(2022) 52, 176–197

The Review of Regional Studies

The Official Journal of the Southern Regional Science Association

Accounting for Aversion: Costs of the Renewable Fuel Standard after Reaching the Blend Wall*

Michael D. Noel[a], Travis Roach[b]

[a]*Department of Economics, Texas Tech University*
[b]*Department of Economics, University of Central Oklahoma*

Abstract: In response to escalating renewable requirements in the U.S., the EPA has approved the use of E15, a 15% ethanol blend, to eventually replace E10. Since a minimum of 10% of vehicles cannot use E15, both E10 and E15 must remain available. Due to EPA and car manufacturers' disagreements about the safety of E15 in cars made between 2001-2012, a substantial portion of consumers will have a choice laden with uncertainty. Using a regionally-calibrated model we discuss the potential for consumer aversion to E15 and assess the change in consumer expenditures from that aversion if the mandate is met by moving consumers to E15. We find that consumer burden would amount to nearly $230 million dollars per month in our most conservative of estimates, and upwards of $929 million dollars per month if there is a modest amount of ethanol aversion. We also discuss consumer burden costs regionally for each of the eight Petroleum Administration Defense Districts. In light of this consumer burden, we discuss policy prescriptions to help mitigate such costs should the EPA choose to increase the amount of conventional biofuels that are blended into the fuel supply.
Keywords: ethanol, consumer burden, renewable fuel standard
JEL Codes: H3, L91, Q41, Q42, Q48

1. INTRODUCTION

A common assumption in economics is that consumers possess full information and that they will behave in a utility-maximizing manner. In a market with low transaction costs and an increasing availability of information, such as modern gasoline markets, one would expect that the standard outcomes will hold, and that consumers will make gasoline purchasing decisions optimally over time. However, the decision to blend increasing amounts of ethanol into the fuel supply to meet energy and environmental policy goals holds the potential for unintended costs and consequences due to consumer uncertainty. This rings especially true

*Michael Noel is a Professor of Economics at Texas Tech University, Lubbock, TX. Travis Roach is an Associate Professor and Chair in the Department of Economics at University of Central Oklahoma, Edmond, OK. *Corresponding Author:* T. Roach, E-mail: troach2@uco.edu

ISSN 1553-0892, 0048-49X (online)
www.srsa.org/rrs

given the potential for 'irrational' behavioral responses, such as status-quo bias or loss-aversion, that may affect decision making after making a large purchasing decision (e.g. a vehicle) (Fernandez and Rodrik, 1991; Kahneman et al., 1991). In this paper we highlight one such unintended cost of changing energy policy that has often been disregarded in the literature that, if realized, results in substantial consumer burden.

Virtually all gasoline sold in the United States is E10[1] and its rollout over the past decade has been largely without incident in terms of possible vehicle damage.[2] Now, in the face of quickly escalating renewable volume requirements under the Energy Independence and Security Act of 2007, the Environmental Protection Agency (EPA) has approved the sale of E15, a fifteen percent ethanol blend, to replace E10.[3] The move to E15 fuel has been an arduous process, but has been made possible by the passing of two partial waivers that "allow but do not require" the sale of E15 (US EPA, OAR, 2015). The first waiver was passed in November of 2010 and specified that E15 may safely be used in model year 2007 and later vehicles. The following year, a second waiver was issued allowing the use of E15 in model year 2001-2006 vehicles.

Although consumers quickly adopted E10 without worry of vehicle damage, the potential for vehicle damage from the use of E15 in the United States has been more controversial.[4] The EPA has certified E15 as a safe fuel for all vehicles manufactured after 2001 meaning that most vehicles on the road can use it. However, there remains a substantial percentage of older vehicles that cannot use the fuel. Further, a large portion of manufacturers disagree with the EPA's safety assessment and have stated that E15 is safe only for use in most post-2012 models, or only about 10% of vehicles on the road.[5] Manufacturers state that buyer warranties will not cover any E15 damage used in vehicles for which it is not recommended.

Regardless of who is right and who is wrong, it is clear that there is a significant group of consumers, those with vehicles manufactured before 2001, for whom there is no disagreement and who are advised on both sides against using E15. Because of these consumers, the EPA cannot fully replace E10 with E15 in the near term (as they had fully replaced E0 with E10), and E10 must remain available to those who need it.

For owners of vehicles made between 2001 and 2012, there are disputes over E15 safety, and the lack of agreement can be expected to create concern. According to the Bureau of Transportation Statistics, the average age of all light duty vehicles in use in the United States

[1]Gasoline blended with ten percent ethanol by volume.

[2]The mandate itself has been controversial. See Griffin (2013) for a good overview of positive and negative impacts of the U.S. ethanol mandate.

[3]There is also a push to replace E10 and E15 with the even more controversial E20. The 2012 Minnesota Omnibus Agriculture Policy Act mandates twenty percent ethanol content in that state to commence in 2013, since postponed to 2015 as the state seeks an EPA waiver for E20 fuel. Researchers at Minnesota State University have produced a series of studies funded by industry groups arguing no ill effects of using E20.

[4]Groups on both sides of the issue have commissioned studies which support their own points of view.

[5]The Alliance of Automobile Manufacturers and several other industry trade sued the EPA over its E15 roll-out. The U.S. Supreme Court affirmed the appellate court decision that the trade groups lacked legal standing to sue. (Alliance of Auto. Mfrs. v. EPA, No. 12-1167 and related cases.) Separately, twelve manufacturers wrote to Congress opposing the fuel and warning consumers not to use E15. See *http://sensenbrenner.house.gov/uploadedfiles/e15_auto_responses.pdf*, last accessed March 9, 2014.

has been between 11.2 and 11.9 years since 2012.[6] So, even in 2021 a non-trivial proportion of the vehicle fleet was produced in a time period in which E15 was not specifically designed for in the production process and manufacturers warned against its use at the time. Regardless of whether these concerns turn out to be real or perceived, the fact remains that a substantial portion of consumers can be expected to avoid E15 and seek out the more familiar, and 'warranty-proof', E10.

In light of this risk aversion, to induce those who can safely use E15 to actually use E15 (even when both blends are simultaneously available) E10 must necessarily be price rationed. This can occur through regulatory means, market forces, or a mixture of the two. For example, the increase in the price of Renewable Identification Numbers (RINs) going forward effectively increases the production cost of E10 relative to E15.[7] Given there must be a price gap, the fact that there are significant numbers of consumers who would seek to avoid E15 for whatever reason, even when the price is higher, creates a potentially significant cost to consumers from the expanded mandate. This is true not only for those consumers with older vehicles where there is no disagreement about E15 compatibility, but also for a potentially large proportion of those consumers with newer vehicles where there are conflicting opinions.

While arguments about the benefits and costs of the ethanol mandate on both sides are many, our paper contributes to the literature by examining the potential for increased fuel costs due to consumer aversion away from the EPA's newer, higher ethanol blend and towards the older, EPA disfavored, lower ethanol blend. This cost has not been well recognized in the literature.

