requiring fuel providers to reduce the carbon intensity of fuels sold in the state by 10% by 2020. These policies have two disadvantages relative to first-best. First, the renewable fuel subsidy distorts firms' and consumers' supply and demand decisions as both the level and relative price of fuels will differ from first-best (Holland et al., 2009; Lapan and Moschini, 2012). Second, the renewable subsidy is determined by the 'binding-ness' of the mandate, and not to the degree of innovation. Thus, the rewards to innovation differ from, and likely under-incentivize, large investment in new technologies (Clancy and Moschini, 2015).

We study one of the largest and most ambitious such policies to date: the Renewable Fuel Standard (RFS). Passed in its current form in 2007, the RFS mandated future U.S. biofuel consumption far beyond what was, and remains, technologically feasible. Complying with the RFS requires large investments in (i) the development, commercialization, and production of cellulosic biofuels; (ii) production and blending capabilities of biofuels by upstream and midstream fuel providers; and (iii) alternative fuel vehicles by consumers. The policy has struggled to incentivize any large-scale production of cellulosic ethanol to date and has faced significant challenges related to the latter two forms of investment since 2013.

In this paper, we critically review the design, evaluation, and implementation of the RFS. We begin with a review the program, highlighting key features of the program as developed by Congress and the challenges it has faced in meetings its standards to date. Second, we critically review the methods used to evaluate the program in the Environmental Protection Agency's (EPA) Regulatory Impact Analysis (RIA) to highlight that many of the issues could have been anticipated ex-ante. We conclude with lessons that, in hindsight, would have improved the policy. Specific to RFS rulemaking, our lessons include: (1) incorporate uncertainty analysis into rulemaking; and (2) implement and enforce multi-year rules. More general recommendations for designing climate policy include: (3) tie waiver authority to compliance costs or incorporate cost-containment provisions; and (4) fund R&D of new technologies directly through other programs. While ex-post in nature, the purpose of this manuscript is to inform both future EPA rulemakings as well as other climate policies. It is therefore very much in the spirit of recent calls in the literature for retrospective studies of policies as a means to understand the effectiveness of rules and regulations to improve the analysis of regulations ex-ante as well as the design of future regulations.

Our review is timely for two reasons. First, by adjusting the 2014-2017 standards, the EPA has triggered a provision of the enacting legislation that calls for a 'reset.' The 'reset' requires the Agency to modify the RFS mandates through 2022 based on a review of the program's implementation and an analysis of the fuel industry's production capabilities and environmental impact (Bracmort, 2017). Also, the statutory RFS mandates are applicable only through 2022 and require that the EPA set subsequent mandates for 2023 and beyond. Both the reset and future mandates will require an extensive evaluation of the current state of the policy and biofuel industry as well as an assessment of the benefits and costs of the regulation. Our work also provides a more general evaluation of the costs and benefits of regulations ex-post. The Trump administration and new leadership at EPA have questioned the need for and effectiveness of regulations (e.g., Exec. Order No. 13771, 82 F.R. 9339, 2017). While ex-ante regulatory impact cost-benefit analyses are cited as evidence of their effectiveness, retrospective studies provide a critical data point as to the realized costs and benefits of regulations. To this end, our work provides an example of methods available to researchers that may be used to evaluate other important regulations.

The balance of this paper proceeds as follows. In Section 2, we provide background information on climate change, biofuel policies, the Renewable Fuel Standard, and the blend wall. In Sections 3, we describe the EPA's Regulatory Impact Analysis. We conclude with our lessons in Section 4.

2. Background: Policy Design and Implementation

2.1. Climate Change and Policy

Greenhouse gases in the earth's atmosphere play a pivotal role in keeping the planet warm enough for life to flourish. The primary greenhouse gas is carbon dioxide (CO_2), but others include methane, nitrous oxide, and fluorinated gases. The transportation sector is among the largest contributors to greenhouse gases in the United States, and most of those emissions are the direct result of burning fossil fuels (EPA, 2017). Due mostly to human activity, the earth's average temperature has risen by 0.85°C in the past century.

Two facts stand out in studies of the economic effects of climate warming. First, the average estimated effects are not catastrophic. The consensus estimate under "business as usual" conditions is that average temperature will increase by a further 3°C by 2100 and reduce world GDP by 4% (Nordhaus and Sztorc, 2013). The estimated mitigation costs of these damages are not crippling. The current figure used by U.S. regulators in is \$43 per metric ton of CO_2 (Auffhammer et al., 2016).[2] This translates roughly into a \$0.38/gal tax on gasoline and \$0.43/gal tax on diesel fuel, less than current average state and federal taxes.[3] Second, uncertainty of the climate sensitivity, the economic impacts of climate change, and irreversible tipping points increase the estimated social cost of carbon and the returns to early action (Lemoine, 2016; Lemoine and Traeger, 2016; Weitzman, 2011).

In response to these concerns, policymakers have enacted or considered a range of climate policies. The transportation sector is home to many of these policies. The focus on the sector is justified: in 2015 it was responsible for 27% of GHG emissions in the U.S., second only to electricity generation (EPA, 2017). These policies have targeted both the vehicles consumers drive and the fuel they use to power their vehicles (Knittel, 2012). However, first-best policies are rarely pursued in the sector, likely due to the feature that they would increase vehicle and fuel prices. Instead, most policies are intensity standards. For example, the Corporate Average Fuel Economy standards require increasing automobile manufacturers to meet increasing *average* fuel economy standards, and the Renewable Fuel Standard requires transportation fuels to contain an *average* minimum amount of biofuels. Both standards are enforced using tradeable credit systems that tax vehicles/fuels above the standard (i.e., low-mileage vehicles and gasoline) and subsidize vehicles/fuels below the standard (i.e., high-mileage vehicles and ethanol). Previous work has shown that these types of policies come at potentially large efficiency costs. For example, Holland et al. (2015) find that renewable energy mandates are two- to four-times more costly at achieving

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[2] Climate models used to calculate the social cost of carbon differ greatly in their representation of the climate, sectoral detail, damage functions, and discounting, and therefore yield different estimates of the social cost of carbon. Even when varying the discount rate alone, the range in the social cost of carbon is large, ranging from \$12 to \$117 per metric ton of CO_2 in 2015 (Environmental Protection Agency, 2015).

