Title: Interactions Between California's Low Carbon Fuel Standard and the National Renewable Fuel Standard

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Abstract:

This study investigates the economic interactions between a national renewable fuel policy, namely the Renewable Fuel Standard (RFS), and a sub-national renewable fuel policy, the Low Carbon Fuel Standard (LCFS) in California. The two policies have a similar objective of reducing greenhouse gas emissions, but the policies differ in the manner in which those objectives are met. The RFS imposes a hierarchical mandate of renewable fuel use for each year whereas the LCFS imposes a specific annual carbon-intensity reduction with less of a fuel specific mandate. We model the interactions using a partial-equilibrium structural model of agricultural and energy markets in the US and Rest-of-World regions. Our results suggest the policies are mutually reinforcing in that the compliance costs of meeting one of the requirements is lower in the presence of the other policy. In addition, the two policies combine to create a spatial shift in renewable fuel use toward California even though overall renewable fuel use remains relatively unchanged.

Keywords: Renewable Fuel Standard; Low Carbon Fuel Standard; Compliance costs

Introduction

Renewable fuel use in the US transportation sector is governed primarily by policies at two levels. At the federal level, the Renewable Fuel Standard (RFS) calls for increasing volumes of renewable fuel that meet certain predetermined greenhouse gas (GHG) emission reductions. At the state level, California and other states have enacted Low Carbon Fuel Standards (LCFS) that require reductions in the carbon intensity (CI) of motor fuel used within the state over time through the use of lower CI renewable fuels. While the RFS and LCFS have similar goals (e.g. lower GHG emissions), each policy achieves those goals with a different structure.

The cost of renewable identification numbers (RINs) for the RFS program and carbon credits for the LCFS program suggest that both policies are binding and could affect fuel use. In previous years, the average LCFS credit cost per metric ton of carbon avoided (mt CO₂e) increased steadily from nearly \$30 in 2014 to \$52 the following year and the year-to-date average is just less than \$105 as of October 2016. At the same time, the RIN values associated with a gallon of corn starch ethanol averaged \$0.49 (\$377.38/mt CO₂e)¹ in 2014 and rose to \$0.55 (\$423.59/mt CO₂e) in 2015. The changes in the price of both compliance mechanisms highlight the rising importance of these two policies.

Researchers have estimated impacts of these policies to support policy making, but typically in isolation, with few studies considering whether the RFS and LCFS complement or complicate one another. Furthermore, their interactions could have important effects both economically and environmentally by exacerbating compliance costs or reducing the effective GHG reductions. This study sheds more light on those interactions using a policy structure that

¹ Calculated as

$$\frac{\$0.49}{RIN(\text{gallon conventional ethanol})} \times \frac{\text{gallon conventional ethanol}}{(0.01144 * 0.1135)\text{mt CO}_2\text{e avoided}}$$

Where the denominator in the conversion factor is the carbon emissions from one gallon of gasoline multiplied by the reduction obtained from one gallon of conventional ethanol, both of which were obtained from CARB.

more closely resembles the policies that are currently in place in the US and California and what those interactions could mean for biofuel and broader motor fuel markets within those regions.

The RFS was first established as part of the Energy Policy Act of 2005, and it was revised as part of the Energy Independence and Security Act of 2007. In its current form, the RFS is composed of four nested renewable fuel mandates. At the broadest level, there is an overall requirement for fuels that attain at least a 20% reduction in GHG emissions. Of that total amount, conventional ethanol derived from cornstarch may account for no more than 15 billion gallons beginning in 2015. The rest of the overall requirement must be met by advanced biofuels that attain at least a 50% reduction in GHG emissions. A portion of that requirement, at least 1 billion gallons according to the legislation, must be met using biomass-based diesel that also must attain at least a 50% reduction in GHG emissions. Another portion must be met with cellulosic biofuels that attain at least a 60% reduction in GHG emissions. The remaining portion of the advanced requirement was met, historically, with imports of sugarcane-based ethanol from Brazil. More recently, owing perhaps to actual or proposed waivers that partially lowered these requirements, ethanol imports have fallen dramatically and their role in attaining the RFS requirements has been replaced to a large extent by additional use of biomass-based diesel.

The RFS requirements are implemented each year as percent shares of motor fuel sold in the domestic market. Obligated parties (e.g. domestic oil refiners and fuel importers) demonstrate their compliance with the mandates by submitting the requisite number of Renewable Identification Numbers (RINs) to the EPA. RINs are generated and assigned to renewable fuels as they are produced or imported from qualified producers. Once the renewable fuel is blended with petroleum blendstock, the RINs are separated and can then be traded among market participants. Obligated parties can obtain the necessary RINs by physically blending

renewable fuel themselves or by purchasing surplus RINs from others. Surplus RINs can also be banked by obligated parties to offset their requirement for the following year.²

We focus as well on California's LCFS. There, the LCFS legislation was signed into law in 2010 and went into effect in 2011. The aim of the LCFS is to reduce by 10% the GHG emissions in California's transportation sector by 2020. Qualified fuels are assigned CI ratings based on their respective lifecycle GHG emissions. Some CI assignments are generic and apply to broad production practices, but the California Air Resources Board (CARB) included an approval process in the LCFS framework by which fuel producers can propose more precise CI ratings based on their specific production processes.