We examine this source of consumer burden with reference to the recent experience of New South Wales, Australia, which introduced an ethanol mandate in 2007. The Australian experience parallels the current U.S. situation, and holds lessons for the challenges faced by the EPA in rolling out E15 while there are indisputably incompatible vehicles and a range of disagreement and consumer uncertainty about much of the rest.

The current transition in the U.S. is from the usual 10% blend to a more controversial 15% blend. The transition in New South Wales was from their usual 0% blend (i.e. no ethanol) to a 10% blend. While E10 has been safely used in the U.S. for many years, Australian cars differ, and the consensus on all sides of the debate was that about 20% of vehicles on New South Wales roads were not certified for and should not use E10.[8] In the U.S., originally between 30% and 90% of vehicles were not certified for E15, depending on the source. Today, the amount that are not certified is closer to 10%, but there is a substantial vehicle vintage range for which the EPA and auto manufacturers disagree (2001-2012). To accommodate the potential compatibility concern in New South Wales, the mandate allowed for an ethanol-free substitute to remain available for those who needed it, just as in the U.S. an E10 substitute

[6] Bureau of Transportation Statistics Table 1-26: Average Age of Automobiles and Trucks in Operation in the United States. https://www.bts.gov/content/average-age-automobiles-and-trucks-operation-united-states accessed on December 11th, 2021.

[7] RINs are essentially tradable credits that firms earn when blending ethanol into gasoline. Firms can then sell them if they exceed their ethanol blending requirements, and can buy them if short.

[8] We discuss the Federal Chamber of Automotive Industries list in more detail below.

must continue to be made available for E15.[9] In our model we follow this policy design and assume that premium fuels continue to be made available with the conventional 10% blend of ethanol. Further, we allow for a portion of regular E10 to remain in the marketplace. This, too, is similar to the New South Wales mandate because rural areas were exempted from legislation due to the large cost associated with changing over storage tanks.

In a model that is calibrated with historical U.S. price and volume data, we show the potential for consumer burden due to aversion away from a controversial higher ethanol blend can be large when both blends must be made available. We also show that the increased fuel costs from aversion can be significant and even dwarf the expected increased fuel costs more typically associated with a mandate (due to the higher energy-adjusted price of the new higher ethanol blend). We disaggregate the model by Petroleum Administration Defense Districts (PADD areas) so that we may offer region-specific estimates of the total consumer burden.

Under our most conservative but realistic assumptions (in which there is no ethanol aversion) we find that as much as $229 million per month is spent to accommodate the switch to E15. On a per gallon basis, this is as if consumers pay an additional 3 cents more per gallon on average, and for an average commute to work an additional $15 per year. This is likely not the scenario U.S. policy makers will face given the current conversation around E15. We find that if there is any ethanol aversion, and we base this on a very modest measure of ethanol aversion, consumer burden is as much as $929.9 million per month on average, or $11.16 billion per year. This translates to a 5 cent per gallon price increase on average. If there is a high amount of ethanol aversion, then we expect to see an effective 18 cent per gallon increase. Our estimated consumer burden estimates are large in aggregate, but the per-gallon cost to consumers may seem like a rational expenditure. If there is any uncertainty of whether or not E15 will cause damage to a car resulting in the loss of a major investment, then paying up to 18 cents more per gallon is a cost-effective insurance policy to avoid breaking warranties, future damage, or the loss of a vehicle. This relatively small cost per gallon increase to the consumer is at the crux of why it is difficult to transition the vehicle fleet to accommodate higher ethanol blend ratios through changing blend ratios alone. Our most simple policy proposal to achieve higher ethanol blends is thus: First, mandate that all new vehicles be able to accommodate higher ethanol blends without breaking warranties. Wait. Then, increase volumetric ethanol standards with the introduction of a fuel with a higher ethanol blend.

The rest of the paper continues as follows: Section two offers a background on ethanol policies in the U.S. and the reference case of New South Wales, section three describes the data and methodology, section four discusses the consumer burden estimates, and section five concludes with a policy discussion.

[9]Even during the U.S. transition from E0 to E10, there were numerous websites and blogs maintaining lists of stations where ethanol averse consumers could still find E0.

2. BACKGROUND

Over the past decade ethanol mandates have become almost commonplace, and currently sixty-two countries have some form of one. A typical mandate requires that producers blend a certain percentage or certain volume of ethanol into the overall supply of gasoline. The original U.S. mandate required 18.2 billion gallons of renewable fuels, primarily ethanol, be blended into the gasoline supply in 2014, up from 16.6 billion in 2013 (US EPA, OAR, 2015).[10] Since the original mandate, there has been almost yearly uncertainty in the amount of mandated fuels. For example, in April of 2015 the EPA still had not finalized 2014 volume standards.[11]

In 2017, the EPA-mandated volume of renewable fuels was 19.28 billion gallons, and this volume has since been increased to 20.09 billion gallons in 2020.[12] For reference, total refiner motor gasoline sales volumes were 142.9 billion gallons in 2017 in the United States. This means that the EPA mandate for fuel blending was effectively 13.5% in 2017. Holding fuel demand constant, the 2020 volume mandate implies an increase to a 14.05% ethanol standard. For comparison, the European Union requires 5.75% renewable fuels in the fuel supply by 2010 and 10% by 2020.

Ethanol mandates have been contentious (Griffin, 2013; Grafton et al., 2012; Serra and Zilberman, 2013). Advocates for ethanol mandates have often argued that it is a "silver bullet" of sorts because increased ethanol use cuts the amount of carbon dioxide emissions from on-road vehicles, promotes a renewable source of energy, slows down the exhaustion of fossil fuels, and promotes energy security (Khanna et al., 2008). Advocates also champion the idea that ethanol consumption supports domestic farming and production industries. However, these purported benefits have also been linked to substantial social costs.

The environmental value of an ethanol mandate has been subject to criticism due to ethanol's energy-intensive production cycle and lower energy yield. Condon et al. (2015) argue against any immediate need for fossil fuel replacement and make note of the risk of higher food prices when crops grown for food are converted to ethanol use.[13] Noel and Roach (2017) find that ethanol mandates cause a minimal decrease in carbon dioxide emissions. Jaeger and Egelkraut (2011) show that a gasoline tax would be more effective at reducing carbon dioxide emissions than the introduction of biofuels. Holland et al. (2009) find that fuel content mandates in the U.S. are a very expensive way to reduce emissions.

An important consumer concern regarding ethanol blends, or increased ethanol blends in the face of escalating ethanol requirements, surrounds fuel-vehicle compatibility and the potential for long run damage in older vehicles. In the United States, where E10 is sold at virtually all gasoline stations, the concern surrounds higher blends such as E15 and E20. In Australia, where ethanol-free gasoline has been almost universal for decades, the concern

[10]The ultimate goal is 36 billion gallons by 2022.

[11]Federal Register Volume 79, No 236, published 12/9/2014. Accessed 4/8/2015

[12]15 billion gallons must come from conventional biofuels, 5.09 from advanced biofuels.