[3] According to the EIA one gallon of pure gasoline (diesel) contains around 19.64 (22.38) pounds of CO_2.

the same emissions reductions as a tax.

As governments continue to implement such policies, it is important to quantify their costs and benefits of these regulations. Federal Agencies have studied the ex-ante costs and benefits of large regulations since the Reagan administration, though federal agencies and the executive branch have only recently retrospective studies on the actual impacts of policies (Morgenstern, 2015). While challenging, ex-post evaluations can serve to improve and redesign the studied regulations, provide guidance on how to better anticipate issues that may arise with policies ex-ante, and inform the design and evaluation of future regulations.

2.2 Biofuel Policies: A Historical Perspective

Ethanol made from corn has a long history in the U.S. as a prospective motor fuel (Thome and Lin Lawell, 2017). In 1920, the U.S. Geological Survey estimated that petroleum production would peak within a few years (White, 1920). At the same time, U.S. agricultural prices declined as European agricultural production recovered from World War I. Lower prices motivated US farmers to look to alternative sources of demand for their crops.[4] The push for ethanol grew in the 1930s when the Great Depression brought further hardship to rural America. In the early days of the New Deal, members of the Farm Chemurgic Movement worked closely with the US Department of Agriculture (USDA) on a farm-relief program that would subsidize ethanol production from farm crops (Wright, 1993). However, by this time large new oil fields had been discovered in Texas, Oklahoma, and California. These discoveries led to high oil production and low prices. Ethanol was not price competitive and faded into the background until the oil shocks of the 1970s.

The first variant of an ethanol mandate entered the US Congress in 1978. Additional ethanol bills entered Congress in 1987, 1992, 2000, 2001, 2003, and 2004, where they consistently received strong support from the corn lobby.[5] The 1978 Gasohol Motor Fuel Act proposed that production of alcohol motor fuel supply at least 1 percent of US gasoline consumption by 1981, 5 percent by 1985, and 10 percent by 1990. This bill never became law, but the 1980 Energy Security Act (ESA) included a weaker version of the proposal. Rather than mandating ethanol production, the 1980 ESA directed the Departments of Energy and Agriculture to prepare and evaluate within the next year a plan "designed to achieve a level of alcohol production within

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[4] Newspaper articles expressing this expectation include "Big Future for Alcohol," *Los Angeles Times*, 11/2/1919; "What's Coming in Fuel Drama?" *Los Angeles Times*, 9/12/1920; "Auto Fuel Problem," *New York Times,* 4/27/1919; Alcohol as a Fuel," *New York Times,* 10/19/1919; "More Alcohol Wanted," *New York Times,* 2/13/1921; and "Ford Predicts Fuel from Vegetation," *New York Times,* 9/20/1925, among many others. Carolan (2009) studies peer-reviewed and popular press reports from this period and finds that alcohol fuel had strong support among scientists, automobile engineers, and farmers.

[5] Bills introduced in Congress: The Gasohol Motor Fuel Act of 1978 (S.2533), the Ethanol Motor Fuel Act of 1987 (H.R.2052, S.1304), Amendment to the Energy Policy Act of 1992 (H.AMDT.554), Renewable Fuels Acts of 2000 and 2001 (S.2503 and S.670.IS), and the Energy Policy Acts of 2003 and 2004 (H.R.4503, S.2095).

the United States equal to at least 10 percent of the level of gasoline consumption within the United States." However, the ensuing report concluded that this ethanol-use target, "though technologically attainable, is not economically feasible even under optimistic market scenarios" (USDA and USDOE, 1983). As a result, ethanol constituted less than one percent of finished motor gasoline in 1990.

An environmental benefit of ethanol gave the corn-ethanol industry a new argument with which to lobby for favorable legislation. The 1990 amendments to the Clean Air Act required that, in regions prone to poor air quality, oxygenate additives be blended into gasoline to make it burn more cleanly. Ethanol and methyl tertiary butyl ether (MTBE), a natural-gas derivative, were the leading contenders to fulfill the oxygenate requirement. Johnson and Libecap (2001) document the lobbying battle between advocates for ethanol and those for MTBE. Ethanol received some favorable treatment in the final legislation,[6] but MTBE became the dominant additive because it was less expensive. However, leaks in underground storage tanks caused MTBE to contaminate drinking water, and at least 25 states subsequently banned MTBE blending.

Without competition from MTBE, ethanol was able to cement its place as a fuel additive in the 2005 Energy Policy Act. This law included the first RFS that mandated four billion gallons (bgal) of ethanol use in 2006, rising gradually to 7.5 bgal by 2012. This 2012 quantity corresponded to 5 percent of projected domestic gasoline use. Thus, it represented a small expansion of the proportion of oxygenates in gasoline. In 2005, US oxygenate production (ethanol and MTBE combined) totaled 4.6 percent of finished motor gasoline supplied. Legislation to increase the RFS entered Congress even before the 2005 Energy Policy Act had passed, and more bills followed in 2006.[7] These proposals led to the current RFS.

2.3 The Renewable Fuel Standard: Policy Background

The Energy Independence and Security Act (EISA) of 2007 created the RFS in its current form. The law significantly increased the mandates set in 2005, expanding the ultimate goal to 36 billion gallons (bgal) per year by 2022. The Environmental Protection Agency (EPA) administers the program, and although the EISA provides specific biofuel consumption targets, the EPA has relatively broad discretion in setting the mandates each year (Bracmort, 2017). Figure 1 graphs RFS statutory mandates for each of the four biofuel categories included in the mandates. The categories differ with respect to their estimated reductions in lifecycle greenhouse gas emissions relative to gasoline and diesel, and are (i) cellulosic biofuel, which can be produced from wood, grasses, or the inedible parts of plants and must generate a 60 percent reduction in emissions to qualify under the program; (ii) biomass-based diesel, typically produced from oilseeds such as soybeans or canola, tallow or used cooking oil; (iii) other advanced biofuel that, along with biodiesel must generate 50 percent emissions reductions; and (iv) conventional

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[6] Ethanol was allowed a 1 lb. waiver in the Reid Vapor Pressure requirement.