Unlike the RFS, the LCFS does not require specific volumes of renewable fuel to meet the GHG reduction targets each year. The average CI of the motor fuel pool just has to equal the target level, and it is up to the obligated parties (i.e. fuel producers and importers) to determine the mix of fuels that will meet that goal. In contrast, the RFS allows a sort of one-way displacement: biodiesel can displace advanced and advanced can displace conventional, but the reverse is not permitted. Similar to the RFS, LCFS compliance is demonstrated through use of tradeable credits. Blending fuels with a lower CI than the target reduction generates credits while blending higher CI fuels generates deficits. Obligated parties³ with deficits can purchase credits from those parties with a surplus. In addition, LCFS credits can be banked. Unlike the RFS, of which 20% can be met by RINs generated in the previous year, LCFS credits can be banked indefinitely and can be used to meet any of the future GHG reduction targets.

² Obligated parties that fall short of their requirement in a given year may also declare a "deficit" so long as they make up the difference in the following year in addition to the next year's obligation.

³ In many cases, these are the same parties obligated under the RFS. The LCFS rules allow some transfer of obligation by mutual consent, but we are not aware of how often that occurs in practice.

Adjustments have been made to both policies in the years since their initial implementation. As indicated earlier, the EPA has used its waiver authority to reduce the cellulosic biofuel requirements each year, and the EPA finalized lower overall and advanced requirements, as well, for 2014-2016. Similarly, the CARB has lowered the targeted reduction in CI each year the LCFS has been in effect. CARB completed the re-adoption process to determine a targeted reduction path going forward that will still meet the original 10% reduction by 2020.

Both the RFS and the LCFS have, as separate policies, received considerable attention in the literature. Much of the research has tended to focus on how the policies are structured and what their implementation implies going from theoretical understanding to market reality (Jussila Hammes 2014; Holland, Hughes, and Knittel 2009; Leiby and Rubin 2013; Thompson, Meyer, and Westhoff 2010; Thompson, Meyer, and Westhoff 2011). Particularly in the case of the RFS, the literature expanded to include studies of effects in other sectors and markets (Rajagopal, Hochman, and Zilberman 2011; Rajagopal 2013; Rajagopal et al. 2015; Thompson, Whistance, and Meyer 2011; Whistance and Thompson 2014b; Whistance and Thompson 2014c) although there are several similar studies related to the LCFS (Holland et al. 2013; Lade and Lin 2013).

However, the interaction between the two policies has received less attention in the literature (Chen et al. 2014; Huang et al. 2013; Rubin and Leiby 2013; Rubin, Leiby, and Brown 2014). Furthermore, those studies that have looked at RFS-LCFS interactions typically do so in the context of a hypothetical *federal* LCFS rather than the existing state level policies. For example, Huang et al (2013) used a structural model that focused on biofuel and environmental policies and found that a national LCFS policy, in addition to a RFS, led to increased demand for second-generation biofuels compared to the RFS by itself. As a result of that shift away from first-generation biofuels, the LCFS-RFS combined policy scenario also showed less of an effect

on corn and soybean prices than an RFS by itself. Rubin and Leiby (2013) found similar results in their study of tradeable credits, i.e. a national LCFS and RFS have a degree of “mutual reinforcement” that tends to increase the use of more advanced biofuels beyond the effect of either policy by itself. Rubin et al. (2014) built on their earlier work by disaggregating the model into census districts to see how compliance costs might vary by region. Their results showed that imposing a national LCFS on top of a regional LCFS might lead to cost savings of nearly 10% relative to their no-regional LCFS reference case. In addition, the study highlighted the importance of baseline assumptions regarding fuel CI in the presence of the RFS as those assumptions could have a large effect on the LCFS compliance costs. Namely, the costs of lowering the CI from an already lower average fuel CI that accounts for concurrent RFS compliance were 20% to 40% higher than a reference CI that did not take RFS compliance into account.

Complementary though they might be in terms of increasing advanced biofuel use, there is a concern that such policies could interact in a way that leads to fuel “shuffling” – with both renewables and petroleum products flowing in or out of California based on their relative merits for RFS or LCFS compliance, perhaps without much effect on overall GHG reductions – and land use changes among different areas or regions. Such unintended consequences might reduce the effectiveness of the policies in a broader context. For example, sugarcane ethanol from Brazil has a lower CI rating than much of the conventional ethanol produced in the US, so there is an incentive to increase imports of sugarcane ethanol to meet both the LCFS and the RFS. At the same time, Brazil has its own domestic ethanol mandate to fill that does not distinguish between CI ratings, so there is the possibility that Brazil would import conventional ethanol from the US. Several studies have noted that the two-way trade in this context is inefficient in that the GHG

emissions from shipping ethanol overseas in both directions offset any GHG reductions that occur domestically (Chen et al. 2014; Rajagopal 2013; Rajagopal 2015).

