The Impact of Introducing E15 in California[1]

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I. Executive Summary

The introduction of E15 to California has the potential to impact many different stakeholders and their economic interests, including consumer expenditures on fuels like gasoline and ethanol, oil companies' decisions about ethanol-gasoline blends and octane content, as well as automobile companies' design and manufacturing decisions in response to E15 fuels in California, among others.

This report details the economic viability and implications of adopting E15 in California by analyzing fuel characteristics, market dynamics, and regulatory influences. We present a review of the literature on biofuels in the US and abroad, a conceptual framework that documents important characteristics affecting fuel prices and details how they are interrelated across different fuel types, and a statistical analysis using gasoline and ethanol price data from across the US.

The literature review reveals several important themes regarding the use of ethanol-blended fuels. Historical data shows that biofuels, introduced in response to oil shortages and high gasoline prices, have contributed to reducing fuel prices and enhancing energy security in the US. Studies indicate that biofuels have lowered gasoline usage by 4% and fuel prices by 10-17 cents per gallon. The economic benefits are attributed to improved production efficiencies and lower costs of ethanol over time. The literature also highlights the environmental benefits of biofuels, such as reduced greenhouse gas emissions, aligning with California's goals under the Low Carbon Fuel Standard (LCFS).

The conceptual framework suggests that E15's higher octane rating for regular grade fuel (88 compared to E10's 87) should be expected to result in a value premium due to improved engine efficiency and performance. Despite E15's slightly lower energy content compared to traditional gasoline, the benefits from higher octane and potential engine efficiency improvements should at the very least offset this difference. Introducing E15 increases the fuel supply, thereby reducing overall equilibrium prices through supply-demand interactions. This increased availability and competition are expected to enhance the pass-through of cost savings to consumers, ensuring that

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lower ethanol production costs are reflected at the pump. Additionally, the California LCFS should be expected to further reduce prices for E15 due to its lower greenhouse gas (GHG) intensity. The framework also indicates that increased competition and availability of E15 could lead to greater cost savings passed on to consumers, reflecting the lower production costs of ethanol.

Empirical findings from our analysis corroborate these insights. Using existing gasoline and ethanol-blended fuel data from two primary sources (the Energy Information Administration and E15prices.com), we develop a hedonic pricing model to estimate the absolute and relative importance of different fuel characteristics on prices. Our findings suggest the adoption of E15 is projected to result in approximately 20 cents per gallon discount compared to E10. In particular, our estimates suggest an approximately 20 cents per gallon discount for E15 compared with E10 after adjusting for energy content. If we multiply this estimate by the number of gallons of fuel purchased per year in California (13.49 billion[4]), potential savings for consumers can reach $2.7 billion annually. Low-income commuters may stand to gain the most from a transition towards E15.[5]

However, the adoption of E15 will require strategic considerations regarding market structure and infrastructure modifications. Decisions by branded and unbranded gas stations on whether to add separate E15 nozzles or replace existing E10 nozzles, along with adjustments in pricing strategies, will be critical for successful implementation. The next phase of work will focus more closely on these considerations.

[4] https://www.energy.ca.gov/data-reports/energy-almanac/transportation-energy/california-retail-fuel-outlet-annual-reporting

[5] Following the logic of Wu, JunJie, Steven Sexton, and David Zilberman. "Energy price shocks, household location patterns and housing crises: Theory and implications." *Energy Economics* 80 (2019): 691-706.

II. Introduction and Background

The new millennium have witnessed the introduction of biofuel, and in particular E-10 ethanol, to expand the supply of fuel and reduce its greenhouse gas emission (GHG). The major legislation introducing ethanol mandates set a "blend wall" - an upper bound of 10% on ethanol use with gasoline in a standard gasoline engine. In 2011, the U.S. Environmental Protection Agency legally approved the use of E15 in light-duty vehicles built in 2001 or later years[6]. This means more than 90% of the existing vehicles in operation in the United States are legally approved to use E15[7]. California is the only state that has not yet approved the sale and use of E15[8], despite the completion of extensive vehicle testing by California Air Resources Board[9].

Biofuels were introduced in the 1970s in both the US and Brazil in response to oil shortages and high gasoline prices. The emergence of the US biofuel sector in the new millennium was associated with the drastic increase in the price of oil, and also provided a mechanism to replace MTBE as an octane enhancer. The rise of oil prices in the beginning of the new millennium contributed to the financial crisis of 2007-08, as home prices in the suburbs declined because of higher transportation costs, leading many of these homeowners to default on their mortgages. This set of events emphasized the importance of affordable fuel for the welfare of the American consumer.[10]

Both the need to enhance energy independence and improve octane led to the Energy Independence and Security Act of 2007, which led to the introduction of an ethanol mandate and the use of E10 as a automobile fuel[11]. The initial policy pertaining to biofuel included a subsidy, but it was removed in 2012 as the ethanol industry, through improved efficiency, seemed viable without it. Assessment of the US biofuel program found that they improved the US balance of trade and led to small reductions in greenhouse gas emissions.[12]