[7] 20/20 Biofuels Challenge Act of 2005 (S.1609), BOLD Energy Act of 2006 (S.2571.IS, H.R.5331.IH).

biofuel, which is mostly corn ethanol, and must generate at least 20 percent emissions reductions.

Both the level of the mandates and the source of biofuels were initially modest. In 2008 the mandates required blending only nine bgals of corn ethanol into the fuel supply, 6.5% of U.S. gasoline consumption that year. Both the level and source of the mandates increase aggressively in later years. The 2016 statutory mandates were 22.25 bgals, just under 16% of U.S. gasoline consumption that year. Of those, 4.25 bgals were to be derived from cellulosic biofuel, a fuel that was not commercially available when the law was passed in 2007. By 2022, the overall mandate increased to 36 bgals, of which 16 bgals were supposed to come from cellulosic biofuel.

The EPA administers the RFS through a system of tradable credits, known as Renewable Identification Numbers (RINs). Every domestically blended gallon of biofuel generates a RIN.[8] Obligated parties, oil refiners, and importers must turn into the EPA a certain number of RINs for each gallon of petroleum fuel they sell. For example, in 2016, they must turn in 0.101 RINs for each gallon of gasoline of diesel they sell. These RINs must include at least 0.0201 advanced biofuel RINs. In turn, the advanced RINs must include at least 0.0159 biodiesel RINs and at least 0.00128 cellulosic RINs. RINs are typically generated by blenders, which are firms that blend wholesale fuels for sale to gas stations. Thus, for an oil refiner to comply with the RFS, it needs to purchase RINs from a blender. Some oil companies have blending operations, so they do not have to buy RINs from another firm, but there are enough obligated parties without blending operations to ensure that there is a robust market for RINs. The extra cost of using biofuel in place of petroleum determines the price of RINs. The blender will use the proceeds from selling RINs to help pay for biofuel (if it is priced higher than petroleum) or to pay distribution costs (if blended fuel is more costly to deliver to consumers than pure petroleum).

2.3. Implementation Challenges to Date: The Blend Wall and the (Non)Emergence of a Cellulosic Biofuel Industry

In 2013, the mandates required more biofuel than the fuel industry could easily absorb or produce. Two issues have come to the fore. First, the liquid cellulosic biofuel industry has yet to produce consistent, commercial scale volumes. Second, the mandates now require more biofuel than 10% of regular gasoline, the maximum amount that regular gasoline can contain. Breaching this barrier, known as the blend wall, requires either expanded consumption of biodiesel, which does not face any relevant blend restrictions or increasing sales of a high-ethanol blend of gasoline known as E85, which contains up to 85% ethanol. E85 can only be used in flex-fuel cars and requires fuel station owners to install dedicated fuel pumps.[9]

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[8] A gallon of biodiesel actually generates 1.5 RINs because biodiesel contains 50% more energy than ethanol.

[9] A third possibility is E15, which is a blend of 15% ethanol and 85% gasoline. E15 is approved for use in all cars built since 2001, but it has not been adopted by the industry because it requires new tanks and dispensers to be installed at gas stations and it fails to meet environmental requirements for summer gasoline (the Reid vapor pressure requirement).

Figure 2 illustrates both of these issues. Figure 2(a) shows the projected liquid cellulosic biofuel production volumes from the EPA's yearly Final Rules for 2011 to 2017. The volumes come from the EPA's annual assessment of the industry's potential production capabilities. Two features stand out from the figure. First, the volumes are far below the statutory mandates. Second, both the expected production levels and high-end projection estimates vary substantially from year-to-year as the industry has struggled to produce. For example, the agency was optimistic that the industry would produce 8.65 mgals in 2012 but reduced their estimated production for 2013 to 4 mgals after a disappointing year. A similar story occurs with the 2014-2016 final rule projections and the 2017 projections.

The slow growth is not due to lack of investment or effort. The RFS spurred significant investment in research and development of cellulosic liquid fuels. In 2007, the US Department of Energy Biomass Program provided \$385m to support six large-scale cellulosic ethanol plants. Several hundred million dollars of Department of Energy money followed in later years to support cellulosic research and development. The major oil companies invested more than a billion dollars in biofuels research, much of it in partnership with universities and biofuel companies (Sims et al., 2010). These companies have mostly divested from cellulosic biofuels, but research continues in universities, institutes, and biofuels firms. Nonetheless, large-scale production of liquid fuels from cellulosic materials remains cost prohibitive.

Figure 2(b) shows that the market first hit the blend wall in 2010. In 2013, mandated ethanol use was above the blend wall even without the cellulosic component. The EPA would either have to force the industry 'break' the blend wall or waive part of the conventional biofuel mandate. However, the availability of both FFVs and E85 stations limit ethanol consumption beyond the blend wall. About 6% of registered vehicles in the U.S. have flex-fuel capability, but less than 2 percent of gas stations sell E85.[10] Private market investment in E85 infrastructure has been slow, but in early 2016, the USDA spent \$100 million to fund the installation of E85 fuel dispensers with the goal of doubling E85 retail capacity. Figure 2(c) graphs the number of E85 stations and vehicle models that are FFVs over time. The number of stations offering E85 has shown a steady, near-linear growth trend over time, and the fuel is now offered at more than 3,000 locations. However, the number of vehicle models that are offered as FFVs, while increasing through 2014, as decreased in recent years. While biodiesel can help satisfy some of the gap between the blend wall and the mandated ethanol use, both the production capacity and costs limit the viability of this compliance option in the long run.