This study distinguishes itself from the previous literature by examining the interactions of these two policies. The relevance to energy policy is that we study the actual policies that exist and we estimate the fuel and feedstock market impacts. Our scientific innovation is to focus on a sub-national scale. We also explore the effects using an analytical framework that is relevant to current and future conditions, not to past times when the compliance costs were lower, biofuel use was irrelevant, or the RFS and LCFS did not exist. We investigate the complementary nature of the policies in encouraging overall renewable fuel use and the risk of fuel shuffling.

Method

We rely on a modified version of the FAPRI-MU deterministic model. It is a structural partial-equilibrium model of agricultural and biofuel markets that covers both US and international regions. Typically, the models and data are updated twice per year to account for the latest market information and to generate updated baseline projections. For this study, our model was updated to reflect agriculture and energy market information available as of January 2016.⁴

The biofuel model estimates petroleum product fuel prices and demand based on crude oil price projections obtained from IHS-Global Insight. In addition, the domestic model estimates the supply, demand, and prices for ethanol, biomass-based diesel, and RINs. The model accounts for biofuel trade through import and export equations and allows for two-way trade flows as have occurred in the past. The model itself, or variations thereof, has been used to investigate RFS-related policy questions for quite some time (Thompson, Meyer, and Westhoff 2010;

⁴ For further documentation, please refer to the supplementary material, descriptions available in other articles (listed below), or published documentation of earlier versions (Whistance and Thompson 2014a).

Thompson, Whistance, and Meyer 2011; Whistance and Thompson 2014b; Whistance and Thompson 2014c).

For this study, we modify the model to account for California's LCFS explicitly. We want to see how the policies affect markets, particularly the prices and fuel demand quantities, at both the national and sub-national scale. The methods are similar, but demands for each fuel are divided into California and the rest of the U.S. A key element of this representation includes the potential that the policy will lead the fuel sector to deliver renewables at below marginal costs of production and shift this cost to other fuels. The following equation for regular unleaded retail gasoline price is an example of how the disaggregation of prices is implemented:

Unleaded retail gasoline price by region, Rest of US (ROUS) and California (CA)

$$\begin{aligned} \text{RPG}_i = & \beta_0 \\ & + \beta_1 * (X_{1,i}) \\ & + \beta_2 * (X_{2,i}) \\ & + \beta_3 * (X_{3,i}) \end{aligned} \tag{1}$$

where RPG is the retail price of gasoline (dollars per gallon); $i = \text{ROUS, CA}$; and where X_1 is the wholesale gasoline price. X_2 is the total compliance costs (millions of dollars) of gasoline-replacing fuels for the RFS and, in the case of California the RFS and LCFS, which is weighted by the level of motor gasoline use (million gallons) in the region.⁵ X_3 is a GDP deflator to represent other costs of retailing fuels. The coefficients are defined as follows: β_0 is the intercept, and β_1 , β_2 , and β_3 are the partial effects of their respective variables.

Biofuel production is not disaggregated by region within the US although international trade is represented explicitly and intra-US trade implicitly in the results. Earlier versions of the

⁵ In the ROUS, X_2 is simply $(C_{\text{RFS}}/Q_{\text{gROUS}})$. In California, however, the compliance costs are weighted as follows: $(C_{\text{RFS}} * (Q_{\text{gCA}}/Q_{\text{gASROUS}}) + C_{\text{LCFS}})/Q_{\text{gCA}}$, which simplifies to $(C_{\text{RFS}}/Q_{\text{gROUS}} + C_{\text{LCFS}}/Q_{\text{gCA}})$.

FAPRI-MU model split ethanol and biodiesel into roughly the same CI categories represented in the LCFS, so the primary modification to the supply equations linked each fuel's production to the appropriate wholesale price through fuel-specific net returns. We assume the fuel within each CI category receives not only the RIN value from the RFS but also the marginal value of that fuel toward meeting the LCFS weighted by the share of that fuel used in California. Moreover, the wholesale price of gasoline in our model is the price of blended petroleum and renewable fuels, so it captures some of that adjustment.