[13]There are numerous other pros and cons. On one hand, ethanol blending raises the octane of gasoline in lieu of other potentially more expensive methods and is one of the lesser expensive oxygenating agents to replace MTBE. On the other, ethanol use requires a more expensive dual delivery infrastructure, since it can only be blended with gasoline at the rack immediately before delivery to the retailer.

surrounded E10. In New South Wales 20% of all vehicles were listed as incompatible with higher ethanol blends. Because of this, the New South Wales mandate did not require ethanol blending into all gasoline. It called for blending into regular grade gasoline only and instead left premium grade gasoline as a widely available ethanol-free substitute for those consumers whose vehicles needed it. New South Wales was not alone in this tactic; In several European countries and in parts of Canada, for example, premium was also left to be an ethanol-free or lower-ethanol substitute for E10. In the case of New South Wales, Noel and Roach (2017) show that concerns over incompatibility and aversion caused consumers to divert consumption to the lower ethanol blend *en masse*. This shift resulted in consumers spending $12.3 million dollars more per month than they did prior to the infusion of ethanol into the fuel supply. Ethanol aversion is not particular to New South Wales or European countries. Roach (2019) shows that consumers in Oklahoma willingly pay 25 cents more on average to consume ethanol-free regular grade gasoline. Roach (2019) further finds that nearly half of this price premium is due to market power and consumers' willingness to pay for non-ethanol gasoline, and that only around 12 cents of the price premium is due to wholesale cost differences.

There are several reasons for mandating that further ethanol blending affect regular gasoline only. First, premium and regular gasoline are perfect physical substitutes for consumers who previously used unblended regular. Premium's reputation as a higher quality fuel derives mainly from its higher price and not from its performance.[14] The defining difference between premium and regular is the octane rating, or resistance to pre-ignition, and in the absence of engine knocking, the higher octane in premium has no advantage over regular.

By excluding premium from the mandate, retailers can make an ethanol-free substitute widely available to those who require it without the potentially prohibitive cost to small retailers of installing new underground storage tanks to handle both E10 and E15 versions of regular gasoline (and possibly E10 and E15 versions of premium). The higher price of premium also dissuades consumers who do not truly require E10 from buying it, while eliminating the need for quantity rationing or the need for regulators to pick which retailers do and do not get to sell ethanol-free gasoline. Hence, exempting premium has been a popular option for keeping multiple ethanol-blends available yet managed.

In the U.S., regardless of whether the EPA takes this selective grade blending approach or relies on increases in the price of RINs to drive a wedge between E10 and E15 production costs and prices, or any other approach, the one constant is that the relative price of E10 must rise. The price must rise in order to successfully push consumers onto E15 wherever possible, while still keeping both grades universally available for the benefit of the approximately 10% of consumers who cannot use E15. In the analysis that follows we allow for both sources of costs, and discuss each separately under a variety of parameter specifications. Our results hold lessons for the E15 rollout in the U.S.. They highlight the difficulties and potential costs of the EPA's efforts to move consumers onto E15, absent the ability to take away E10 as a choice.

We note that instead of a specific blend percentage of corn-ethanol the RFS mandate can be fulfilled by technically *any* renewable fuel, though the 2020 mandate is that 15 billion

[14]See, for example, Setiawan and Sperling (1993).

gallons come from "conventional" biofuels. It comes to pass that corn ethanol has been the cheapest source of compliance for the mandate, and that it is why it is often referred to as the "ethanol mandate." The 15 billion conventional mandate is in force until 2022 when the specific volume standards cease to be in force – though these standards are often extended despite the "no win" situation this puts leaders of the Federal government in.[15,16] Regardless, through 2022, the amount of corn ethanol that is mandated to be mixed into the US gasoline supply pool is 15 billion gallons. Pre-COVID, total US gasoline consumption was around 143 billion gallons, which translates into 14.3 billion gallons of ethanol consumed in E10. 15-14.3 billion gallons leaves only 700 million gallons of ethanol consumption to fulfill the statutory maximum for the conventional mandate. This represents only about 0.5% of total gasoline consumption. In other words, it only takes a 10.5% blend rate pre-COVID to fulfill the conventional mandate in its entirety, but there remains 5.09 billion gallons that of conventional biofuels that can be used to meet the full 20.09 billion gallon standard. The burden estimates presented in this paper specifically estimate how much consumer costs will change if regulatory bodies seek to meet the RFS through conventional biofuels only. That is to say, if regulators reach the full 20.09 billion mandate by pursuing a mostly conventional biofuel strategy instead of relying on 'advanced' biofuels like cellulosic or biomass-based diesel. We believe the cost estimates presented here are pertinent for national and regional policy discussion because both alternatives result in greater consumer costs. On the difference between conventional and advanced biofuels, The Economist summarized the problem succinctly, "biofuels that can best compete commercially are not, in fact, green," and "those that are green cannot compete commercially."[17]

3. DATA, METHODOLOGY

The move from a 10% ethanol blend to a 15% ethanol blend presents multiple sources of cost variation: cost increases due to premium switching, cost changes due to the Renewable Identification Number (RIN) market, and cost differences due to ethanol energy density. Figure 1 distills this information into pictorial form, and equation (1) shows the burden calculation explicitly. We discuss each source of consumer costs separately below.

We calculate consumer burden, $Burden_i$, for each region[18], i, as the sum of two distinct channels: (i) costs due to premium switching, and (ii) costs due to the lower energy efficiency of ethanol. Each part of this calculation depends on the the diversion ratio, D, and the RIN price, RIN. In the three $Burden_i$ scenario evaluations below[19], we vary each parameter while holding the other constant. Volumes and prices are recent averages for each PADD, and this is the value used for each burden calculation. Note, in this calculation we assume complete RIN price pass-through which drives E15 prices lower relative to E10 (and could

[15] Eric Wolff, "Trump set to duck no-win ethanol decision until after election" *Politico* August 17, 2020.

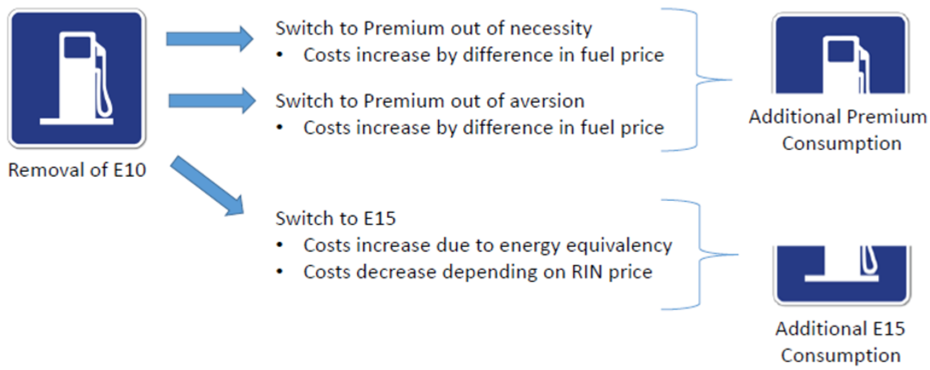
[16] David Pitt, "Corn farmers unleash anger at Trump, EPA over final ethanol rule" *Chicago Tribune* December 19, 2019.