In response, the EPA has waived most of the cellulosic mandate since 2011 and reduced the overall mandates for 2013-2016. Figure 3(a) graphs the resulting volumes from the EPA's final rules. For example, the EPA set 2016 volumes at 18.11 bgal of biofuel, of which no more than 14.5 bgals can be corn ethanol. The 0.7 bgal gap between the mandated volume and the blend wall is most likely to be met by increased biodiesel use, but the gap is large enough that some increase in E85 sales may be required.

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[10] http://www.afdc.energy.gov/locator/stations/

The mandate cuts have not gone smoothly. After proposing substantial cuts to the 2014 mandates in November 2013, the EPA did not release a final ruling for the 2014-2016 mandates until November 2015. There was significant uncertainty over that period as the whether, and the extent to which, the mandates would be above the blend wall. Similar issues arose in 2016 when the Agency proposed and finalized the 2017 mandates. The combination of expensive compliance options beyond the blend wall and uncertainty surrounding the level of the mandates has led to high volatility in RINs markets, graphed in Figure 3(b). RINs prices reflect the necessary subsidy for the marginal biofuel to meet the RFS mandates. As the mandates began pushing above the blend wall in 2013, the subsidy increased substantially. However, as soon as the EPA first suggested it would relax the mandates in 2014 and beyond, prices plummeted. RINs prices have since increased or decreased sharply with every announcement related to the mandates with few exceptions. This volatility is not costless. Lade, Lin Lawell, and Smith (2017) show that commodity prices related to the marginal biofuel as well as stock prices of advanced biofuel firms were affected by the large drop in RINs prices in 2013.

Looking ahead, the EPA may permanently reduce the mandate in the coming years. EISA requires that the EPA modify the required volumes for all years if it waives at least 20% of the mandated volume for two consecutive years. The 2016 volumes were 18.6% below the statute, and the 2017 volumes were 19.7% below the statute. The soonest the EPA could reset the volume of total renewable fuel would be for the 2019 and later compliance years. Absent legislative action, EISA also requires the EPA administrator to set mandates for beyond 2022. Rulemaking for major regulations typically takes several years. As a result, the EPA is likely to take up consideration of post-2022 mandates in futures years. Both the reset and determination of the post-2022 mandates will require analysis by EPA staff to determine the costs, benefits, and feasibility of proposed actions. The next section takes a look back at the analysis that went into the initial regulatory impact analysis by the EPA, with an eye towards identifying methods to better estimate impacts of future mandates to help guide these processes.

3. EPA's Regulatory Impact Analysis

In February 2010, the EPA released an extensive Regulatory Impact Analysis (RIA) of the expected benefits and costs of the RFS (EPA 2010). RIAs are meant to serve as documents outlining agency's best projections on the market impacts, costs, and benefits of regulations before implementation. The EPA's RIA on the RFS primarily focused on long-run outcomes and found large net benefits from the RFS2 in 2022. In its summary of findings, the EPA estimated net benefits ranging from \$12.8 to \$25.97 billion per year. The benefits come from the sum of estimated fuel market benefits as well as non-market benefits to energy security, health, and GHG emissions reductions attributed to the policy in that year. The RIA presents each component as a single number, except for the GHG emissions benefits for which the EPA gives a range depending on the social cost of carbon (SCC) used.

The largest share of benefits of the rule was found in fuel markets, contributing $11.8 billion per year in savings. These constitute nearly all the low-SCC case benefits and just under half of the benefits in the high-SCC case. In this section, we focus on two key aspects of the RIA that led to these estimates. First, we discuss the EPA's use of a single and limited forecast of future energy prices and biofuel production costs. Second, we discuss the EPA's in attention to potential delays in production and infrastructure development.[11]

3.1. Fuel Market Impacts: Addressing Price Uncertainty

A complete assessment of fuel market costs would take into consideration price changes due to the policy, the associated deadweight loss to consumers, and the corresponding loss in producer surplus to gasoline producers and the gain in producer surplus to biofuel producers. Rather than conducting a welfare analysis, RIAs typically focus on cost-benefit analyses. To calculate the fuel market impacts of the policy, the Agency compared expenditures across two baseline BAU and three RFS scenarios. Thus, the Agency's assessment of fuel market impacts came down to its assumptions on future fuel prices and demand.

Its first simplifying assumption was to hold demand for vehicle miles traveled constant. The RIA then relied on price projections from the Energy Information Administration's (EIA) 2009 Annual Energy Outlook and the FASOM model, a dynamic nonlinear programming model of the US agricultural sector, to project future oil and biofuel prices, respectively. This approach and the resulting net positive benefits immediately bring to bear two important conceptual flaws of the RIA. First, estimating that the RFS2 dramatically reduces fuel market prices is inconsistent with the notion that a binding regulation increased total costs in a market. Second, by considering a single reference case, the RIA ignored the inherent unpredictability of energy prices.

Figures 4(a) and 4(b) illustrate this second point. Figure 4(a) contrasts historical oil prices from 2000-2016 with the EIA's projections from its Annual Energy Outlook in 2009 and 2017, including both the baseline case as well as a high- and low-oil-price scenarios. Although oil prices followed the 2009 projects for the first three years of the projects rather closely, prices plummeted and fell below even the EIA's low-oil-price scenario by 2015. The range of the EIA's projections is even wider in the 2017 AEO, highlighting the increasing degree of uncertainty in oil markets. In its RIA, the EPA considered only the baseline 2009 projections. Figure 4(b) graphs the resulting gasoline and ethanol price projections used in the RIA and contrasts them with realized wholesale gasoline and ethanol prices. The EPA used a wholesale gas price of $3.42 per gallon and an ethanol price of $1.716 per gallon.[12] However, observed ethanol prices ranged from $1.42 to $3.15 per gallon from 2007 to 2016, whereas gasoline prices ranged between $1.02 and $3.37 per gallon. Moreover, the two prices were positively correlated, with high ethanol prices typically corresponding with high gas prices.

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[11] Lade, Lin Lawell, and Smith (2015) provide a more detailed discussion of the RIA.

[12] In fact, the EPA reported three cases for ethanol, with a narrow and precise range of $1.688 to $1.732.