A meta analysis of the literature on the impact of biofuel suggests the introduction of biofuel reduced the usage of gasoline in the US by 4% between 2005 - 2020 and reduced the price of fuel by slightly more than 5%, or between 10-17 cents/gallon, to the American consumer.[13] The cost of producing corn and processing ethanol have declined drastically over time–declining by

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[6] https://www.epa.gov/fuels-registration-reporting-and-compliance-help/e15-fuel-registration#about-e15
[7] Experian Automotive. Automotive Market Trends Report. June 2024. Available at: https://www.experian.com/automotive/auto-market-trends-webinar-form
[8] https://energy.agwired.com/2024/01/04/montana-becomes-49th-state-to-approve-e15/
[9] https://www.sciencedirect.com/science/article/abs/pii/S0016236123014497)
[10] Wu, JunJie, Steven Sexton, and David Zilberman. "Energy price shocks, household location patterns and housing crises: Theory and implications." *Energy Economics* 80 (2019): 691-706.
[11] Rajagopal, Deepak, and David Zilberman. "Environmental, economic and policy aspects of biofuels." *Foundations and Trends® in Microeconomics* 4, no. 5 (2008): 353-468.
[12] Khanna, Madhu, Deepak Rajagopal, and David Zilberman. "Lessons learned from US experience with biofuels: comparing the hype with the evidence." *Review of Environmental Economics and Policy* 15, no. 1 (2021): 67-86.
[13] Hochman, Gal, and David Zilberman. "Corn ethanol and US biofuel policy 10 years later: A quantitative assessment." (2018): 570-584.

45% in the US between 1983 and 2010. This contributed to reducing the cost of ethanol, and these gains in productivity are likely to continue to put downward pressure on fuel prices in the future.[14] The literature on biofuel suggests that it has contributed to lowering fuel prices for consumers, enhancing energy security, and improving the US balance of trade.

There is a rich literature on the pricing of E10 gasoline, as well as E85 gasoline to some extent, under current regulatory policy. There is evidence that non-blended gasoline has a price premium over E10, reflecting some price discrimination against consumers with preference to avoid ethanol.[15] But, this is not the case when the mandate is binding and the only gasoline available is blended with some fraction of ethanol.

Market power is another important consideration in evaluating fuel prices. For example, entry of a new gas station into a region tends to reduce the incumbent's price of gasoline by 2 cents on average.[16] This suggests that regulations, primarily constraints on new station entry and modification of existing gas station infrastructure, may reduce the price effect of enabling more intensive use of E15.

The literature suggests that when it comes to E10, there is full cost pass-through at the pump. Namely, if the cost of ethanol declines, the cost of E10 will decline proportionally.[17] However, there is evidence from Minnesota of only partial pass-through for E85, especially when the availability of E85 is limited, and the consumer price may be higher than predicted by a competitive model. However, increases in competition and availability of E85 in multiple stations will lead to increased pass-through. This suggests that increased availability of higher grade ethanol will eventually reflect the lower cost, and as a result, pricing at the pump, based on the fuel's actual energy content.[18]

Furthermore, because the supply of ethanol seems to be more price-sensitive than the supply of gasoline in the US, increases in ethanol-share may lead to reductions in the price of ethanol fuel blends. The literature suggests that ethanol and gasoline should be substitutes e.g., reduced price of ethanol will tend to shift away from gasoline and reduce the overall price to consumers.[19] However, during periods when ethanol is blended with gasoline at fixed proportions and under a binding blend wall, the two behave like complementary goods with prices moving the same

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[14] Khanna, Madhu, Deepak Rajagopal, and David Zilberman. "Lessons learned from US experience with biofuels: comparing the hype with the evidence." *Review of Environmental Economics and Policy* 15, no. 1 (2021): 67-86.
[15] Roach, Travis. "Market power and second degree price discrimination in retail gasoline markets." *Energy Economics* 84 (2019): 104514.
[16] Taylor, Reid. "The Impacts of Entry and Market Power in the California Retail Fuel Industry." University of California, Davis. 2023.
[17] i.e. a 10% decline in the cost of ethanol will lead to a 1% decline in the cost of E10.
[18] Li, Jing, and James H. Stock. "Cost pass-through to higher ethanol blends at the pump: Evidence from Minnesota gas station data." *Journal of Environmental Economics and management* 93 (2019): 1-19.
[19] De Gorter, Harry, and David R. Just. "The economics of a blend mandate for biofuels." *American Journal of Agricultural Economics* 91, no. 3 (2009): 738-750.

direction.[20,21] If the assumption of complementarity between ethanol and gasoline holds under all circumstances, removing the blend wall will increase the price of gasoline.[22] However, relaxing the blend wall and allowing E15 and other higher ethanol blends, along with increasing the supply of ethanol, is likely to increase the substitutability of ethanol and gasoline, and thus reduce the price of fuel to consumers.[23,24]