[17] The Economist "Thin Harvest," April 18, 2015. https://www.economist.com/science-and-technology/2015/04/18/thin-harvest?Fsrc=Scn/Tw/Te/Pe/Ed/Thinharvest

[18] Each calculation is aggregated by Petroleum Administration Defense District (PADD)

[19] Each scenario also has three possible parameter values included representing a high, low, and moderate value assumed – this yields 9 total burden estimates.

Figure 1: Fuel Switching Cost Breakdown



Notes: Visual description of how the burden estimates are constructed. Example is of removing one gallon of regular E10 fuel and replacing it with a gallon of new consumption that is either premium or E15.

hence offset any cost increases due to the former two mechanisms).

Let the diversion ratio be represented by the variable D with $0 < D < 1$. This diversion ratio measures the percentage of former regular E10 gasoline purchases that are replaced by new premium purchases. $1 - D$, then, measures the degree to which consumers divert their purchases to the intended fuel, E15. The degree of efficiency losses is represented by the variable L, which is a constant.[20] The RIN price, RIN, is assumed to be fully passed-through in the form of lower fuel prices. We use observed prices and volumes of E10 and premium fuels to calibrate our burden estimates by region. For ease of exposition, subscript E represents regular grade E10 fuel, and subscript P represents premium grade fuel. In all cases we assume it is just the volume of E10 fuel that is diverted into E15 or premium fuels. The two main cost components are bracketed below: costs that arise due to premium switching (left hand bracket) and costs that arise due to the switch to E15 (right hand bracket).

$$Burden_i = [D * Volume_{Ei} * Price_{Pi}] + [(1 - D) * L * Volume_{Ei} * (Price_{Ei} - 0.05 * RIN)] \tag{1}$$

From this we arrive at two basic relationships that determine many of the results presented below

$$\frac{\partial Burden_i}{\partial D} > 0 \tag{2}$$

$$\frac{\partial Burden_i}{\partial RIN} < 0 \tag{3}$$

Given the received literature on consumer acceptance of higher ethanol blends, we do not expect the market to be fully accommodating of E15. For example, there are a number

[20] Pure ethanol is 33.3% less efficient than gasoline, which means that E10 is 3.33% less efficient than non-blended regular gasoline. In other words, relative to E10 it is expected that a car using a gallon of "E0" would travel 3.33% further. E15 is thus 1.67% less efficient than E10.

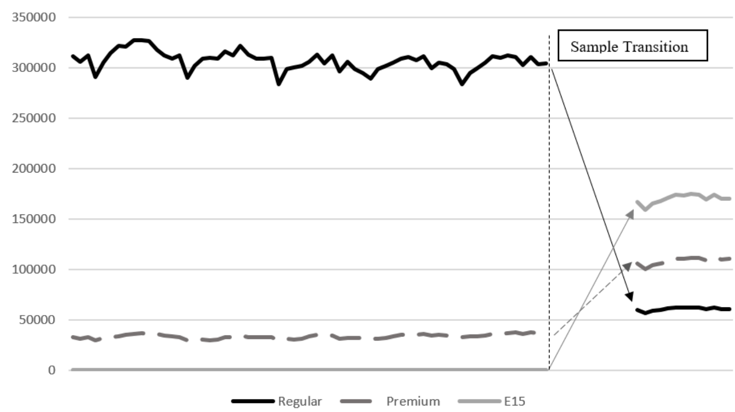
of consumers that are simply not able to switch to E15 due to vehicle compatibility issues. These consumers must continue to search for E10 where available, or divert their consumption to premium. The costs incurred by these consumers are guaranteed to be positive as the price of premium fuel is higher than regular fuel for all PADD areas. Second, there remains a significant portion of the population that is ethanol averse and will choose to consume premium instead of E15. We remain agnostic to the reason that this aversion exists and simply account for further premium diversion in our calculations. Both sets of consumers, those who must switch and those who switch even though they don't have to, are included in the ratio of consumers diverting to premium.

There are a number of cars that can and will make the switch to E15 from E10. These consumers may face two possible cost scenarios that we account for in our model. Because ethanol has a lower energy conversion rate the amount of miles that can be driven on a single gallon of E15 is slightly less than the amount from E10. Thus, we must account for differences in energy equivalence. Another confounding factor is the Renewable Identification Number (RIN) mechanism that the government uses to implement and monitor the Renewable Fuel Standard. The existence of the RIN market allows for ethanol-blenders to be compensated for scarcity in ethanol-blending. This secondary income stream allows ethanol-blended fuels to have a lower at-the-pump price and incentivizes consumption. For instance, if the RIN price is $0.71, then E10 could be sold at a $0.071 cent discount compared to E0, all else equal. This implies that the E15 price should be lower than the E10 price depending on the RIN price. Taken together, consumers could be better off or worse off depending on RIN prices. If RIN prices are high enough to drive the price of E15 considerably lower, then even after energy-equivalence issues are accounted for consumers could spend less per mile driven. We calculate consumer costs under various RIN prices to show the effect that this market has on our overall burden calculation. Even under conservative diversion ratios and a RIN price that matches the peak RIN price from 2013 ($1.47) we find that consumer burden would be more than $580 million per month for the entire United States.

As an illustrative example, let us first consider the cost of an E15 mandate when E15 is fully accepted and there is no RIN market. In other words, the only source of consumer burden is due to the engineering differences and relative heat rate differences between E10 and E15. We find that each PADD area will pay an average of $45.2 million per month in additional fuel expenses with the Midwest PADD accumulating as much as $87.9 million more per month in extra expenditures. The total expense per month is over $316 million. We note that this cost is strictly due to the fact that more fuel must be consumed to travel the same distance as E10.

Now, suppose that the regulating authority would like to remove this consumer cost by subsidizing the E15 price relative to the E10 price. The mechanism that currently exists to subsidize E15 relative to E10 (or E0) is the RIN permit market where RINs are openly traded so that firms may meet their requirements under the Renewable Fuel Standard. If the RIN price is low, then that means firms are meeting their mandated amount of ethanol blending. If the price of a RIN increases, then this means blenders are not able to meet escalating requirements and higher ethanol blends. However, by receiving a higher subsidy per gallon, fuels like E15 are able to have a lower price than E10. Using data from 2013-2015 Knittel and Smith (2015) find that RIN prices pass through to retail prices completely, and

Figure 2: Sample Transition



Notes: Example time-series of the transition to E15 using historical data to show how displaced E10 consumption (black line) being replaced by both new E15 (grey line) and premium fuel (dashed line).

that downstream prices reflect RIN price changes within two business days. If regulators would like to 'remove' the burden due to the lower heat rate of E15, or in other words offset the efficiency difference through a price discount, then the RIN price in a "no-aversion" scenario ought to be approximately $0.97. We note, though, that this would only remove the consumer burden associated with a move to E15. The higher RIN price still reflects a cost to blenders that are not able to meet their requirements and are purchasing RINs in the market.

