Designing Climate Policy: Lessons from the Renewable Fuel Standard and the Blend Wall*

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Abstract

Many policies mandate renewable energy production to combat global climate change. These policies often differ significantly from first-best policy prescriptions. Among the largest renewable energy mandates enacted to date is the Renewable Fuel Standard (RFS), which mandates biofuel consumption far beyond what is feasible with current technology and infrastructure. In this article, we critically review the methods used by the Environmental Protection Agency to project near- and long-term compliance costs under the RFS, and draw lessons from the RFS experience to date that would improve 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. (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 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.

Key words: climate policy, mandates, renewable fuel standard

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Introduction

The year 2016 was the warmest 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 and impact energy demand in two ways. First, they raise fuel costs and reduce energy demand. Second, they reduce the relative price of low-carbon intensive fuels, making renewable fuels more competitive in the marketplace. In addition to pricing externalities, many economists recommend subsidizing basic research into climate change mitigation technologies because private research and development (R&D) may be lower than the socially optimal amount. Firms may under-invest in R&D because there are positive spillovers - when a company invents a new technology, other firms may free ride on or 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, most governments have enacted renewable fuel mandates that implicitly subsidize renewable fuels. For example, the European Union has a 10% biofuel consumption target by 2020, with an additional requirement that fuel providers reduce the greenhouse gas intensity of their fuels by 6%. The Low Carbon Fuel Standard in California establishes an aggressive carbon intensity standard for fuels sold in the state, a 10% reduction in the average carbon intensity of fuel by 2020. These policies have two disadvantages relative to first best. First, renewable fuel mandates and subsidies distort supply and demand decisions since both the level and the relative price of fuels will differ from first best (Holland et al., 2009; Lapan and Moschini, 2012). Second, the implicit subsidy for renewable fuels under a mandate is endogenous to the policy's stringency and not to the degree of innovation. Therefore, the rewards to innovation differ from, and likely under-incentivize, investment in new technologies (Clancy and Moschini, 2017).

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 is, technologically feasible. Complying with the RFS requires substantial investments in (i) the development, commercialization, and production of cellulosic biofuels; (ii) biofuel production and blending capabilities by upstream and midstream fuel providers; and (iii) alternative fuel vehicles by consumers. To date, the policy has struggled to incentivize large-scale production of cellulosic ethanol, and has faced significant challenges related to the latter two forms of investment since 2013.

In this article, we critically review the design, evaluation, and implementation of the RFS. We begin with a review of the program, highlighting its key features as passed by Congress and the challenges it has faced in meetings its standards to date. Second, we critically review the methods used to evaluate the policy 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. The purpose of this manuscript is to inform both future RFS rulemakings and the design of other climate policies. We, therefore, follow the spirit of recent calls in the literature for more retrospective studies of policies (Cropper et al., 2017). These studies are important to both understand the effectiveness of existing rules and regulations, as well as to improve the ex-ante analysis and design of future policies.

Our review is timely for two reasons. First, by adjusting the 2014 to 2017 standards, the EPA has triggered a provision in 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 that includes an analysis of the fuel industry's production capabilities and the policy's environmental impact (Bracmort, 2017). Second, the statutory mandates are only specified through 2022. Absent future legislation, the law requires the EPA to set mandates for 2023 and beyond. Both the reset and process of setting 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.

The balance of the article proceeds as follows. We first provide background information on climate change, biofuel policies, the Renewable Fuel Standard, and the blend wall. We then describe the EPA's Regulatory Impact Analysis. We conclude with our lessons.

Background: Policy Design and Implementation

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. However, greenhouse gas (GHG) emissions have increased precipitously since the industrial revolution due to human activity, increasing global temperatures. Two facts stand out in studies of the economic effects of climate warming. First, the average estimated costs of climate change mitigation 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 current consensus value of these damages is $43 per metric ton of CO_2 (Auffhammer et al., 2016).[1] Incorporating these damages into fuel prices would translate roughly to increasing gasoline prices by $0.38/gal and diesel fuel prices by $0.43/gal. This is less than most current state and federal fuel taxes.[2] 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 variety 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 (Knittel, 2012). First-best policies are rarely pursued in the sector. Instead, most policies are intensity standards. For example, the Corporate Average Fuel Economy standards require automobile manufacturers to meet *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 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 the same emissions reductions as a fuel tax.