Our summary over-simplifies the extensive work that went into projecting the long-run costs of the policy. Extensive analysis went into producing the document. We identified over 20 models used in the RIA to calculate fuel, agricultural, greenhouse gas, and health impacts of the RFS. For example, the RIA presents the estimated change in oil refinery production of 47 different products over five regions of the US. Such detailed output creates the impression of rigor and precision, when in fact, it reflects numerous modeling assumptions made about the relevant economic systems.

Moreover, the complexity of the models and the time required to run them precluded proper accounting of uncertainty and consideration of alternative future market outcomes. Simplifying the economic models underlying the analysis would allow for more transparent review of the potential long-run costs and benefits of the regulation. For example, the Agency could bound the costs and benefits of the policies using high- and low-oil-price scenarios provided by the EIA along with an 'optimistic' and 'pessimist' biofuel production cost scenario. Alternatively, the agency could represent break-even relationships between, for example, ethanol and gasoline prices to account for the range of prices of each over which the policy increases or decreases average fuel market expenditures.[13]

3.2. Fuel Market Impacts: Demand and Technology Uncertainty

By focusing on long-run outcomes, the EPA was unable to adequately address potential transitional costs and barriers to complying with the RFS in interim years. The two most significant obstacles that have affected the program were the blend wall and the development of a large advanced biofuel industry. While EISA explicitly gave the EPA waiver authority to address potential delays in the development of the cellulosic biofuel industry, the legislation gave the EPA much less apparent authority with regards to its ability to address potential infrastructure and demand-side constraints. Here, we consider the treatment of the blend wall in the RIA, discuss the implications of the lack of attention given towards it, and describe potential methods for incorporating such considerations into future analyses.

The RFS and corresponding RIA were written when the economy was expanding, and gasoline demand was expected to keep rising. The 2006 EIA projection placed the blend wall at 15.9 bgal in 2013, rising to 16.5 bgal in 2016. The corn-ethanol component of the mandate plateaus at 15 bgal, so if the EIA projection had come true, we never would have hit the blend wall with conventional ethanol. Only the cellulosic component would have required breaching the blend wall. However, forecasting the blend wall proved to be nearly as challenging as forecasting oil prices. Figure 4(c) plots historical level of 10% of gasoline consumption in the U.S. and contrasts it again with projected consumption from the 2009 and 2017 AEO. The actual blend wall initially dipped well below the EIA's projections from 2011 to 2015 before increasing back

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[13] See Figure 9 in Lade, Lin Lawell, and Smith (2015) for an example of such an exercise.

to the levels from 2009 by 2015. The actual blend wall was 13.6 bgal in 2013 and around 14.3 bgals in 2016. Thus, rather than being a billion gallons below the blend wall, the 2016 mandate was set at more than a billion gallons above the blend wall, increasing the need for more expensive compliance options sooner than originally anticipated. While the decrease in gasoline use in the U.S. was more dramatic than manner industry analysts predicted back in 2007, it was not altogether a shock. In fact, the 2009 AEO predicted that motor gasoline use in 2016 could range between 12.5 and 15 billion gallons. Also, while the decrease in gas use brought the blend wall to the fore earlier than originally anticipated, it was inevitable that the barrier would have to be overcome. For 2017 and beyond, the EIA projections largely reflect expectations of decreasing gasoline use in the future. Such a development would only place greater stress on demand-side constraints to increasing biofuel use.

Given this, the lack of attention given in the RIA to the likelihood that consumers and fuel providers would struggle to overcome this barrier is surprising. Moreover, explicit consideration of the constraints would have revealed the inherent costly nature of the mandates beyond the blend wall, highlighting potential issues with the policy's design long before the mandates reached such a level. To this end, in addition to considering a variety of long-run scenarios, the interim experience of the RFS to date suggests that considering short- to medium-term scenarios with and without transitional barriers such as the blend wall would publicly highlight potential design flaws in policy. Thus, to the same extent that policymakers 'stress-test' banks in the post-Dodd-Frank era, climate policies that mandate substantial changes in markets should stress test policies ex-ante in order reveal potential implementation issues and policy design flaws. While it is impossible to consider all possible barriers to successful implementation of policy, stress-testing based on known issues well in advance of them binding such as along supply and demand constraints could potentially serve as a valuable exercise in ex-ante analyses.

4. Lessons from the RFS Experience

The RFS has transformed the fuel sector in the U.S. and abroad. Nearly all gasoline U.S. consumers use now contains 10% ethanol (EIA, 2016). In addition, the domestic biofuel industry has grown exponentially and, in addition to supplying over 10% of the domestic fuel market, is a major exporter of ethanol and biodiesel to international markets. Despite these successes from a programmatic perspective, the policy has hit some roadblocks that have sidetracked it. Many of these issues were known well in advance of their coming to the fore. We believe several features of the policy's design in the enacting legislation contributed to these problems. Also, the manner in which the ex-ante analysis of the policy's impacts likely contributed to the delayed reaction to these (ex-post) obvious problems.

A Google Scholar search for the phrase "climate policy" returns 130,000 results. Included in these thousands of papers are plenty of recommendations for designing climate policy. These recommendations include important points such as (i) the least expensive policy would be to put a price on carbon through a carbon tax or a cap-and-trade program; (ii) research and development into clean energy and carbon sequestration technologies is imperative; and (iii) carbon emissions represent a global externality, so coordinating policy across countries is vital. Rather than reiterating these well- established points, we focus on the lessons we can draw from eight years of the RFS, which is a centerpiece of US climate policy.

To this end, we conclude by drawing from our retrospective study of the policy and its RIA to provide four overarching recommendations that, in retrospect, would have improved the policy and its implementation. The first two recommendations pertain specifically to the EPA's implementation of the policy and are meant to improve future rulemaking and regulatory impact analyses under the RFS and similar policies. The second two pertain to design of the RFS in its enacting legislation and is meant to improve the design of future climate policies and, potentially, future legislative revisions to the policy.