3.1. Data, Calibration

We calculate the potential costs of the move to E15 under a variety of policy scenarios in a model calibrated with data on fuel consumption and prices in the United States. We are also able to offer region-specific analyses by using data aggregated by Petroleum Administration for Defense Districts. The data used to calibrate our model comes from the Energy Information Administration, and is at a monthly interval over the time period from October 1997 - September 2017. Summary statistics for each series are displayed below in table 1.[21]

In our baseline model we assume that a proportion of regular E10 continues to exist while regular E15 is gradually phased in, but later toggle this to allow for full accommodation of E15. We also assume that premium gasoline remains in the market at a 10% ethanol blend; a near-perfect substitute for the replaced regular (E10) gasoline. This assumption matches how higher ethanol blends have been phased into existence in other countries pursuing more stringent ethanol goals. In our baseline model we assume that 20% of the amount of regular E10 that was previously bought and sold continues to be sold at stations that have not converted to selling E15. The remaining 80% of fuel demand is thus replaced by E15 (which is intended) or premium gasoline (which is unintended) depending on the diversion ratio

[21] Without loss of generality we choose to exclude midgrade fuel from our analysis. We do this for the following reasons: Midgrade has the lowest market share of all fuels in each PADD area, the higher price would still result in an increase in consumer burden, and we expect aversion to some in-between blend (e.g. E12.5) would still be present.

Table 1: Summary Statistics

Variable	Full Sample Mean	Five Year Mean	Standard Dev.	Min	Max
New England					
Regular Volume	441,102.91	441,659.23	43,034.75	327,528.00	528,134.60
Premium Volume	57,717.05	50,881.73	15,359.32	36,321.00	105,979.70
Regular Price	2.36	2.89	0.88	0.97	4.10
Premium Price	2.62	3.28	0.92	1.17	4.32
Central Atlantic					
Regular Volume	1,133,876.49	1,077,125.24	119,017.56	809,316.00	1,356,067.10
Premium Volume	199,975.27	149,959.62	65,602.35	119,576.80	370,946.00
Regular Price	2.36	2.89	0.87	0.95	4.08
Premium Price	2.61	3.29	0.92	1.13	4.32
Lower Atlantic					
Regular Volume	1,585,026.06	1,666,613.55	181,335.89	1,063,560.40	1,817,027.80
Premium Volume	246,054.86	198,076.28	72,584.11	155,523.00	448,384.00
Regular Price	2.33	2.81	0.87	0.87	3.99
Premium Price	2.54	3.22	0.92	1.06	4.25
Midwest					
Regular Volume	2,615,594.47	2,711,761.34	170,911.27	2,034,789.00	2,975,379.00
Premium Volume	243,681.24	216,764.54	78,362.49	147,597.00	474,089.20
Regular Price	2.28	2.76	0.86	0.89	3.99
Premium Price	2.53	3.16	0.89	1.07	4.20
Gulf Coast					
Regular Volume	1,521,145.17	1,699,393.05	199,118.68	1,007,792.80	1,942,912.60
Premium Volume	172,452.48	164,215.81	46,325.51	106,563.00	310,936.20
Regular Price	2.19	2.61	0.83	0.89	3.93
Premium Price	2.46	3.02	0.09	1.09	4.18
Rocky Mountain					
Regular Volume	318,549.36	351,719.47	40,556.05	217,629.00	419,594.30
Premium Volume	55,048.64	67,259.27	10,405.92	37,976.40	92,990.70
Regular Price	2.31	2.80	0.83	0.96	4.08
Premium Price	2.55	3.13	0.85	1.14	4.31
West Coast					
Regular Volume	1,545,375.44	1,557,616.85	116,801.04	1,175,750.80	1,781,535.90
Premium Volume	281,830.42	322,171.30	37,043.35	215,043.00	390,671.30
Regular Price	2.57	3.23	0.91	1.07	4.37
Premium Price	2.81	3.51	0.93	1.30	4.60

Notes: Five year mean is the average over the final five years of the sample (2012m9-2017m9). Volume is expressed in thousands of gallons, prices are in dollars.

between the two. For example, if 30% of consumers choose to use an ethanol blend of 10% due to incompatibility issues or ethanol aversion, then we would expect that from the diverted regular sales, 10% will be forced to purchase premium-grade while the remaining 90% will shift their consumption to E15. An example transition of fuel sales using the baseline diversion ratio assumption is shown in Figure 1. All results are calculated at the average from the final five years in the data.[22]

4. BURDEN ESTIMATES

Our goal is to measure the costs of transition to E15. To do so, we run a set of policy experiments that allow us to examine how each cost mechanism changes the overall consumer burden while holding other factors that influence consumer burden constant. *Ceteris Paribus*, as it were. In the analyses that follow we show how consumer burden changes under different RIN prices holding the premium diversion ratio constant; we then discuss how consumer burden changes when RIN prices change when there is no premium switching; we conclude by showing how consumer burden changes under various premium diversion ratio assumptions holding RIN prices constant. In total, ten different policy scenarios are considered. To preview results, we find that consumer burden is increased in nine out of the ten scenarios.[23]

4.1. Consumer Burden Due to Energy Efficiency Differences and RIN Price

We begin our discussion of consumer burden by examining the effects of RIN prices when there is a small population of consumers that will avoid E15. Because there is a difference in energy efficiency between E15 and E10, it is unclear whether consumers would be made better or worse off due to a lower E15 prices (relative to E10 prices). That is to say, if the RIN price is sufficiently high consumers could be more than compensated for the losses felt due to the difference in energy efficiency.

Our baseline assumption of the diversion ratio allows for a very modest amount of consumer aversion to ethanol-blended fuels. The American Automobile Association (2013) (or more commonly, AAA) has estimated that 90% of all vehicle drivers must avoid E15. The AAA's estimate includes any car that does not specify that E15 is safe for use from their manufacturers. The EPA, on the other hand, has specified that any post-2001 car may use E15 safely. According to a 2009 National Household Travel Survey the amount of vehicles that are made before 2001 is at least 36% of the vehicle fleet. Work by the IHS, a consulting agency, finds that the average vehicle age in the U.S. is 11.4 years (IHS, 2014). More recently, the IHS has estimated that the average vehicle age actually increased to 12.1 years, and the Bureau of Transportation Statistics estimates that the average light duty vehicle in 2020 is 11.9 years old. This is partly due to high car prices for both used and new cars due to chip shortages. This means that a substantial amount of the vehicle fleet is model year 2009 or

[22] Cost estimates based on the average over the full twenty year sample are available from the authors on request

[23] The only scenario which does not result in increased consumer burden is unlikely to actually ever occur. This scenario assumes that there is no aversion switching, but a binding RIN market with a RIN price greater than the historical peak.