We estimate ethanol, biomass-based diesel, and other non-petroleum (e.g. electric, natural gas, etc.) fuel substitutes used in California. There are three categories of ethanol based on feedstock: conventional (from cornstarch), advanced (primarily from sugarcane), and cellulosic. We count ethanol produced from sorghum as an “other” advanced ethanol in the model, so it contributes to overall ethanol supply and counts toward both RFS and LCFS compliance. There are four biomass-based diesel categories based on feedstock: Soybean oil, distillers corn oil, other oils, cellulosic. The CI ratings for each category of ethanol and biomass-based diesel are based on values provided by CARB (California Air Resources Board 2015). However, we do not assume those values are static throughout the projection period. Rather, we allow LCFS credit prices to drive CI ratings to some extent. As LCFS credit prices rise, there is an incentive for renewable producers to improve the CI ratings of each fuel, and that is reflected in the model. We assume fuels with comparatively high CI values (e.g. conventional ethanol) are more responsive to credit prices in order to take advantage of this added value. Moreover, we assume that the CI ratings of these fuel categories do not “leapfrog” one another. For example, the improvements in CI for the conventional ethanol category are not so great as to give conventional ethanol a CI rating that is more favorable than an advanced or cellulosic ethanol.

We also make a simplifying assumption in our model that fuels within each broad category are used in California in the order in which they are most useful (in terms of CI rating) to meet the LCFS targets. If two fuels are priced the same in trading outside of California, then California buyers will choose to bring in the low CI fuel instead of the high CI fuel. This pattern is consistent with the view that parties meeting the LCFS will try to minimize the cost of doing so.⁶ For example, because the corn oil biodiesel CI is less than the soybean oil biodiesel CI in LCFS calculations yet both are priced the same outside of California, we assume corn oil biodiesel is used in its entirety before soybean oil biodiesel is used. We recognize this assumption does not always hold strictly in reality, and test the sensitivity of the results by relaxing this assumption. In addition to their CI ratings, the order in which fuels are used depends on prices, which are in the model, and on transaction costs relating to finding, acquiring, and shipping the fuels that are not explicitly included. Furthermore, situations could arise, particularly at a time of low oil prices, in which low CI oil might have a price advantage relative to low CI renewable fuels. Obligated parties might choose to generate credits by using the low CI oil, instead (i.e. the “petroleum shuffling” to which Rubin et al. (2014) referred). Regardless, as low CI fuels are used, LCFS credits are generated.

The credits that are generated may be applied to the current year’s LCFS requirement, or they may be banked for use in later years. As noted earlier, LCFS credits are not subject to the same quantity and lifespan restrictions as RINs, so the stock of LCFS credits is driven to a large extent by the credit prices and anticipated LCFS requirements. The supply and demand of LCFS credits must also balance.

⁶ For simplicity, the model equations will assign all of the lowest CI fuel of a type to California before moving up to the next-best CI fuel in the type, where each fuel type has the same price outside of California (e.g. conventional ethanol, advanced ethanol, and so on). This structure assumes that California can account for 100% of US use of any particular fuel type. Relaxing that assumption does not change the results of this study in a meaningful way (as shown in the appendix).

LCFS and RFS impose fuel requirements, but neither creates direct taxes or subsidies. Fuel market impacts are motivated by the costs of compliance on the one hand and the indirect impacts on consumer fuel costs and biofuel supplier prices. A higher CI credit price or RIN price associated with rising compliance costs will tend to push down volumes of some fuels and encourage the production and use of other fuels. The result is a cross-subsidization of motor fuels. In other words, the LCFS credits and RFS RINs essentially lower the consumer cost of using low CI fuels and raise the consumer cost of using higher CI fuels. This representation is what we expect from theory (Thompson, Meyer, and Westhoff, 2009), and it is in line with other empirical studies (Rubin and Leiby, 2013; Rubin et al., 2014).

Data

We obtain national level, annual data from numerous sources including the US Department of Agriculture (USDA), the Energy Information Administration (EIA), and Oil Price Information Service (OPIS). For state level (i.e. California) data, we rely on the State Energy Demand System, which is maintained by EIA, and the California Air Resources Board (CARB) for LCFS data.

Scenarios

To analyze the interaction of the RFS and the LCFS, we simulate six scenarios and compare the results. Our first scenario reflects a “no policy” environment, in which there is neither an RFS nor an LCFS in the future. From there, we develop a counterfactual scenario that maintains the absence of RFS requirements but includes the revised GHG reduction path and the \$200/ton CO₂e inflation-adjusted LCFS credit price cap as specified in the re-adopted LCFS framework.

Next, we have a pair of scenarios that more closely resemble the current policy environment as of July 2016. In both scenarios, we assume the RFS requirements for 2014-2016 (2017 for biomass-based diesel) are adopted as finalized in November 2015. As before, we include one scenario without LCFS requirements and one scenario in which they are imposed. A comparison of RIN prices and RFS compliance costs between the two scenarios illustrates the marginal effect of the LCFS on renewable fuel use and how much it affects the difficulty in meeting the RFS requirements.