As governments continue to implement such policies, it is important to quantify their costs and benefits. Federal Agencies have studied ex-ante costs and benefits of large regulations since the Reagan administration, but have only recently encouraged retrospective studies (Morgenstern, 2015). While challenging, ex-post evaluations can serve as a means to improve and redesign 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.

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 output recovered after World War I. Lower prices motivated US farmers to look to alternative sources of demand for their crops.[3] 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. Congress introduced additional ethanol bills in 1987, 1992, 2000, 2001, 2003, and 2004, all of which consistently received strong support from the corn lobby.[4] 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 a plan "designed to achieve a level of alcohol production within 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,[5] 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. The 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.[6] These proposals led to the current RFS.

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 bgals per year by 2022. In addition to promoting production of lower-carbon fuels to address climate change concerns, the policy was motivated by a desire to enhance rural incomes and increase energy independence. 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 plots RFS statutory mandates for each of the four biofuel categories. The categories differ with respect to their estimated reductions in lifecycle GHG 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 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 modest initially. 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 mandate levels and source of biofuels are ambitious 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.[7] Obligated parties, oil refiners and fuel importers, must turn into the EPA a certain number of RINs for each gallon of petroleum fuel they sell. For example, in 2016 obligated parties had to turn in 10.1 RINs for every one hundred gallon of gasoline or diesel that they sold. This RIN bundle had to include at least 2.01 advanced biofuel RINs. In turn, the advanced RIN bundle had to include at least 1.59 biodiesel RINs and at least 0.128 cellulosic RINs. RINs are typically generated 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 downstream blender. Some oil companies own blending operations, so they do not have to buy RINs from another firm. However, 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).

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

By 2013, the statutory 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, referred to 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.[8] Pouliot and Babcock (2016) show that, while feasible, meeting statutory mandates in the presence of the blend wall may come at a considerable cost, particularly to motorists.

Figure 2 illustrates both 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. First, the volumes are far below the statutory mandates shown in Figure 1. 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 estimate to 4 mgals in 2013 after a disappointing year. A similar situation arose between 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 liquid cellulosic fuels. In 2007, the US Department of Energy Biomass Program provided $385 million 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. Major oil companies have invested more than a billion dollars in biofuels research, much of it in partnership with universities and biofuel companies (Sims et al., 2010). While oil companies have now mostly divested from cellulosic biofuels, research continues at universities, private 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. By 2013, statutory mandates for ethanol use were above the blend wall even without considering the cellulosic mandate. Thus, to meet the statutory mandates beyond 2013, the EPA had to either force the industry to 'break' the blend wall or waive part of the conventional biofuel mandate. However, the availability of both FFVs and E85 stations have limited ethanol consumption beyond the blend wall. As of 2017, only around 6 percent of registered vehicles in the U.S. are flex-fuel capable, and less than 2 percent of gas stations sell E85.[9] Private market investment in E85 infrastructure has been slow, though in 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 offered as 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, have decreased in recent years. While biodiesel can help satisfy some of the gap between the blend wall and the mandated ethanol use, both its production capacity and costs limit the viability of this compliance option in the long run.

In response to these two issues, 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.

These mandate cuts have not gone smoothly. After first proposing cuts to the 2014 mandates in November 2013, the EPA did not release a final rule for the 2014-2016 mandates until November 2015. There was significant uncertainty over that period as to whether, and the extent to which, the mandates would be set 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 increased above the blend wall in 2013, the subsidy increased substantially. However, as soon as the EPA 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 costly. 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 mandates in the coming years. EISA requires that the EPA modify the volumes for all years if it waives at least 20% of the mandated volumes 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 total renewable fuel volumes is 2019. Absent legislative action, EISA also requires the EPA administrator to set mandates beyond 2022. Rulemaking for major regulations typically takes several years. Thus, the EPA is likely to take up consideration of post-2022 mandates soon. Both the reset and determination of the post-2022 mandates will require extensive analysis by EPA staff to determine the costs, benefits, and feasibility of any proposed actions. The next section looks back at the analysis that went into the initial regulatory impact analysis conducted by the EPA, with an eye towards identifying methods to better estimate impacts of future mandates to help guide these processes.