Table 2: Consumer Burden by RIN Price

	$0.05	**$0.75**	**$1.50**
PADD 1A - New England	$53,378,865	$41,038,075	$27,815,799
PADD 1B - Central Atlantic	$130,701,094	$100,602,857	$68,354,746
PADD 1C - Lower Atlantic	$233,507,971	$186,939,333	$137,044,364
PADD 2 - Midwest	$327,387,455	$251,620,929	$170,442,507
PADD 3 - Gulf Coast	$209,251,340	$161,768,785	$110,894,620
PADD 4 - Rocky Mountain	$36,670,593	$26,841,575	$16,310,483
PADD 5 - West Coast	$147,657,896	$104,128,225	$57,489,292
Average Cost Per Gallon	$0.10	$0.08	$0.05

Notes: Table holds constant the diversion ratio from E10 to premium, calculates consumer burden due only to adjusting the RIN price.

older.

Using a baseline diversion ratio assumption of 70% diversion to E15 and 30% diversion to premium we are able to discuss how RIN prices affect the overall burden of increasing ethanol requirements. We later measure how the RIN market and energy efficiency differences affect consumer burden when there is no diversion to premium.

Prior to the RIN price run-up of 2013, historical RIN prices were very low and maintained a price close to zero. In this time frame the ethanol requirements were, in a sense, non-binding for two reasons: consumers readily accepted 10% ethanol blends, and producers were able to meet their requirements through blending and didn't have to resort to the secondary RIN market to fulfill their legal obligations under the Energy Independence and Security Act. Under mounting uncertainty about future EPA-mandated volumetric requirements, reaching the blendwall of 10% ethanol blends, and general macroeconomic distress, RIN prices shot upwards reaching as high as $1.47 per RIN. While we remain agnostic to the reason for these tensions in the RIN market, we do recognize the price effects that the existence of this market have on break-even prices. Thus, we allow increasing RIN prices to drive a wedge between regular E10 and E15 prices that make E15 substantially less expensive relative to E10 under high RIN prices, and vice versa in the non-binding scenario of low RIN prices. Table 2, below, shows our consumer burden estimate under non-binding policy scenarios as well as binding policy scenarios similar to when the RIN price reached its peak in 2013 using a 70/30 diversion ratio.[24]

The potential cost borne by consumers under escalating renewable fuel standards are sizeable. We find that when the RIN price is $0.05 cents, the burden on consumers is more than $1.13 billion per month across the United States. The average change in cost per gallon to consumers is approximately 10 cents in this scenario. The cost borne by consumers when switching to an E15 system under these assumptions is very large, and remains so under very high RIN prices. We find that the total burden of moving to E15 remains positive even as RIN prices increase and producers can offer E15 at a lower energy-adjusted price than

[24]Note, that the burden estimate when the price of a RIN is low but still binding (e.g. $0.60) is shown in the baseline specification of table 4, below.

regular E10. Even when RIN prices surpass their 2013 peak, consumers will still pay an average of \$0.05 cents more per gallon simply due to the infusion of E15 into the fuel supply. The aggregation of this cost results in as much as \$588 million dollars extra per month, or more than \$7 billion over a year, for the entire United States.

4.2. Consumer Burden Due to Energy Efficiency Differences and RIN Price, No Premium Switching

The prior section showed that even under historically high RIN prices there is a substantial consumer burden due to the switch to E15. A large portion of this burden is due to consumers that must move to premium-grade fuels to avoid consuming E15.[25] We next examine the burden that consumers will bear when there is no premium switching. In this scenario RIN prices and energy efficiency differences are the only determinants of consumer burden. We still assume that 30% of cars do not use E15, so the amount of regular that remains in the market is now set at 30% instead of 20% (as we assume in all other scenarios). The same range of RIN prices is displayed in table 3 as before, though we must note that it is *very* unlikely to see a RIN price that matches the peak historical price when consumers readily accept the higher ethanol blend.

The absence of premium switching is the best-case scenario for policy makers. Here, the only possible source of increased costs to consumers are caused by differences in energy efficiency between the two fuel grades, and the relative price difference between E10 and E15. In this best-case scenario we find that consumer burden is still substantial. When RIN prices are low and similar to their pre-2013 levels, consumer burden is as much as \$299.9 million dollars per month for the entire nation, or over \$3.6 billion dollars in a year. This translates into a 2.8 cent increase in the cost per gallon. This model specification is our preferred specification and is the model underlying most of our 'headline' results. It is below the median burden estimate across all policy experiments. Recall, that as RIN prices increase, the difference between the price of E10 and E15 grows. Thus, it is only when RIN prices are substantially high that the price of E15 more than compensates for the loss in energy efficiency. In this no-premium-switching scenario, we find that the break-even RIN price would need to be approximately \$0.97 for consumer burden to be \$0. This is why consumer burden is negative for all PADD areas at a RIN price of \$1.50. If RIN prices were to reach the one dollar mark, we find that consumers are still negatively affected by the transition to E15 in the West Coast PADD, and others are nearly breaking-even compared to no policy change with an average savings per gallon of one tenth of one cent. We find that when the RIN price is \$1.50 consumers save two cents per gallon on average. We report this number with a degree of hesitation, though. Remember that we have assumed in this section that there is absolutely no premium switching. It is highly doubtful that when there are no incompatible vehicles on the road *and* consumers readily accept E15 that the market for RINs would be "binding." Elevated RIN prices signal that producers are not able to meet their requirements under the Renewable Fuels Standard. We do not expect that producers will have a difficult time meeting their blending requirements if consumers switch to E15 without trepidation. Thus, we believe the RIN price scenario of \$0.05 cents per RIN is more

[25] The prior diversion ratio was 70/30, now we assume no diversion.

Table 3: Consumer Burden by RIN Price, No Premium Switching

	\$0.05	**\$0.75**	**\$1.50**
PADD 1A - New England	\$14,227,353	\$3,454,926	\$8,086,959
PADD 1B - Central Atlantic	\$34,861,688	\$8,587,227	\$19,563,981
PADD 1C - Lower Atlantic	\$51,012,664	\$10,362,010	\$33,192,262
PADD 2 - Midwest	\$83,148,104	\$17,015,819	\$53,840,202
PADD 3 - Gulf Coast	\$49,158,843	\$7,712,444	\$36,694,411
PADD 4 - Rocky Mountain	\$11,034,046	\$2,452,849	\$6,741,290
PADD 5 - West Coast	\$56,442,582	\$18,438,012	\$22,281,170
Average Cost Per Gallon	\$0.03	\$0.007	\$0.02

Notes: Table assumes no diversion from E10 to premium, calculates consumer burden due only to adjusting the RIN price.

realistic for this no-premium-switching scenario and better matches what was realized in the market prior to ethanol blend-wall being reached. If we assume that the RIN price is \$0.60 per RIN, the average price over the prior few years, we find that consumer burden amounts to over \$117 million per month.[26]