III. Conceptual Framework

Economic theory suggests that introducing E15 should affect California fuel prices through three primary channels: energy content, octane level, and engine efficiency improvements associated with higher blends of ethanol in fuel. The basic models of biofuel suggest that at a fundamental level, consumers pay for fuel based on the energy content.[25] If prices of all fuel types are consistent with respect to effective energy content, then the following relationship should hold:

$$PE_B^E = (1 - B)PG^E + BPE^E + 0.05BPE^E$$

Where PE_B^E is the price of fuel with ethanol blend proportion B based on a unit of energy content, PG^E is price of gasoline based on a unit of energy content, and PE^E is the price of ethanol based on a unit of energy content. The final term in the formula is an engine-efficiency improvement factor; a recent literature review found that there is an approximately 0.5% increase in engine efficiency for every 10% increase in ethanol fuel by volume.[26] This factor accounts for larger engine-efficiency improvements with higher ethanol blends.

Applying this formula to assess the price of E15, we substitute values in accordingly:

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[20] Tenkorang, Frank, Bree L. Dority, Deborah Bridges, and Eddery Lam. "Relationship between ethanol and gasoline: AIDS approach." *Energy Economics* 50 (2015): 63-69.
[21] Pouliot, Sébastien, and Bruce A. Babcock. "Compliance path and impact of ethanol mandates on retail fuel market in the short run." *American Journal of Agricultural Economics* 98, no. 3 (2016): 744-764.
[22] Qiu, Cheng, Gregory Colson, and Michael Wetzstein. "An ethanol blend wall shift is prone to increase petroleum gasoline demand." *Energy Economics* 44 (2014): 160-165.
[23] Tenkorang, Frank, Bree L. Dority, Deborah Bridges, and Eddery Lam. "Relationship between ethanol and gasoline: AIDS approach." *Energy Economics* 50 (2015): 63-69.
[24] Pouliot, Sébastien, and Bruce A. Babcock. "Compliance path and impact of ethanol mandates on retail fuel market in the short run." *American Journal of Agricultural Economics* 98, no. 3 (2016): 744-764.
[25] De Gorter, H., Dusan Drabik, and David R. Just. *The economics of biofuel policies: impacts on price volatility in grain and oilseed markets*. Palgrave Macmillan, 2015.
[26] Leone, Thomas G., James E. Anderson, Richard S. Davis, Asim Iqbal, Ronald A. Reese, Michael H. Shelby, and William M. Studzinski. "The effect of compression ratio, fuel octane rating, and ethanol content on spark-ignition engine efficiency." *Environmental science & technology* 49, no. 18 (2015): 10778-10789.

$$PE^{E}_{15} = 0.85PG^{E} + 0.15PE^{E} + 0.05(0.15)PE^{E}$$

where PG^{E} is price of gasoline based on energy content, and PE^{E}_{15} is the price of E15 based on energy content. Since the energy content of ethanol is 2/3 that of gasoline,[27]

$$PE^{E}_{15} = 0.85PG^{E} + 0.15 * \left(\frac{2}{3}PG^{E}\right) + 0.05(0.15)\left(\frac{2}{3}PG^{E}\right) = 0.955PG^{E}$$

One can similarly assess the energy content price of E10:

$$PE^{E}_{10} = 0.9PG^{E} + 0.1 * \left(\frac{2}{3}PG^{E}\right) + 0.05(0.1)\left(\frac{2}{3}PG^{E}\right) = 0.97PG^{E}$$

Ethanol tends to raise octane in fuel. Estimates suggest that moving from E10 to E15 can increase the octane of the most common and lowest-grade fuel from 87 to 88.[28] Scientists have found significant economic and environmental benefits associated with higher octane gasoline.[29] When it comes to E10, the spread between regular and premium grade fuel spans 30-50 cents.[30] The octane rating of regular grade fuel is typically 87, while that of premium fuel is between 91-94.[31] This suggests that one point increase in octane is worth between 4.5 - 12.5 cents, assuming the value of a one unit increase in octane is constant across all octane levels. Our empirical analysis suggests a premium that is approximately 11 cents. Importantly, ethanol as a medium to boost octane is much cheaper (per unit of octane) than typical octane boosters[32].