EPA's Regulatory Impact Analysis

The EPA released an extensive Regulatory Impact Analysis (RIA) of the expected benefits and costs of the RFS in February 2010 (EPA, 2010). RIAs are documents that outline agency's best ex ante projections of the market impacts, costs, and benefits of regulations. The EPA's 2010 RIA studied long-run costs and benefits of the RFS and concluded that the program would have large net benefits by 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 and non-market benefits to energy security, health, and GHG emissions reductions attributed to the policy. 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).

The largest share of benefits was to 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 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 inattention to production and infrastructure delays.[10]

Fuel Market Impacts: Addressing Price Uncertainty

A complete assessment of fuel market impacts of the RFS would estimate fuel price and demand changes due to the policy, any associated deadweight loss to consumers, the loss in gasoline producers' surplus, and the gain in biofuels' producer surplus. Moschini, Lapan and Kim (2017) provide an example of such an exercise. Rather than studying welfare outcomes, RIAs typically conduct cost-benefit analyses. To calculate the fuel market impacts of the policy, the EPA compared expenditures across two 'business as usual' scenarios 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 in the RIA. First, estimating that the RFS2 dramatically reduces future fuel prices is inconsistent with the notion that a binding regulation increases 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 closely followed the 2009 projections from 2010 to 2013, prices plummeted and fell below even the EIA's low-oil-price scenario by 2015. The range of the EIA's projections is wider in the 2017 AEO, reflecting increasing oil price uncertainty. In its RIA, the EPA considered only the 2009 baseline projections. The EPA used a wholesale gas price projection of $3.42 per gallon and an ethanol price projection of $1.716 per gallon.[11] Figure 4(b) contrasts these price projections with realized wholesale gasoline and ethanol prices. Ethanol prices ranged from $1.42 to $3.15 per gallon from 2007 to 2016, and gasoline prices ranged between $1.02 and $3.37 per gallon. Moreover, the two prices are positively correlated - high ethanol prices typically correspond with high gas prices. The Figure highlights the large disparities between expected and realized outcomes over a relatively short period.

Our summary over-simplifies the EPA's work in the RIA. Extensive analysis and effort went into producing the document. We identified over 20 models used 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 conditions. Simplifying the economic models underlying the analysis would allow for a 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 over which the policy increases or decreases average fuel market expenditures.[12]

Fuel Market Impacts: Demand and Technology Uncertainty

By focusing on long-run outcomes, the EPA was unable to address potential transitional costs and barriers to complying with the RFS in interim years. The two most significant obstacles facing the program were the blend wall and the development of an advanced biofuel industry. While EISA explicitly gave the EPA waiver authority to address delays in the development of the cellulosic biofuel industry, the legislation gave the EPA much less apparent authority concerning its ability to address 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 continue rising. The 2006 EIA projection placed the blend wall at 15.9 bgal in 2013 and 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 the conventional ethanol mandate. Only the cellulosic ethanol component of the mandate 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 levels of 10% of U.S. gasoline consumption and contrasts it with projected consumption from the 2009 and 2017 AEO. The actual blend wall dipped well below the EIA's projections from 2011 to 2015 before increasing back to 2009 levels in 2015. The actual blend wall was 13.6 bgal in 2013 and around 14.3 bgal 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 the Agency anticipated. While the decrease in gasoline use in the U.S. was more dramatic than many industry analysts predicted in 2007, it was not altogether a shock. 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. Looking forward, from 2017 onward the EIA expects gasoline use to decrease. This would only place greater stress on demand-side constraints to increasing biofuel use.