In the third pair of scenarios, we assume a more stringent path of RFS requirements going forward. We do not go so far as to assume the original path laid out in the Energy Independence and Security Act of 2007. Instead, we assume an overall requirement path that reaches 20 billion gallons of renewable fuel by 2022, which is well beyond the 10% ethanol blend limit (also known as the “blendwall”) and motivates additional ethanol use in the E85 market. Similar to the other two pairs, we include one scenario with the LCFS requirements and one without. This pair not only illustrates the marginal effect of the LCFS relative to the stronger RFS, but also, by comparing to the earlier scenarios, illustrates how the marginal effect changes as the RFS becomes more binding.

Results

The key assumptions we make in each of the scenarios relate to the RFS and LCFS requirements. Figure 1 shows how the certain components of the RFS requirements grow over the projection period under the alternate high- and low-RFS assumptions. Under both assumptions, the amount of conventional ethanol that can count toward the requirement is capped at 15 billion gallons, so growth in the overall requirement is met, to some extent, with additional biomass-based diesel and other advanced biofuels. Under a current policy assumption,

we assume the RFS standards for 2014-16 are implemented as finalized in November 2015 and that the overall volume requirements grow by an average of 1.9% per year and reach nearly 20.3 billion gallons by 2025. The more stringent RFS scenarios assume an average growth rate of 2.6% per year and reach just over 21.5 billion gallons by end of the projection period.⁷ The CI reductions under the LCFS program are assumed to follow the path outlined in the re-adoption proposal, which still meets the 10% reduction by 2020. We assume the CI reduction is held at the 10% level indefinitely beyond 2020.

Fuel use effects are shown in Table 1. Across all scenarios, the differences in total finished motor gasoline use, which includes petroleum-based fuel and ethanol, can be attributed primarily to the changes in use within California that occur as a result of LCFS implementation. On the other hand, in the low RFS case there is a large enough adjustment in ROUS motor gasoline to show up at the rounded level. Rounding errors aside, the LCFS creates nearly a 1:1 substitution effect in California of ethanol for motor gasoline. As these are in volume terms, not energy equivalent measures, this trade-off suggests some reduction in miles travelled given the rising share of ethanol, which has lower energy content than gasoline. Elsewhere, motor gasoline use remains relatively unchanged. The substitution away from petroleum diesel is greater than the increase in biodiesel use, which suggests an increase in non-petroleum based renewable fuels.

There is very little change in ethanol and biodiesel use in aggregate across the scenarios. Instead, the results indicate a spatial movement in where the biofuels are consumed. The LCFS is a sub-national policy so fuels used to satisfy those requirements are, in a way, double counted in

⁷ We considered increasing the requirements even faster for this scenario, but to expand the use requirement much further would imply expanding the 15 billion gallon conventional “gap” (the amount of the RFS that can be met with cornstarch-based ethanol) or an even larger increase in the requirement for advanced biofuels that might lead to sharply higher imports. We do not consider either of those possibilities in this exercise.

that they satisfy the RFS as well. When the LCFS is in effect and binding, there is an increase in biofuel use in California to meet the requirements within that state and an offsetting decrease in biofuel use in the rest of the US. The overall use remains roughly the same and is still enough to meet the RFS. Based on the results of previous literature, this result is not unexpected. However, the spatial shift in where GHG emissions occur (i.e. “carbon leakage”, whereby policy-driven reductions in one region are partly offset by increases in other regions) that appears in previous literature does not appear to be an issue in this context (Chen et al. 2014; Leiby and Rubin 2013; Rajagopal 2015; Rajagopal et al. 2015; Thompson, Whistance, and Meyer 2011). Perhaps that is due to the representation of the LCFS as a sub-national policy, not a hypothetical national policy, and the fact that the RFS covers both regions.

Not only is there a shift in where the fuels are used, there is also a shift in the type of fuels consumers buy and use (Table 2). In aggregate, a more stringent RFS is met through increased reliance on higher blends of ethanol fuel. As the requirements push past the 10% blending level, otherwise known as the “blendwall”, there is more substitution away from E10 and toward higher blends such as E15 (a 15 % blend with gasoline) and E85 (an 85% blend) in order to meet the RFS. Adding the LCFS creates an additional incentive to replace low blend fuel use with E85. This is particularly evident in California where the share of ethanol used in E85 increases much more than the rest of the US across all scenarios. Such levels of ethanol use in high-blend fuels, although ubiquitous in Brazil, have not been seen before in the US, but rising RIN or LCFS prices can offset the costs of the input fuels to such an extent that retailers and consumers could face strong incentives to adopt E85. We make an assumption regarding the strength of those incentives, as suggested by studies of consumer purchases in the event E85 price is well below the prices of competing fuels (Aguilar et al. 2015; Johnson, Halvorsen, and

Solomen 2011; Jensen et al. 2010). Although consumer adoption at certain prices has been confirmed, the exact pace of expansion in E85 infrastructure and vehicle fleet in the US is currently unknown.