A. General Equilibrium and Policy Considerations

Assessing the impact of introducing E15 also has to account for general equilibrium effects. It will increase fuel supply, and thus reduce the overall equilibrium price through interactions of supply and demand.[33,34]

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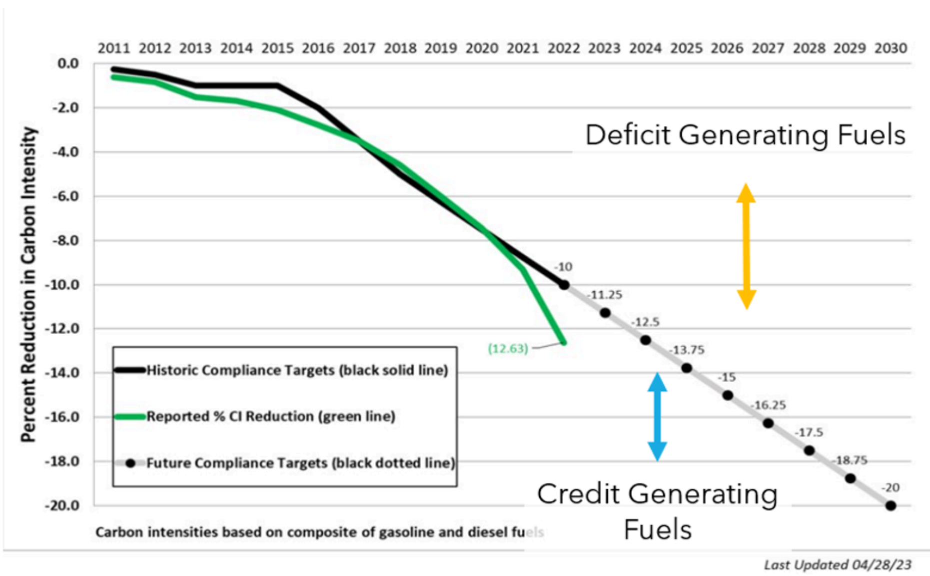
[27] https://www.eia.gov/tools/faqs/faq.php?id=27&t=4#:~:text=The%20energy%20content%20of%20ethanol,energy%20content%20of%20pure%20gasoline.
[28] https://iowarfa.org/ethanol-center/e15/e15-facts/
[29] Speth, Raymond L., Eric W. Chow, Robert Malina, Steven RH Barrett, John B. Heywood, and William H. Green. "Economic and environmental benefits of higher-octane gasoline." *Environmental Science & Technology* 48, no. 12 (2014): 6561-6568.
[30] https://www.costulessdirect.com/blog/what-is-the-price-difference-for-regular-or-premium-fuel-and-which-is-best//
[31] https://www.eia.gov/energyexplained/gasoline/octane-in-depth.php#:~:text=Regular%20(the%20lowest%20octane%20fuel,fuel%E2%80%93generally%2091%E2%80%9394)
[32] Ethanol is typically cheaper than gasoline blendstock at wholesale, it is considerably less expensive than other octane boosters (BTX). The U.S. Grains Council publishes BTX prices: https://grains.org/ethanol_report/
[33] Rajagopal, Deepak, Steven E. Sexton, David Roland-Holst, and David Zilberman. "Challenge of biofuel: filling the tank without emptying the stomach?." *Environmental Research Letters* 2, no. 4 (2007): 044004.
[34] Rajagopal, Deepak, Gal Hochman, and David Zilberman. "Indirect fuel use change (IFUC) and the lifecycle environmental impact of biofuel policies." *Energy Policy* 39, no. 1 (2011): 228-233.

The Low Carbon Fuel Standard (LCFS) reduces the penalty on greenhouse gas emissions from lower-carbon fuels, which would reduce the price of E15 compared to E10. In short, it enacts a credit system where production of low-carbon fuels generates credits, which can be purchased by producers of higher-carbon fuels. The California Air Resources Board (CARB) provides an informative and concise overview of the LCFS.[35] Importantly, the standard becomes more stringent over time, and so credit-generating fuels may in fact become deficit-generating fuels over time.

Figure 1 plots the LCFS trajectory. The black line indicates the historic compliance targets set by the LCFS, while the shaded gray line with black points shows the future trajectory of the standard. The green line represents the observed carbon intensity reduction; one can see that observed reductions to date are outperforming the LCFS standard.

Figure 1: Mandated and Observed Carbon Intensity Levels Associated with the Low-Carbon Fuel Standard



Source: California Air Resources Board (CARB)

It is important to consider the impact of the LCFS on fuel prices, particularly the prices of fuels with increasing levels of blended ethanol. Considering the carbon intensity of ethanol-blended fuels, one can write a general relationship to account for the ethanol blend level B in the fuel:

$$CO_B = BCO_E + (1 - B)CO_G$$

[35] https://ww2.arb.ca.gov/resources/documents/faq-standardized-regulatory-impact-assessment-low-carbon-fuel-standard. Provided by Scott Richman of the Renewable Fuels Association, based on CARB LCFS Reporting Tool Quarterly Summaries

Where CO_G and CO_E denote the greenhouse gas emission intensity of gasoline and ethanol, respectively, and are estimated to be $CO_G = 101.92$ and $CO_E = 60.06$. Based on the assumption that E85 has an ethanol blend level of approximately 83%,[36] one can write the carbon intensity of E85 as:

$$CO_{85} = 0.83CO_E + 0.17CO_G$$

Whereas the carbon intensity of E10 can be written:

$$CO_{10} = 0.1CO_E + 0.9CO_G$$

And so, the price differential between E10 and E85 in California can be decomposed into two primary elements: the energy differential effect and the LCFS effect. Namely:

$$P_{10} - P_{85} = \alpha\Delta Energy + \beta\Delta Carbon$$

Where α and β are the estimated marginal impacts of energy content and carbon intensity on price, respectively. By estimating each of these parameters, we can predict the cost reduction associated with lower CO_2 emissions in the transition from E10 to E15 in California. Of course, this will be an approximation, since the difference in price may include other effects correlated with energy content and carbon intensity.