The lack of attention given in the RIA to the likelihood that consumers and fuel providers would struggle to overcome the blend wall is surprising. Moreover, explicit consideration of the constraint 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 juncture. To this end, in addition to considering a variety of long-run scenarios, the interim experience of the RFS 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 to reveal potential implementation challenges and policy design flaws. While it is impossible to consider all barriers to successful implementation of policies, stress testing based on known issues in advance of them binding could serve as a valuable exercise in ex-ante analyses.

Lessons from the RFS Experience

The RFS has transformed the fuel sector in the U.S. and abroad. Nearly all gasoline in the U.S. now contains 10% ethanol, and the U.S. has become a major ethanol and biodiesel exporter (EIA, 2016). The program has been largely successful in its goals of enhancing farm income and increasing energy independence. Despite these successes, the policy has also hit several roadblocks that have sidetracked it. This is particularly true of its ambitions to increase the production and use of low-carbon fuels. Many of these issues were known well in advance. We believe that several features of the policy's design in the enacting legislation contributed to these problems. In addition, the manner in which the EPA conducted its 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) a least expensive policy prices carbon; (ii) research and development for 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 ten years of a centerpiece of US climate policy, the RFS.

To this end, we conclude by drawing from our retrospective study of the RFS and its RIA to provide four overarching recommendations that, in retrospect, would have improved the policy. The first two recommendations pertain specifically to the EPA's implementation of the policy to date, and are meant to improve future rulemaking and regulatory impact analyses of the RFS and similar policies. The second two pertain to the design of the RFS in its enacting legislation, and are meant to improve the design of future climate policies and, potentially, future legislative revisions of the RFS. While based on the authors' experience studying the policy to date, many of the prescriptions and issues discussed here are normative. As such, they are meant to guide future policy as well as to promote future work and discussions on the issues highlighted below rather than outline specific policy revisions.

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 modes of transportation, fuel technologies, sources of renewable and fossil fuels, and carbon sequestration technologies will emerge. Forecasters are uncertain about future fuel prices. As such, 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 important for climate policies that require 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 of policies. Such studies should consider both short- and medium-term compliance scenarios that model binding transitional constraints, as well as long-run scenarios that allow for a range of prices and production costs.

Implement multi-year rules

The RFS legislation specifies biofuel use for each year. To implement the mandate, Congress charged the EPA with converting the volume standards to rate standards every year, and the legislation specified formulas and a deadline by which to release them. While there is little discretion concerning the calculations, 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 repeatedly. For example, when the technology and infrastructure constraints became binding in 2013, the Environmental Protection Agency (EPA) initially deferred decisions about whether to enforce the mandate and eventually proposed future cuts, 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 its standards from 2013 to 2016 left the fuel industry in an uncertain state. One problem with this uncertainty is that it deters investment and thereby undermines the statute. 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. 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 influence policy in a non-transparent way.

It is not clear that the EPA has the authority to move to multi-year rules without congressional action or at least without co-operation from the Energy Information Administration.[13] However, even if it does not implement multi-year rules, EPA could issue multi-year guidance within its current structure. Alongside annual rules, the Agency could issue predictions of the likely required blend rates under several scenarios for future fuel consumption. This action would incorporate uncertainty about future rulemakings, consistent with our first recommendation, and it would provide more information to markets.

Our recommendation that one-year rules are undesirable is guided by the EPA's rulemaking experience to date. Since 2013, the discretion afforded to the Agency has led to legal challenges and rulemaking processes that take far more than a year to address. However, there are clear tradeoffs between short and long rulemakings. Longer rulemakings afford the EPA less flexibility in responding to evolving market conditions. While adoption of our next recommendation would address concerns over the lack of flexibility of multi-year rules, it is difficult to prescribe an efficient length of rules in the absence of a more detailed model and analysis of firm investment decisions under policy uncertainty. We leave this issue for future research.