The compliance cost implications can be seen in Table 3. Examining the RIN prices, we see that more stringent requirements result in higher RIN prices – as expected, a higher RFS means the per-unit compliance cost rises. A key point is that there is a decrease in RIN prices and total RFS compliance costs when California's LCFS is in effect for a given level of RFS requirement. It is interesting to note that the CI of conventional ethanol decreases enough to the point that the RIN price in terms of \$/mt CO₂e increases. The LCFS prices spur additional growth in E85 use in California, as it was shown earlier, and that eases the pressure on RIN prices to drive that switch away from low blend uses. Thus, the complementary nature of the policies makes the RFS somewhat less binding. At the same time, as the RFS becomes more binding, biofuel use to meet the RFS complements biofuel use to meet the LCFS. In Table 3, we see the impact of a rising RFS on the LCFS costs: LCFS credit prices and total LCFS compliance costs are lower in the High RFS scenario than in the Low RFS scenario.

The RIN prices and the LCFS credit prices affect retail prices for gasoline and ethanol. The fuel price effects and compliance cost implications that drive fuel use changes can be seen in Table 3. As the RFS requirements increase, we see higher average motor gasoline prices at the retail level and lower implied retail ethanol prices. These implied retail price effects indicate, for example, that the higher RIN prices cause a higher price of E10, given that it's comprised of 90% gasoline, and a falling price of E85 that contains more ethanol than gasoline. When the LCFS is in effect, these same price effects are compounded in California. Because the addition of the LCFS complements the RFS, we also see a slight increase in implied retail ethanol prices

in the Rest of US. A less binding RFS requires less of an ethanol price discount relative to gasoline to motivate use. This effect is most pronounced in the Rest of US region in the Low RFS case and is diminished in the other two scenarios. In the No RFS case, there is very little need to increase ethanol use beyond low level blends, and in the High RFS case, the mandate is binding enough that even with the complementarity of the LCFS a substantial ethanol price discount is necessary. As other studies have shown in the case of a hypothetical national LCFS combined with a RFS, the results in Table 3 depict the cross subsidization that occurs from these two policies. Both policies encourage the use of lower carbon fuels (e.g. ethanol) and penalize the use of higher carbon fuels (e.g. gasoline) (Huang et al. 2013; Chen et al. 2014; Rubin and Leiby 2013; Rubin, Leiby, and Brown 2014).

Conclusion and Policy Implications

This study examines the interaction between national and sub-national biofuel policies, namely the national level RFS and the state level LCFS in California. The policies are similar in their stated goals to reduce GHG emissions, particularly within the transportation sector. However, they differ in the means they use to achieve that end. The RFS requires, in the form of nested biofuel mandates, certain amounts of fuels that meet specific levels of GHG reductions. The LCFS, on the other hand, lays out a path of CI reductions and lets motor fuel producers determine and provide the mix of fuels that will meet those requirements.

We examine three alternative RFS mandate paths, with and without the LCFS, to see how those policies interact and affect the biofuel and overall motor fuel markets, subject to limitations listed below. The fuel market results presented here indicate that the sub-national LCFS policy behaves in a manner similar to that observed by previous studies of a national LCFS. The LCFS is complementary to the RFS and reduces the difficulty of meeting the RFS as evidenced by

lower RIN prices. Although biofuel use remains relatively stable in aggregate, there is a spatial shift in where biofuels are consumed. There is additional biofuel use in California, and additional high-blend fuel use (e.g. E85), driven by the added LCFS requirements. By shouldering some of the burden, so to speak, the model results indicate that the LCFS takes some of the pressure off the RFS to incentivize an increase in high-blend fuel use throughout the rest of the country. To the extent that low CI crude oil can substitute for high CI crude oil, there may be somewhat less incentive for high blend fuel use, and the additional costs of such substitution are not represented fully in this experiment.

At the same time, the complementary nature of the two policies implies that the RFS makes the LCFS easier to meet, according to these results. As the RFS mandates increase and require greater levels of biofuel use at the national level, California will necessarily consume a greater volume with or without the LCFS. When the LCFS is in effect, the greater biofuel use spurred by a higher RFS mandate eases the pressure on the LCFS relative to a lower RFS mandate. In both cases, the model results provide some evidence of the cross-subsidization referred to in previous studies. Each policy, alone, encourages the use of lower CI biofuels and penalizes the use of higher CI petroleum based fuels. In the combined scenarios, the effect is magnified in California.