IV. Data and Descriptive Analyses

We rely on two separate panel datasets with information about prices for different fuel types across several locations and time periods. The first set of data comes from the Motor Gasoline Price Survey (EIA-878), which is generated from a weekly mandatory CIPSEA survey of approximately 800 retail gasoline stations across the country and is made publicly available. The data includes weekly prices for regular, midgrade, and premium gasoline, and is broken down between conventional and reformulated fuel based on location. They define weekly price as the "Cash price per gallon (including taxes) as of 8:00 a.m. local time each Monday." In terms of geographies, there is data at the national level, broken down regionally by the 7 PADD regions, as well as 10 select cities and 9 select states. The data dates as far back as 1990, and back to 1994 for California. Sampling methodology can be found here and geographic area definitions here.

[36] According to ASTM D5798, the allowable range of ethanol blended in E85 is 51-83% (https://afdc.energy.gov/fuels/ethanol-e85-specs). However, California has its own specification for E85 that requires a minimum ethanol content of 79% (https://www.law.cornell.edu/regulations/california/13-CCR-2292.4). According to Scott Richman of the Renewable Fuels Association, E85 in California generally contains 80-83% ethanol.

The second set of data was taken from E15prices.com, and provided to us by Scott Richman. This daily-level data includes prices for E10, E15, and E85 from select gas stations across the country dating back to January 2, 2022. The data comes from 794 unique stations (representing 120 distinct station names/franchises) from 578 cities across 33 states, provided to us by Scott Richman, Chief Economist of the Renewable Fuels Association."

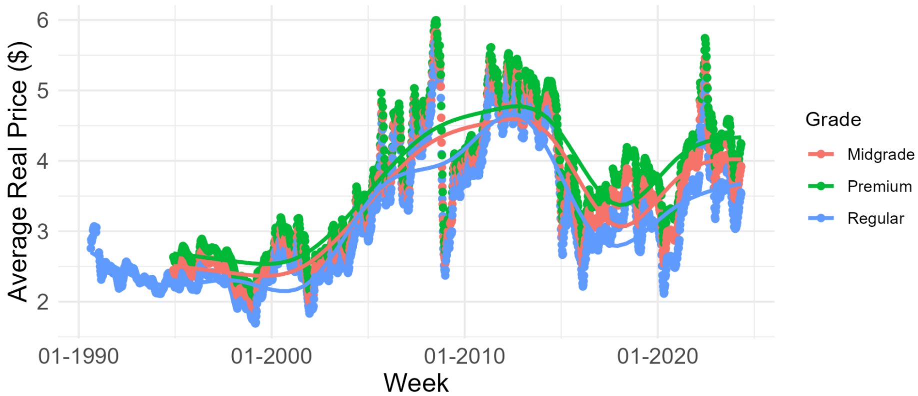
A. Descriptive Statistics

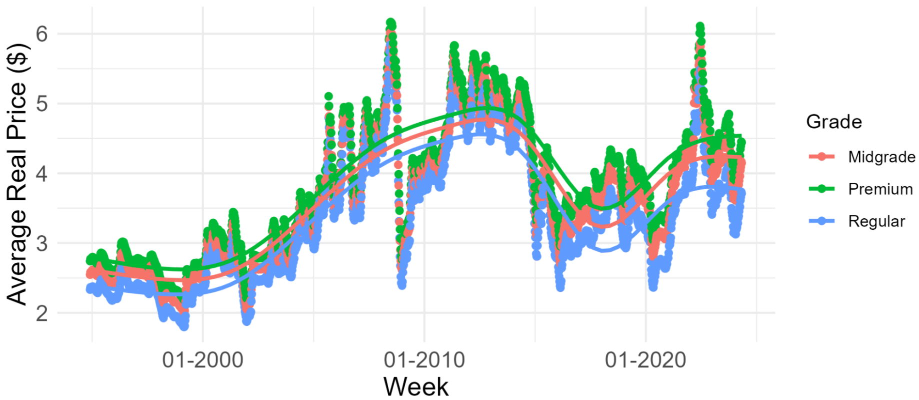
In this section, we present some descriptive statistics of each of the two datasets used in the analysis. Specifically, we provide information on prices over time, across locations, and by fuel type. We also look closely at California individually.

a. EIA Motor Gasoline Price Survey Data

Figure 2 presents average real weekly prices for conventional gasoline (top) and reformulated gasoline (bottom) by grade. One can see cyclical trends for all fuel grades, both for conventional and reformulated fuel. There is a substantial amount of temporal variation in prices.