Tie waiver authority to compliance costs or incorporate cost containment provisions

One outcome of incorporating uncertainty into policy is acknowledging the value of cost containment mechanisms such as a price ceiling on compliance credits. Quantity mechanisms with banking and borrowing provisions leave policies susceptible to significant increases in compliance costs because both current and expected future technological and economic constraints affect compliance credit prices. A price stability mechanism that creates a price ceiling on compliance credits retains the incentive for firms to invest in developing the new technologies required for future compliance, while reducing compliance cost uncertainty (Roberts and Spence, 1976). The efficiency of the RFS would substantially increase if it were to be combined optimally with a cost containment mechanism (Lade and Lin Lawell, 2017).

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 numerous legal challenges to the EPA's yearly rulemakings that have severely delayed implementation of the mandates. If the legislation truly desired to limit economic harm, it should have taken the form of a price cap on RINs. If compliance costs exceed the cap, firms are not forced to comply. Instead, obligated parties could purchase RINS from the EPA at the cap price. This adjustment would remove EPA discretion and eliminate the ability for industries to lobby for favorable treatment. By specifying clear rules and formulas in legislation, the policy's economic burden is ultimately determined by Congress instead of than the regulating agency.

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

To date, commercial production of cellulosic biofuel has proven elusive. The EPA initially expected the biofuel industry to meet the cellulosic mandate with liquid fuels, diesel and ethanol made from cellulosic material. The EPA's RIA projected that 69% of the cellulosic biofuel mandate would be met with cellulosic diesel, and the remaining 31% would be cellulosic ethanol.[14] In 2015, less than 2% of cellulosic biofuel RINs were generated by liquid fuels. Most were generated by renewable natural gas (biogas) production from landfills, highlighting the inherent uncertain in predicting 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 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 is not a credible threat. The way the RFS is implemented also limits its effectiveness in spurring investment. In principle, a firm that develops a successful cellulosic biofuel technology would be able to generate a stream of RINs that could be sold to recoup its 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 cellulosic RINS. 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 ineffective method for forcing technological progress, particularly in the fuel industry. Thus, policymakers should fund research and development in cellulosic biofuel technology directly, rather than indirectly through a cellulosic mandate.

Determining the socially optimal level of R&D investment requires accounting for R&D spillovers, including intra-industry, inter-industry, and international spillovers (Corderi and Lin, 2011; Corderi Novoa and Lin Lawell, 2017), all of which constitute an important area of ongoing and future research. While the US government has already devoted substantial support to the industry through grants and low interest loans, future research could extend the existing literature to determine whether the level of government support has been effective to date.