We make several structural assumptions when implementing the model, particularly as it relates to the LCFS. Changing these assumptions could lead to different results. For instance, we understand that biofuel use in California does not follow the “low CI fuel first” rule that we assume: biofuel used is not always the lowest-CI available in the country. Altering that assumption might lead to differences in the quantity of biofuels consumed within the state (i.e. it takes additional gallons of higher CI fuels to replace the reductions provided by low-CI fuels) with resulting changes in compliance costs. More broadly, explicitly including transportation or

other transaction costs as well as an accounting of crude oil shuffling could be another direction of study. There is also the reality that other states, such as Oregon, are in the process of implementing their own LCFS policies, which would add a new spatial component to the analysis. Expansion of E85 or other fuels with very high biofuel content is uncertain in the US and specifically in California, despite the large ethanol use observed in Brazil, although strong incentives generated by the RFS or LCFS imply that all potential for expansion over the course of a decade might be exploited. In addition, the role of vehicles using non-petroleum fuel (e.g. electric vehicles) is uncertain. To the extent such vehicles play a larger or smaller role in meeting the LCFS requirements than what is represented in this study, the results could differ quite a bit from those presented earlier.

Despite those limitations, this study adds to the growing understanding of biofuel policy interactions in the US. Unlike many previous studies, this work represents the actual LCFS. The existing policy is a state-level policy, not implemented at the national level as other studies have assumed. We adopt the latest proposals for both LCFS and RFS, then project forward to provide forward-looking assessment. It is our goal to inform policymakers about the effects and interactions of current policies. The scope for complementarity in terms of the potential to reduce RIN and LCFS credit prices and our assessment of the possibility of fuel shuffling, as well as the price and quantity impacts, provide policy impact analysis to inform decisions about policies that have become and could continue to be binding on fuel use in the U.S.

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Appendix

The tables in this appendix present the results of an additional scenario in which we relax the “low CI fuel first” assumption. Instead of assuming California uses all of a lower CI fuel before beginning to use volumes of a higher CI fuel, we assume the switch would occur when 75% of the lower CI fuel has been used.

Table A1. Motor fuel use (billion gallons) after relaxing “low CI fuel first” assumption, 2015-2025 average

	No RFS; No LCFS	No RFS; Base LCFS	Low RFS; No LCFS	Low RFS; Base LCFS	High RFS; No LCFS	High RFS; Base LCFS
Motor gasoline ^a	144.7	144.4	144.0	143.9	144.0	143.8
California	15.5	15.3	15.4	15.2	15.4	15.2
Rest of US	129.2	129.2	128.6	128.7	128.6	128.6
Ethanol use	12.3	12.4	15.2	15.2	15.6	15.5
California	1.4	1.6	1.7	1.9	1.7	1.8
Rest of US	10.9	10.8	13.5	13.3	13.8	13.6
Diesel use	54.9	54.1	54.7	54.1	54.6	54.1
California	2.8	2.0	2.7	2.1	2.7	2.2
Rest of US	52.1	52.1	52.0	52.0	51.9	51.9
Biodiesel use	0.9	1.1	2.4	2.4	2.6	2.6
California	0.2	0.3	0.3	0.4	0.3	0.4
Rest of US	0.7	0.8	2.1	2.0	2.3	2.2

a: This is “finished” motor gasoline, which includes the ethanol blending component.

Note: Totals may not equal sums due to rounding error

Table A2. Ethanol blend shares of ethanol use after relaxing “low CI fuel first” assumption, 2015-2025 average

	No RFS; No LCFS	No RFS; Base LCFS	Low RFS; No LCFS	Low RFS; Base LCFS	High RFS; No LCFS	High RFS; Base LCFS
Aggregate						
E10	98%	98%	90%	90%	87%	88%
E15	0%	0%	6%	5%	7%	6%
E85	2%	2%	5%	5%	6%	6%
California						
E10	92%	92%	87%	82%	86%	82%
E15	0%	0%	1%	2%	1%	2%
E85	8%	8%	12%	15%	13%	16%
Rest of US						
E10	98%	98%	90%	90%	87%	87%
E15	0%	0%	6%	6%	7%	7%
E85	1%	2%	4%	3%	5%	5%

Note: Totals may not equal sums due to rounding error

Table A3. Motor fuel and compliance credit prices after relaxing “low CI fuel first” assumption, 2015-2025 average