Figure 2: Avg. Weekly Real Prices for Conventional (Top) and Reformulated (Bottom) Gasoline





Note: Prices are in 2023 USD.

Figures 3 and 4 provide descriptive statistics for California individually. Figure 2 presents average real weekly prices for gasoline in California by grade. Gasoline prices generally follow the same patterns in California as they do nationally.

Figure 3: Average Weekly Real Prices in California

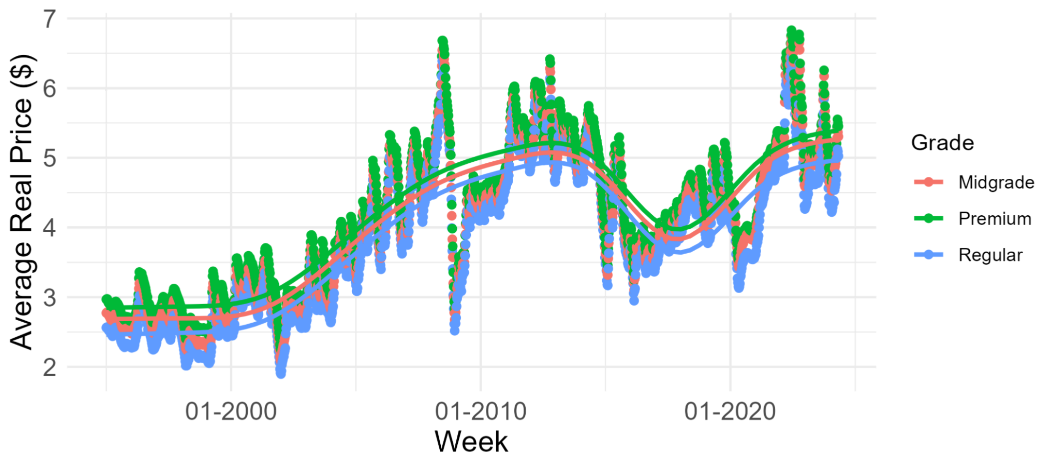
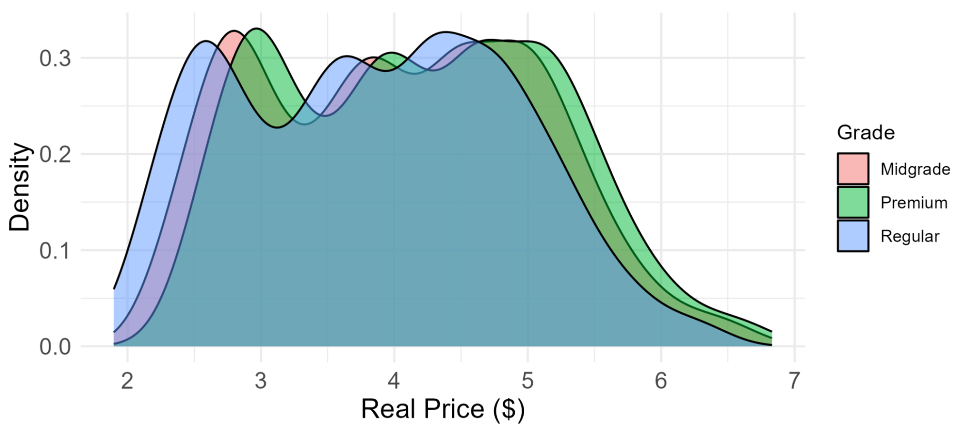


Figure 4 depicts the distribution of real prices in California by grade. Higher grades of fuel are associated with relatively symmetric rightward shifts in the distribution of prices. There does not appear to be significantly fatter tails for higher fuel grades.