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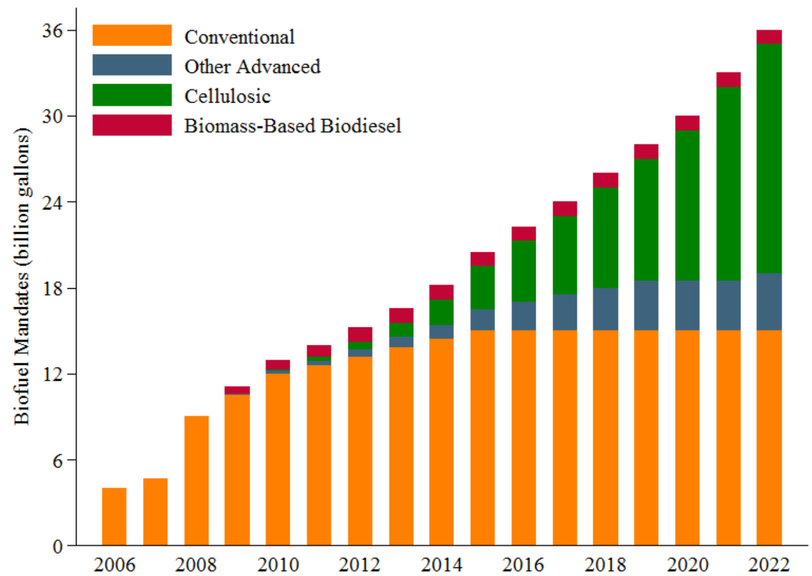
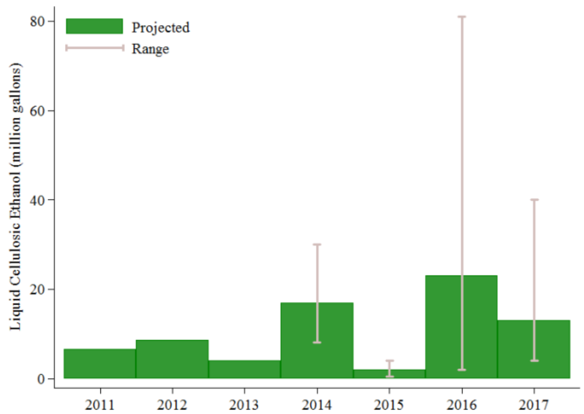
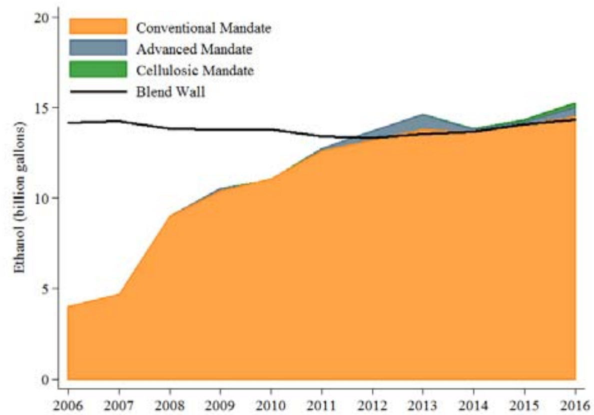


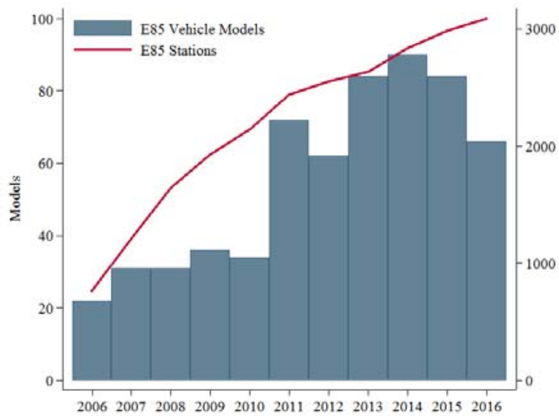
Figure 1: *RFS Statutory Mandates*
(Source: EPA)



(a)

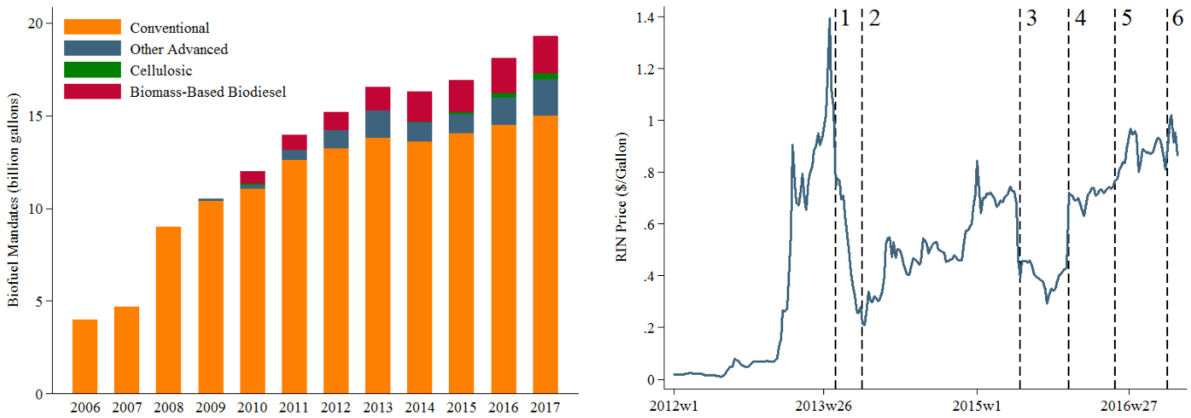


(b)