	No RFS; No LCFS	No RFS; Base LCFS	Low RFS; No LCFS	Low RFS; Base LCFS	High RFS; No LCFS	High RFS; Base LCFS
Retail gasoline (\$/gallon)						
California	\$3.14	\$3.32	\$3.24	\$3.38	\$3.25	\$3.37
Rest of US	\$2.68	\$2.68	\$2.78	\$2.78	\$2.79	\$2.79
Implied retail ethanol (\$/gallon)						
California	\$2.39	\$2.20	\$1.78	\$1.63	\$1.75	\$1.60
Rest of US	\$2.39	\$2.39	\$1.78	\$1.80	\$1.75	\$1.77
RINs (\$/RIN)						
Conventional	\$0.00	\$0.00	\$0.98	\$0.94	\$1.02	\$0.99
Advanced	\$0.00	\$0.00	\$1.06	\$1.02	\$1.16	\$1.12
Biodiesel	\$0.00	\$0.00	\$1.22	\$1.15	\$1.38	\$1.32
(\$/mt CO ₂ e)						
Conventional	\$0.00	\$0.00	658.19	549.33	689.33	577.85
Advanced	\$0.00	\$0.00	214.80	200.16	233.51	219.77
Biodiesel	\$0.00	\$0.00	246.45	232.08	281.90	265.01
RFS compliance cost (billion \$)	0.0	0.0	19.9	19.0	22.3	21.5
LCFS credits (\$/mt CO ₂ e)	\$0.00	\$171.07	\$0.00	\$126.06	\$0.00	\$112.04
LCFS compliance cost (billion \$)	0.0	2.7	0.0	2.1	0.0	1.8

Note: Totals may not equal sums due to rounding error

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Figure 1. RFS requirements in the High and Low RFS scenarios.

Table 1. Motor fuel use (billion gallons), 2015-2025 average

	No RFS; No LCFS	No RFS; Base LCFS	Low RFS; No LCFS	Low RFS; Base LCFS	High RFS; No LCFS	High RFS; Base LCFS
Motor gasoline ^a	144.7	144.4	144.0	143.9	144.0	143.9
California	15.5	15.3	15.4	15.2	15.4	15.2
Rest of US	129.2	129.2	128.6	128.7	128.6	128.6
Ethanol use	12.3	12.4	15.2	15.2	15.6	15.5
California	1.4	1.6	1.7	1.9	1.7	1.9
Rest of US	10.9	10.8	13.5	13.3	13.8	13.6
Diesel use	54.9	54.1	54.7	54.1	54.6	54.2
California	2.8	2.0	2.7	2.2	2.7	2.2
Rest of US	52.1	52.1	52.0	52.0	51.9	51.9
Biodiesel use	0.9	1.1	2.4	2.4	2.6	2.6
California	0.2	0.3	0.3	0.4	0.3	0.4
Rest of US	0.7	0.8	2.1	2.0	2.3	2.2

a: This is “finished” motor gasoline, which includes the ethanol blending component.

Note: Totals may not equal sums due to rounding error

Table 2. Ethanol blend shares of ethanol use, 2015-2025 average

	No RFS; No LCFS	No RFS; Base LCFS	Low RFS; No LCFS	Low RFS; Base LCFS	High RFS; No LCFS	High RFS; Base LCFS
Aggregate						
E10	98%	98%	90%	90%	87%	88%
E15	0%	0%	6%	5%	7%	6%
E85	2%	2%	5%	5%	6%	6%
California						
E10	92%	92%	87%	82%	86%	82%
E15	0%	0%	1%	2%	1%	2%
E85	8%	8%	12%	15%	13%	16%
Rest of US						
E10	98%	98%	90%	90%	87%	87%
E15	0%	0%	6%	6%	7%	7%
E85	1%	2%	4%	3%	5%	5%

Note: Totals may not equal sums due to rounding error

Table 3. Motor fuel and compliance credit prices, 2015-2025 average

	No RFS; No LCFS	No RFS; Base LCFS	Low RFS; No LCFS	Low RFS; Base LCFS	High RFS; No LCFS	High RFS; Base LCFS
Retail gasoline (\$/gallon)						
California	\$3.14	\$3.32	\$3.24	\$3.37	\$3.25	\$3.35
Rest of US	\$2.68	\$2.68	\$2.78	\$2.78	\$2.79	\$2.79
Implied retail ethanol (\$/gallon)						
California	\$2.39	\$2.19	\$1.78	\$1.63	\$1.75	\$1.60
Rest of US	\$2.39	\$2.39	\$1.78	\$1.80	\$1.75	\$1.77
RINs (\$/RIN)						
Conventional	\$0.00	\$0.00	\$0.98	\$0.93	\$1.02	\$0.98
Advanced	\$0.00	\$0.00	\$1.06	\$1.02	\$1.16	\$1.11
Biodiesel	\$0.00	\$0.00	\$1.22	\$1.15	\$1.38	\$1.32
(\$/mt CO ₂ e)						
Conventional	\$0.00	\$0.00	658.19	543.31	689.33	573.02
Advanced	\$0.00	\$0.00	214.80	199.14	233.51	217.52
Biodiesel	\$0.00	\$0.00	256.48	242.51	290.18	277.51
RFS compliance cost (billion \$)	0.0	0.0	19.9	19.0	22.3	21.4
LCFS credits (\$/mt CO ₂ e)	\$0.00	\$167.54	\$0.00	\$120.98	\$0.00	\$105.70
LCFS compliance cost (billion \$)	0.0	2.7	0.0	2.0	0.0	1.7

Note: Totals may not equal sums due to rounding error