4.1. Incorporate uncertainty into rulemakings.

Uncertainty is everywhere. Climate scientists are uncertain about how much warming will occur. Economists estimate the effects of climate change using imperfect models with parameters over which they are uncertain. Prognosticators are uncertain about what new modes of transportation, new fuel technologies, new sources of renewable and fossil fuels, and new carbon sequestration technologies will emerge. Forecasters are uncertain about future fuel prices. In response, policymakers and regulators should make, implement, and analyze policy with a view towards what might happen, rather than a projection of what will happen. This is particularly relevant with regards to climate policies that call for substantial transformations to occur in markets.

Several examples in the RFS legislation and implementation demonstrate that uncertainty has not been taken seriously. The blend wall and lack of cellulosic constraints would have been more transparent if the regulatory impact analysis had incorporated uncertainty explicitly. Also, fuel prices are notoriously difficult to forecast, particularly decades out. Explicit consideration of a variety of outcomes ex-ante would allow for more transparent analyses with regards to market impacts of policy. Such studies should consider both short- to medium-term compliance scenarios that explicitly model binding transitional constraints, as well as consider long-run scenarios that allow for a range of long-run prices and production costs.

4.2. Implement multi-year rules

The RFS legislation specifies biofuel use for each year. To implement the mandate, the RFS charges the EPA with converting the volume standard to a rate standard, and the legislation specifies a formula and a deadline by which to apply it. While there is little discretion with regards to the calculation, the legislation includes the following clause: "EPA may waive the statutory volume in whole or in part if implementation would severely harm the economy or environment of a State, region, or the United States, or if there is an inadequate domestic supply." The discretion allowed in this clause, as well as the potential for industry to lobby and request waivers from the mandate as a result of it, have been a large contributor to the delays in the EPA releasing timely rules to date. Policy can be undermined by political forces, rent-seeking behavior by regulated parties, and legal challenges if the regulating agency has the discretion to adjust the policy stringency repeatedly. For example, when the technology and infrastructure constraints on RFS compliance began to bind in 2013, the Environmental Protection Agency (EPA) initially deferred decisions about whether to enforce the mandate and eventually proposed future cuts, thus undermining the RFS.

Requiring the EPA to make multi-year rules rather than annual rulemaking would allow for longer periods between major regulatory decisions and send greater certainty to markets. The long delays in finalizing percentage standards left the industry in an uncertain state. Investments in E85 infrastructure at this time would have made it possible to deliver more E85 to consumers and so would have lowered marginal compliance costs. However, this investment has not yet happened. One problem with the uncertainty created by delays in agency decisions is that it deters investment and thereby undermines the statute. The EPA is far from the only Agency that has been granted discretionary power by a piece of legislation in recent years. The Affordable Care Act and the Dodd–Frank financial reform act both charged agencies with implementing vaguely written laws, giving industry lobbies the opportunity to drive policy in a non-transparent way.

4.3. Tie waiver authority to compliance costs

One outcome of incorporating uncertainty into policy is the acknowledgment of the value of cost containment mechanisms such as a price ceiling on compliance credits. Quantity-based mechanisms under fuel mandates leave policies susceptible to significant increases in current compliance costs because of expected future technological and economic constraints that limit the feasibility of substantially increasing renewable energy production. A price stability mechanism that acted as a price ceiling on compliance credits would retain the incentive for firms to invest in developing the new technologies required for future compliance.

The enacting legislation gives the EPA authority to waive all or part of the mandates if they cause "severe economic harm." The policy's experience to date strongly suggests that this guidance is too vague. It has produced challenges that have served only to delay rulemaking. If the legislation desired such a clause, then it should have taken the form of a price cap on RIN. If costs of compliance exceed the cap, then firms are not forced to comply. Rather than using biofuel at RIN prices above the cap, obligated parties could purchase RINS from the EPA at the cap price. This adjustment would remove EPA discretion and thus eliminate the ability for industries to lobby the agency for favorable treatment.

Thus, rather than discretionary waiver authority, the RFS should have tied waivers to compliance costs, for example via a RIN price cap. If RIN prices were to rise to the cap, then allow obligated parties to purchase RINs from the EPA at the cap price rather than requiring additional biofuel. By specifying clear rules and formulas in legislation, we place the policy burden on Congress rather than the regulating agency. This is especially important when the agency has to mediate between competing industries, none of which has incentives aligned with the EPA, as in the RFS.

4.4. Fund research and development of new technologies rather than mandating them.

To date, commercial production of cellulosic biofuel has proven elusive. The original expectation was that the biofuel industry would meet the cellulosic mandate with liquid fuels, namely diesel and ethanol made from cellulosic material. The EPA's RIA projected that 69% of cellulosic biofuel would be cellulosic diesel and the remaining 31% would be cellulosic ethanol.[14] However, less than 2% of the cellulosic biofuel RINs generated in 2015 came from these sources combined. The remainder was renewable natural gas (biogas) generated from landfills and other similar facilities, highlighting the uncertain nature of technological development.[15]

The RFS has an escape valve that has allowed the EPA to waive the cellulosic mandate due to insufficient supply. Although it mitigates the potential for fraud and evasion, the escape valve also discourages private industry investment in research and development. If no one invests in the technology, then there will be no supply and the EPA will waive the mandate. The mandate was not a credible threat. The way the RFS is implemented also limits its effectiveness in spurring the desired amount of investment. In principle, a firm that develops a successful cellulosic biofuel technology would be able to generate a stream of valuable RINs that could be sold to recoup the costs of research and development. In practice, once a firm develops a new technology, it is unlikely to be able to monopolize it. New firms will enter and produce cellulosic biofuel at a low marginal cost, thereby lowering the price of RINS. So, unless firms believe that the patent system would allow them to recoup their investment cost, they will underinvest in the new technology even in the presence of a mandate (Clancy and Moschini, 2015).

Researchers and private industry may well produce a breakthrough that will make cellulosic biofuels feasible. However, mandates have proven to be an inefficient and ineffective method for forcing technological progress, particularly in the fuel industry. Thus, policymakers

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[14] Table 1.2-3 on page 70.