(c)

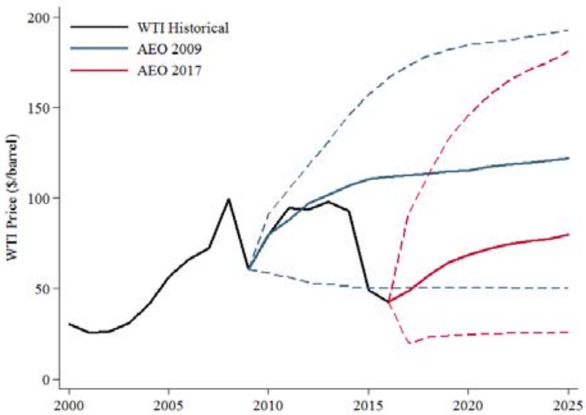
Figure 2: *Cellulosic Production, the Blend Wall, and E85 Vehicle and Fueling Infrastructure (Source: EPA, EIA, DOE AFDC)*



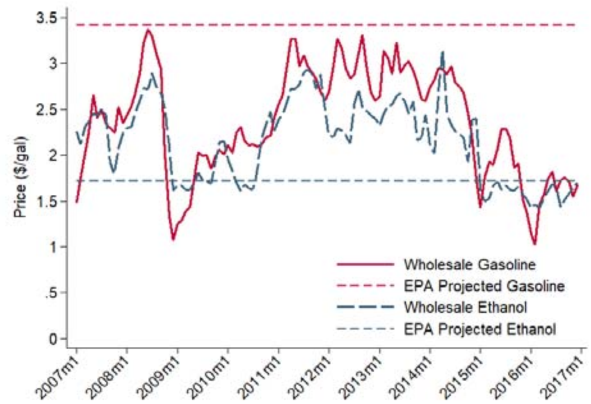
(a) *(b)*

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.*

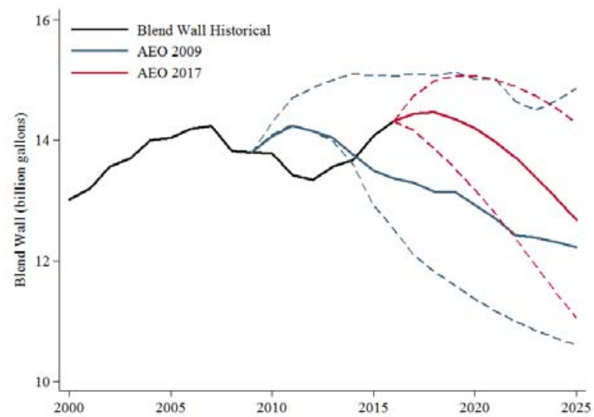
(Source: EPA, EcoEngineers)



(a)



(b)



(c)

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

Notes

[1] 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).

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

[3] 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.

[4] 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).

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

[6] 20/20 Biofuels Challenge Act of 2005 (S.1609), BOLD Energy Act of 2006 (S.2571.IS, H.R.5331.IH).

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

[8] 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 at a large scale 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).

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

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

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

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

[13] The EISA statute specifies "(A) … Not later than October 31 of each of calendar years 2005 through 2021, the Administrator of the Energy Information Administration shall provide to the Administrator of the Environmental Protection Agency an estimate, with respect to the following calendar year, of the volumes of transportation fuel, biomass-based diesel, and cellulosic biofuel projected to be sold or introduced into commerce in the United States. (B) … Not later than November 30 of each of calendar years 2005 through 2021, based on the estimate provided under subparagraph (A), the Administrator of the Environmental Protection Agency shall determine and publish in the Federal Register, with respect to the following calendar year, the renewable fuel obligation that ensures that the requirements of paragraph (2) are met." See https://www.law.cornell.edu/uscode/text/42/7545.

[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.