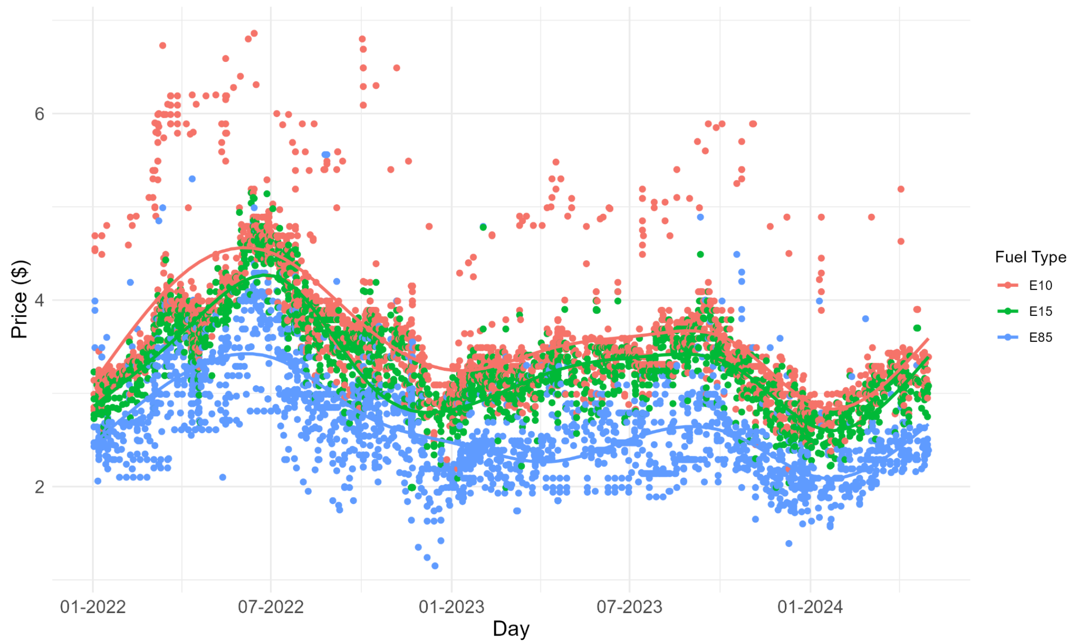
Figure 4: Distributions of Real Prices by Fuel Grade in California



b. E15Prices.com Data

Figure 5 presents information on prices for E10, E15, and E85. The top panel presents average daily prices over the time horizon of the data, while the bottom panel provides density plots for each of the three different ethanol blends. Unsurprisingly, E10 fuel prices appear to exhibit the longest right-tail, driven by its relatively large market share in California. Additionally, E15 fuel prices have larger variance than E10 and E85, driven by its limited adoption to date.

Figure 5: Descriptive Statistics of E10, E15, and E85 Prices



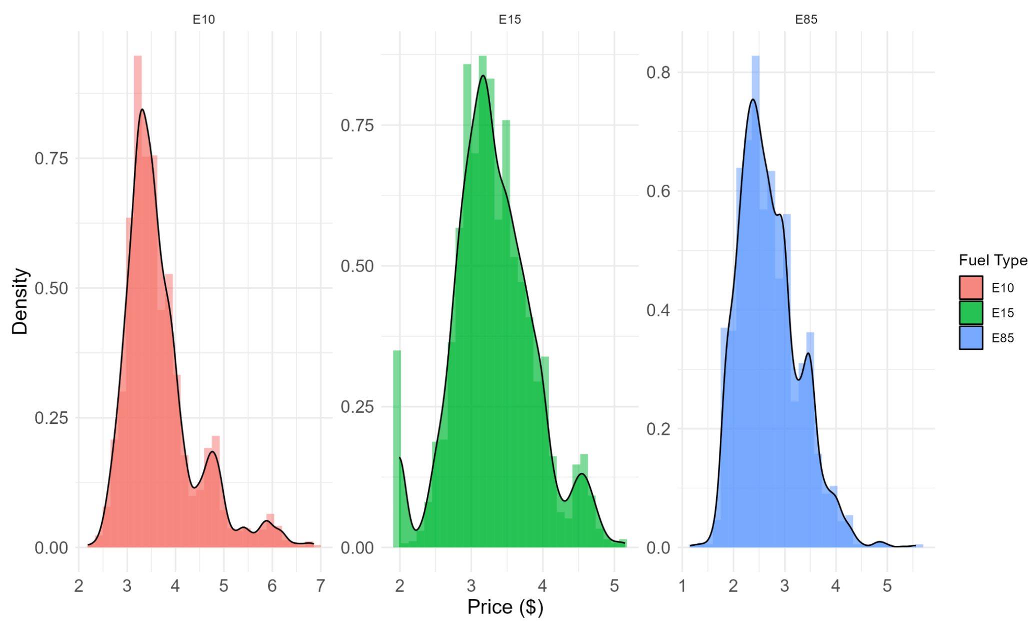


Figure 6 presents average prices for each ethanol blend by state (with the standard deviations noted in black on each respective bar). Among states in the data provided, E85 is not present in Alabama, Mississippi, and New York, while E15 is not present in California. The price gaps between the different fuel blends appear relatively constant across states.