4.3. Consumer Burden Due to Premium Switching

Even when E15 is readily accepted and there is no diversion to premium we find that consumer burden is nearly \$300 million per month on average. However, given the findings of Noel and Roach (2017), Roach (2019), and industry estimates of the amount of vehicles that are simply incompatible with E15, we do not expect such an easy implementation of higher ethanol blends. Thus, we account for a range of ethanol aversion scenarios to understand the full extent to which consumer burden may vary. This final analysis discusses how consumer burden changes depending solely on the underlying premium diversion ratio while holding RIN prices constant at \$0.60.[27]

We first consider a scenario in which there is no aversion to ethanol. In this case we use the minimum vehicle incompatibility estimate of 10% and continue to have a 20% regular E10 market share. In this scenario, we find a substantial burden estimate of more than \$229 per month million. We know that a minimum of 10% cannot use E15, and others have estimated that up to 30% of the market cannot use higher ethanol blends. Whether this is real or perceived, we denote this as a 'low aversion' scenario and assume that consumers whose cars are incompatible with higher ethanol blends will be diverted to premium. Thus, we assume that 90% of consumers that previously purchased regular move to consume E15 while the remaining 10% switch to premium out of necessity.[28] Even in this best-case scenario (for policy makers) the move to higher ethanol blends still comes at a considerable cost. In this scenario we find that consumer burden would still, comfortably, be more than ten million per

[26] See below in Table 4.
[27] RIN Prices have hovered around \$0.60 since the price peak in 2013.
[28] Recall that we allow for 20% of the market to still have access to E10

Table 4: Consumer Burden by Diversion Ratio (E15/Premium)

	Baseline (70/30)	No Aversion	Low Aversion (90/10)	High Aversion (30/70)
PADD 1A - New England	$43,682,530	$12,377,448.39	$18,987,431	$92,721,360
PADD 1B - Central Atlantic	$107,052,480	$26,704,042.00	$46,601,684	$227,112,149
PADD 1C - Lower Atlantic	$196,918,327	$35,260,303.24	$80,329,471	$428,444,370
PADD 2 - Midwest	$267,856,613	$54,105,209.75	$113,271,086	$574,756,765
PADD 3 - Gulf Coast	$171,943,618	$1,098,547.27	$70,098,362	$374,161,467
PADD 4 - Rocky Mountain	$28,947,793	$7,518,950.08	$12,941,179	$60,747,665
PADD 5 - West Coast	$113,456,012	$39,626,514.24	$58,158,555	$223,321,581
Average Cost Per Gallon	$0.05	$0.03	$0.04	$0.18
Breakeven RIN Price	$3.05	$1.45	$1.66	$5.82

Notes: Table assumes constant RIN price, calculates consumer burden due only to premium switching. RIN price assumed to be $0.60, market share of remaining regular E10 is 20%.

month on average for each PADD area. Over a full year the expected costs would be nearly $19 million for the New England Area, and reach $113.3 million in the Midwest. Across all PADD areas the total cost amounts to $400.4 million per month or $4.8 billion over a year. The average cost increase consumers would see is approximately 4 cents per gallon.

We next consider the baseline diversion ratio assumption from above which allows for a very modest amount of consumer aversion to ethanol-blended fuels. Our baseline diversion ratio specifies that 70% of all regular E10 is replaced with purchases of E15, and the remaining 30% of removed E10 is diverted to premium due to incompatibility, aversion, or both. We find that when there is a modest amount of ethanol aversion, consumers will be faced with a burden ranging from $29 million per month to $267.9 million per month depending on the PADD area. Across all PADD areas the total cost amounts to $929.9 million per month or $11.16 billion over a year. These regional-estimates are sensitive to the total amount of fuel sold in a PADD area which is the reason there is large range across geographic regions. On a per gallon basis across all PADD areas, infusing E15 into the fuel supply is tantamount to raising gas prices by approximately 5 cents per gallon.

Our final policy-scenario is one in which there is significant ethanol aversion. This scenario assumes that only 30% of all replaced regular E10 sales are made up with new E15 sales. As one would expect the costs are most dire in this circumstance because a large proportion of consumers are now paying premium prices in order to avoid consuming E15. We find that consumer burden would be as much as $1.98 billion per month or nearly $23.8 billion over a year when there is a large degree of ethanol aversion. We don't consider this scenario to be out of touch, though, because this is how Australian consumers responded to increasing ethanol standards (Noel and Roach, 2017).

Table 4 also displays the breakeven RIN price that would be necessary to make consumer burden $0 on average.[29] We can see that in the baseline model the breakeven RIN price is more than $1.50 greater than the RIN price has ever been. This is more than double the RIN price peak of $1.47 in 2013. The breakeven RIN price remains high even when there is no premium switching. Here, the price exceeds the historical maximum by 19 cents. Finally, the breakeven RIN price that is necessary under a high aversion scenario is nearly four times

[29] Those who switch to premium out of necessity would still be negatively affected by the policy due to higher fuel costs.

more than the historical maximum. This large of a RIN price translates into a $0.29 discount on E15 relative to E10.

An interesting dynamic to make note of is the issue of increasing diversion ratios over time. Noel and Roach (2017) show that in New South Wales each additional increase in the ethanol requirement led to further diversion to premium, instead of the policy-intended ethanol blend. This result is due to reaching the Australian ethanol-blendwall, which turned out to be much lower than policymakers may have estimated given the degree of ethanol aversion. In the U.S. the blendwall has typically been estimated as 10%, though with the approval of E15 regulators are seeking to raise this limit. Given the potential for aversion, it is possible that the issuance of E15 could follow the same dynamic path of increasing diversion ratios over time. In that sense, it is possible that our results show how costs will evolve over time after reaching the blendwall. We would expect that in the very early stages of an E15 rollout consumers with the least aversion will switch to E15 readily while later, under increasing volumetric requirements to meet the 2022 goal, more and more consumers will transfer their consumption to premium fuels. Under this scenario the monthly costs of increasing ethanol requirements could increase by a factor of three from the already non-trivial amount when there is no aversion.

5. CONCLUSION AND POLICY IMPLICATIONS

Ethanol has historically been perceived as a silver-bullet for policymakers. While there may be an ample amount of goals or motivations that policymakers have when considering increasing the amount of ethanol in the fuel supply, our analysis shows that these goals are met at a very high cost to society. Using a regionally-calibrated model we examine the potential future costs that consumers will bear when increases in the volumetric ethanol requirement are achieved through the dispatch of E15, a new blend with a higher ethanol content. We find that even under the most conservative of assumptions, when there is no aversion to this higher blend and only a small fraction of the vehicle fleet must continue to use E10 due to incompatibility issues, costs to consumers amount to over $229 million per month, or $2.7 billion over a year. Moreover, we find a large and positive estimate of consumer burden in nine out of ten simulated policy experiments ranging from $68 million per month to nearly $2 billion per month. In the only version of the model we see a net benefit the total amounts to about $188 million per month. The median burden estimate across all scenarios is about $588 million per month.