[15] The high percentage contribution of biogas to the cellulosic mandate was enabled by a rule proposed by EPA in June 2013 and finalized in July 2014. This rule stated that "biogas generated by landfills, municipal wastewater treatment facility digesters, agricultural digesters, and separated MSW digesters are predominantly cellulosic in origin," so it could be counted towards the cellulosic mandate. Prior to the rule, these fuels had qualified as advanced biofuels for RFS compliance. These fuels are used in natural gas powered vehicles.

should fund research and development in cellulosic biofuel technology directly, rather than indirectly through a cellulosic mandate. Even in the presence of an efficient carbon tax, firms may underinvest in research and development because potential spillovers (positive externalities) from new technologies or the inadequacies of patent law would preclude them from extracting the full benefits of their investments. These points suggest that subsidies for basic research into climate change mitigation technologies are a critical component of efficient and effective climate policy.

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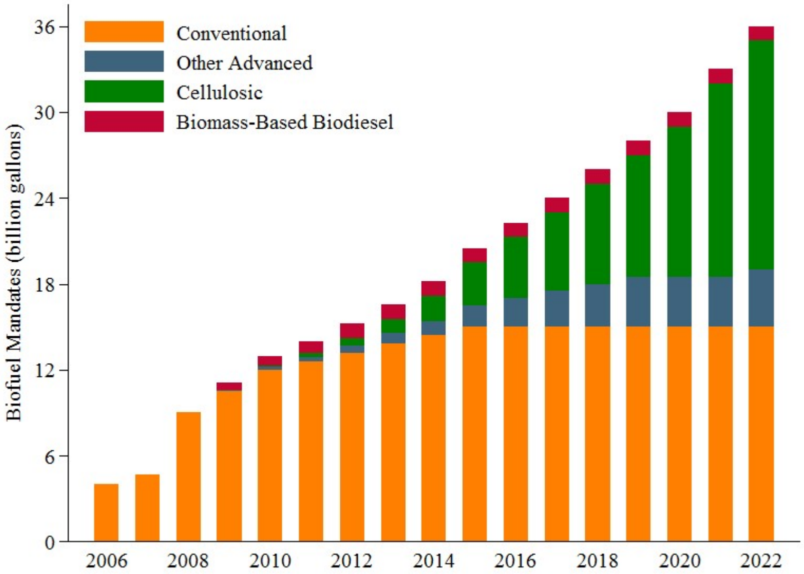
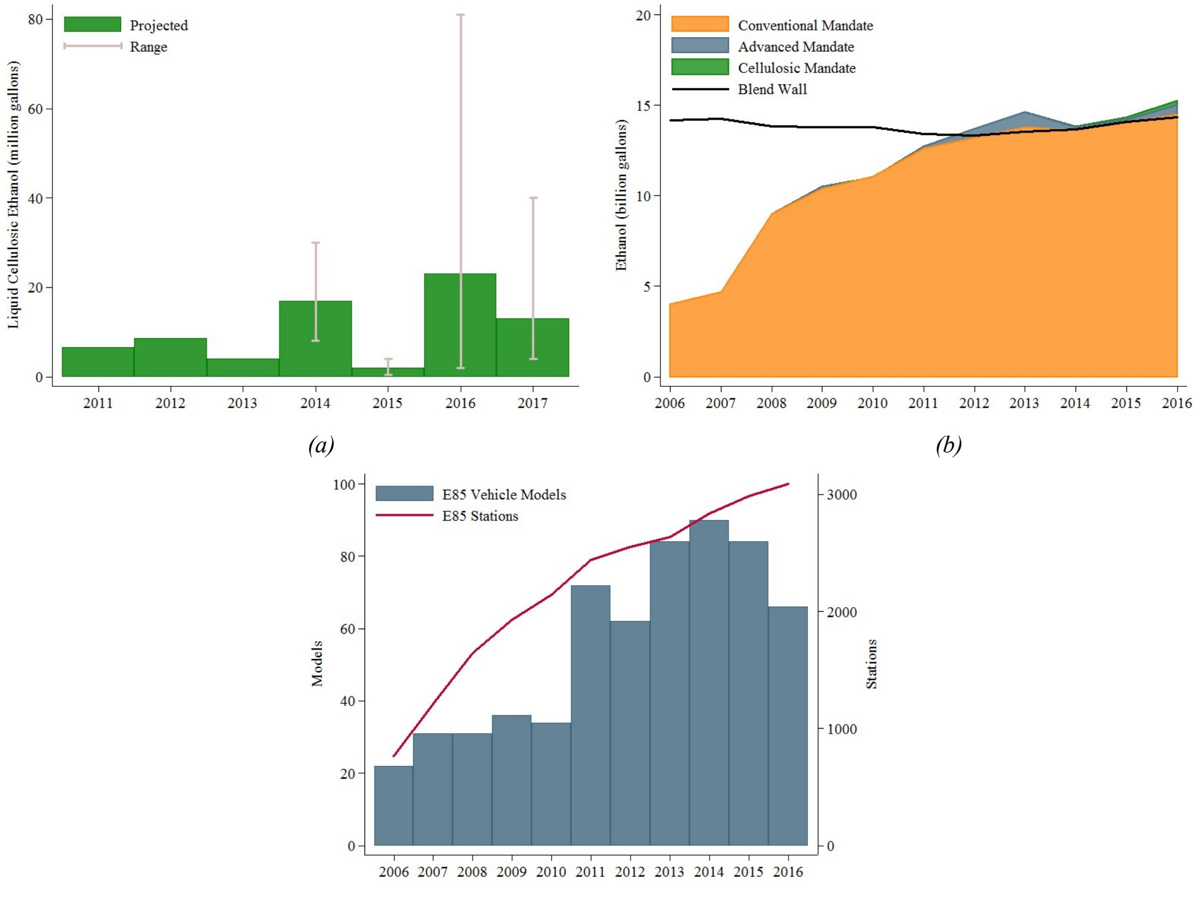


Figure 1: *RFS Statutory Mandates*
(Source: EPA)

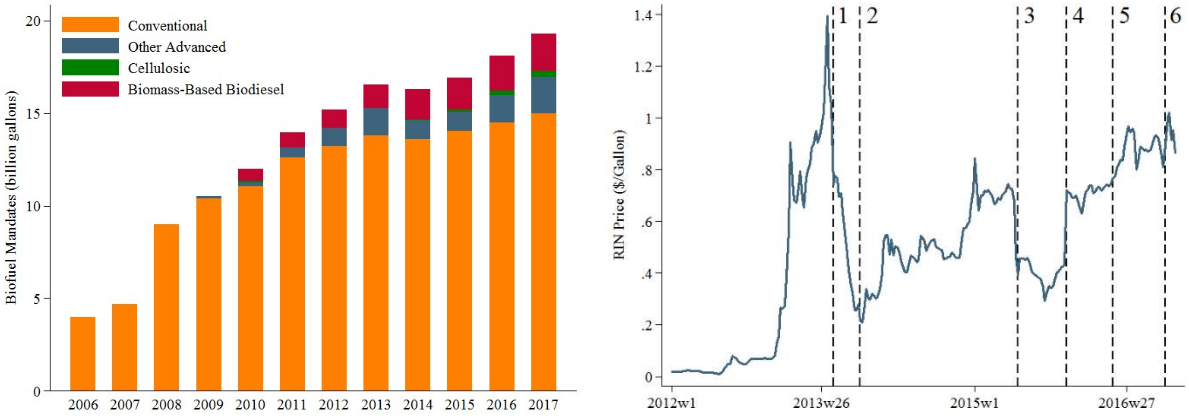


(a)

(b)

(c)

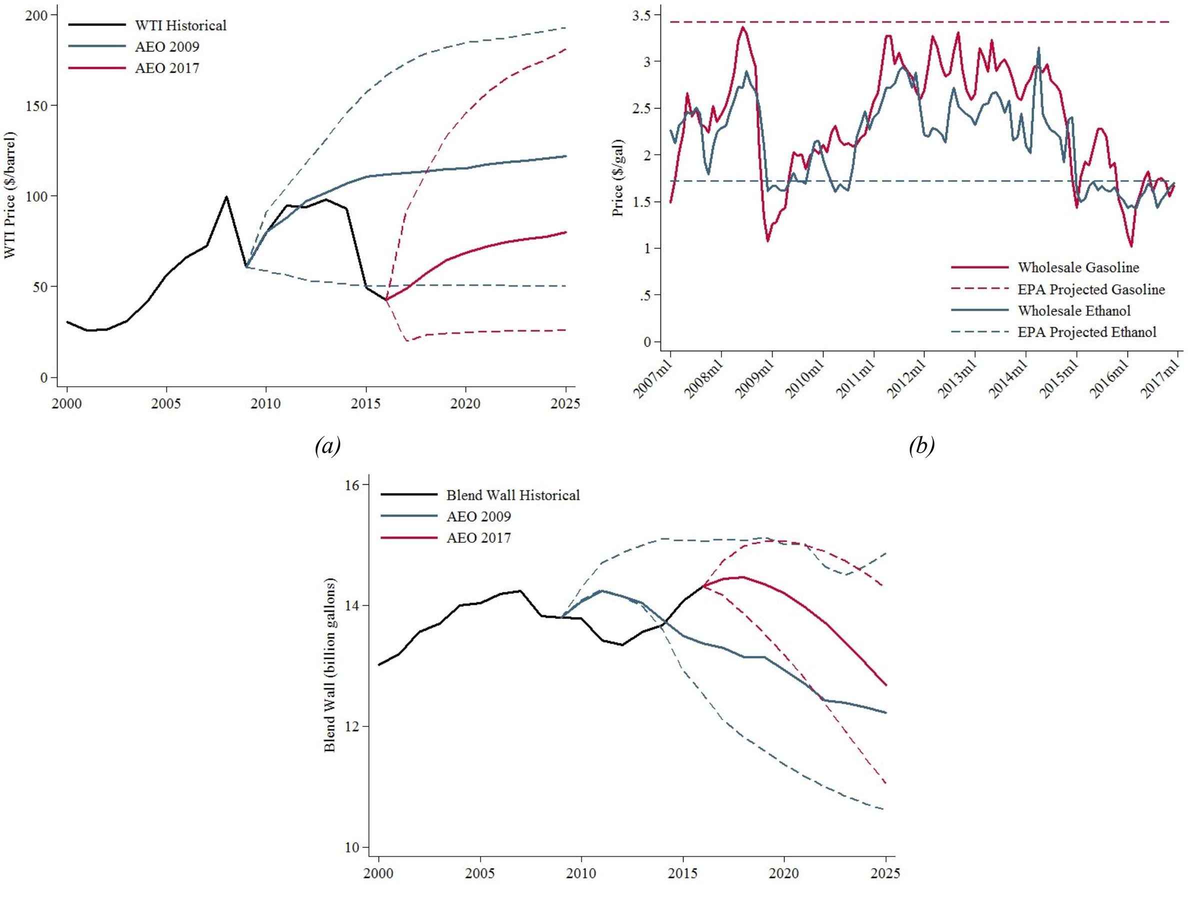
Figure 2: *Cellulosic Production, the Blend Wall, and E85 Vehicle and Fueling Infrastructure (Source: EPA, EIA, DOE AFDC)*



(a) *(b)*

Figure 3: *EPA Final Rule Mandates and Conventional (D6) RIN Prices. In Figure 3(b), the vertical lines correspond to the following EPA final and proposed rule release dates: (1) 2013 Final Rule, (2) 2014 Proposed Rule; (3) 2014-2016 Proposed Rule; (4) 2014-2016 Final Rule; (5) 2017 Proposed Rule; and (6) 2017 Final Rule.*

(Source: EPA, EcoEngineers)



(a) (b)

(c)

Figure 4: Historical and Projected Oil Prices, Gasoline and Ethanol Prices, and the Blend Wall (Sources: EIA, Nebraska Energy Office)