The introduction of higher ethanol blends have been controversial elsewhere in the world, and there is substantial evidence that consumer sentiment in the United States towards a higher ethanol blend may be unfavorable. Consider the fate of E85, for instance, in attracting a customer base that is not made up of government fleet drivers.[30] Given the discord between the EPA and vehicle manufacturers over the safety of E15 at least a fair amount of ethanol-aversion can be expected. Whatever the cause of this aversion: risk aversion, loss aversion, status-quo bias, or simple animus, we can expect ethanol-averse consumers to avoid E15 by

[30] Even federal fleet drivers, who must purchase E85 when available, are unsure about E85. When surveyed 26.5% did not know if their car could even use the fuel (Daley et al., 2014).

continuing to purchase E10 in any form, even if they must choose (more expensive) premium fuel. When we account for only a small amount of aversion we find that consumers will pay an extra $400.4 million per month, or $4.8 billion over a year. If ethanol-aversion is relatively high, this increases to over $929 million per month, or more than $11 billion over a year. The aggregation of costs over the entire United States is substantial, however, on a per-consumer basis the decision to avoid higher blends of ethanol conforms to salient findings in the behavioral economics literature. If there is any uncertainty of whether or not E15 will cause damage to a car resulting in the loss of a major investment, then paying up to 18 cents more per gallon is a very cost-effective insurance policy to avoid future damages or the loss of a vehicle.

We must note that the costs reported here are simply due to elevated at-the-pump expenditures and energy efficiency differences. We have not included firm-level costs in the form of new underground fuel tank or pump changeovers. These costs may be passed on to consumers in the form of higher fuel prices which we are not able to account for. We have also not included any search costs in our model. If regular E10 is still available, but only in rural or increasingly scarce city locations, then consumers may invest in time, effort, and fuel to find these locations. This cost is obviously idiosyncratic to the individual so we have not included it. Both search costs and infrastructure changeover costs pose a potential charge to the consumer. This means that our cost estimates, while already quite large, may in fact underestimate the true additional cost that consumers could face. We also abstract away from costs incurred to try and educate the public about the safety of E15. Most consumers display a level of inertia in their decision-making, and many use markings next to or printed on their gas caps. Only in the most recent vintage of vehicles is E15 specified as safe for use in vehicles.

There are some benefits to adding ethanol to the fuel supply, though these are contested within the literature with reference to land price changes, and the emissions intensity of ethanol production. Nevertheless, this policy does stand to reduce carbon dioxide emissions from vehicle travel so we calculate these benefits. In our preferred conservative specification that yields a burden estimate of approximately $299.9 million per month[31], we estimate that carbon dioxide emissions decrease by approximately 169,286 tons per month.[32] While this is obviously beneficial from an environmental perspective, the cost of this reduction is approximately $1,771 per ton of carbon dioxide removed. This is drastically greater than equivalent permit prices in carbon dioxide cap and trade markets, and also outpaces many estimates of the social cost of carbon. Indeed, ethanol mandates have already been found to be an expensive way to reduce carbon dioxide emissions (Noel and Roach, 2017).

While we have presented evidence that the cost of infusing more ethanol into the fuel supply would be substantial, we do have a policy recommendation should the EPA and other law-making authorities continue to favor heightened ethanol requirements. First, mandate that all new vehicles be able to accommodate higher ethanol blends without breaking warranties. Wait. Then increase volumetric ethanol standards with the introduction of a fuel with a higher ethanol blend. This will ensure against any incompatibility switching, real or perceived. We must note, though, that even when E15 is fully accommodated, the best

[31]No premium switching and a low RIN price of $0.05.
[32]Against a baseline of all gallons of gas being E10.

of circumstances, consumer burden would be $3.6 billion over a single year due to energy efficiency differences.

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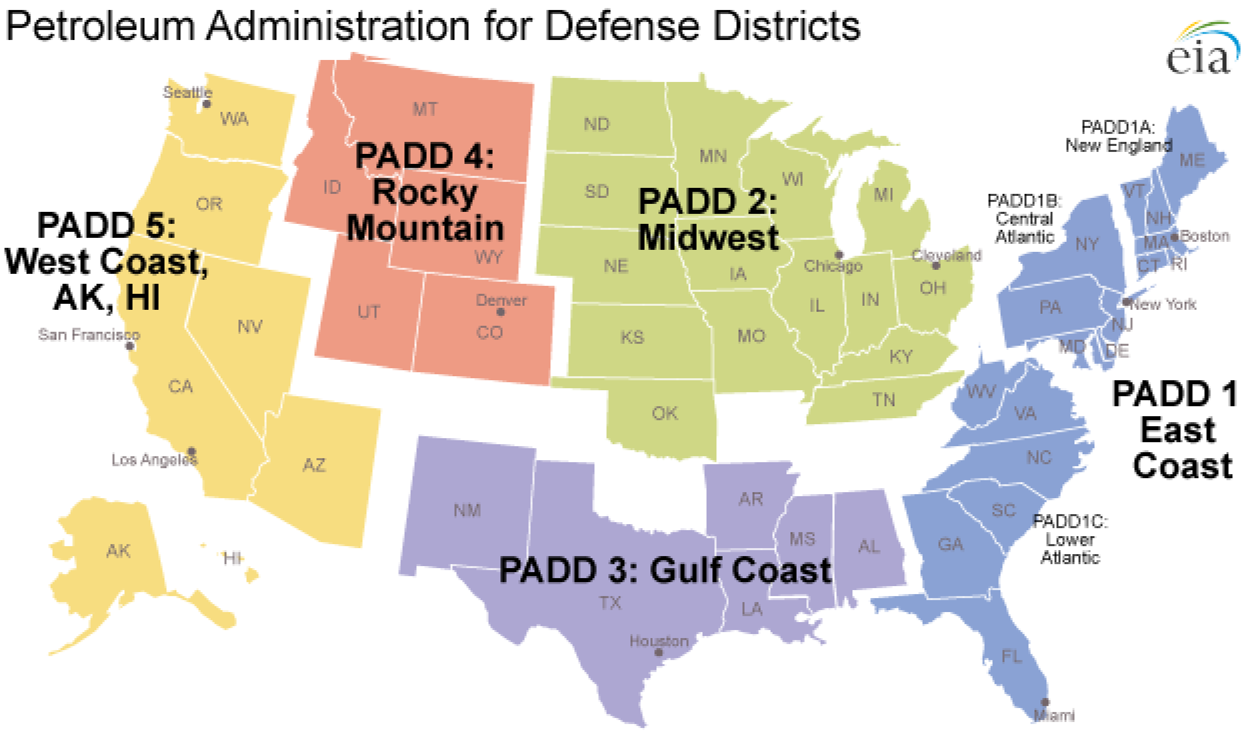
APPENDIX

PADD Map



Notes: Example time-series of the transition to E15 using historical data to show how displaced E10 consumption (black line) being replaced by both new E15 (grey line) and premium fuel (dashed line).