Figure 6: Average Prices of E10, E15, and E85 by State

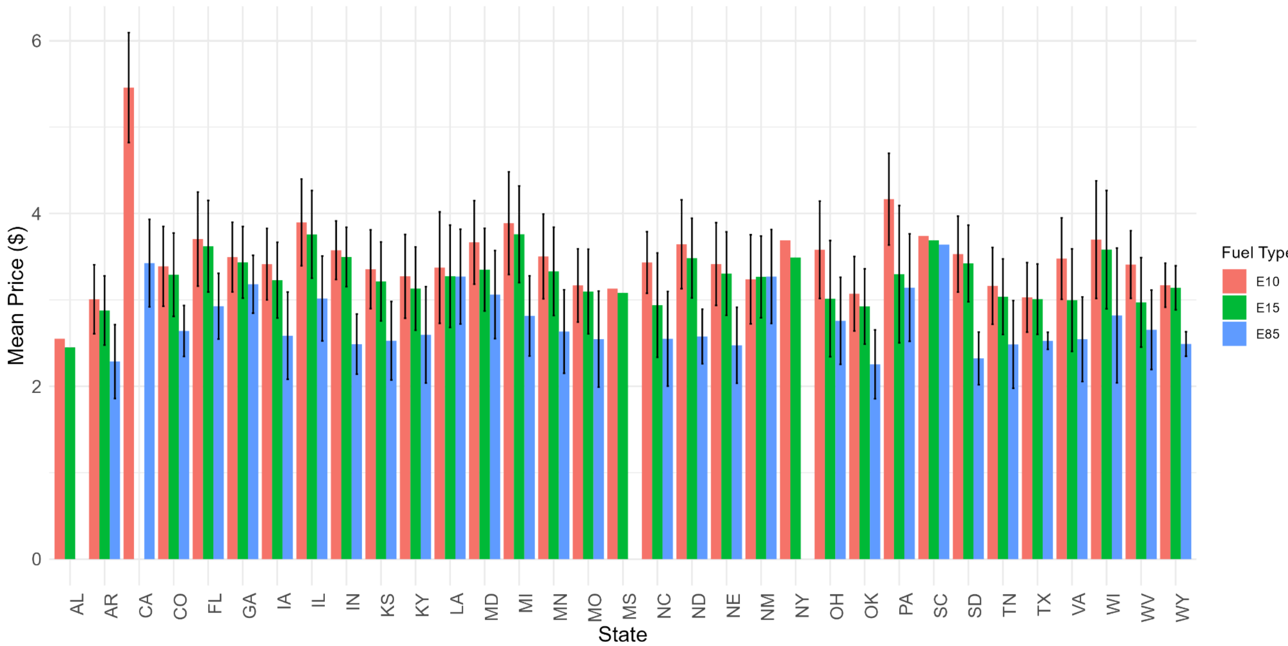


Table 1 provides more specific information on the average price spread between E10 and E15 by state, ranked from largest to smallest spread. The table suggests a significant price differential between E10 and E15. In general, the price spread is a function of several key characteristics of the fuel, with energy content and octane rating being two of the most important. Of course, the price spread also varies significantly among states, which could be due to several other factors including different compositions of fuel consumption by grades (i.e. the fuel economy and other features of vehicles purchasing E10 vs. E15), the location, and source of purchased fuel. In summarizing this table, there appears to be a 4.3% - 20% discount for E15, with an average close to 11% among the 10 states with the largest price spreads. The analysis will provide further context and detail explaining this spread, including assessing the respective impacts of octane and energy content.

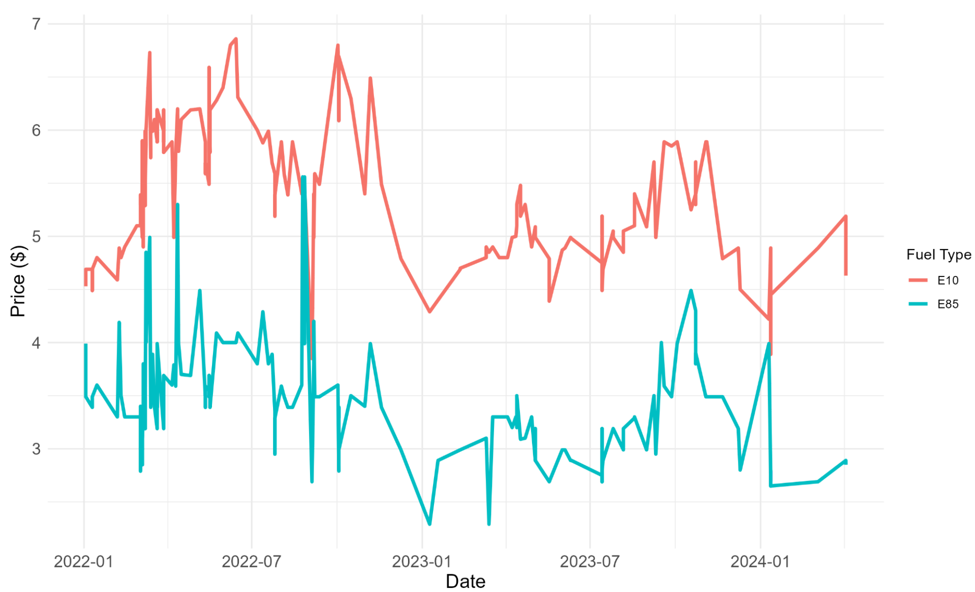
Table 1: E15 and E10 Price Spread (10 States with Largest Absolute Spread)

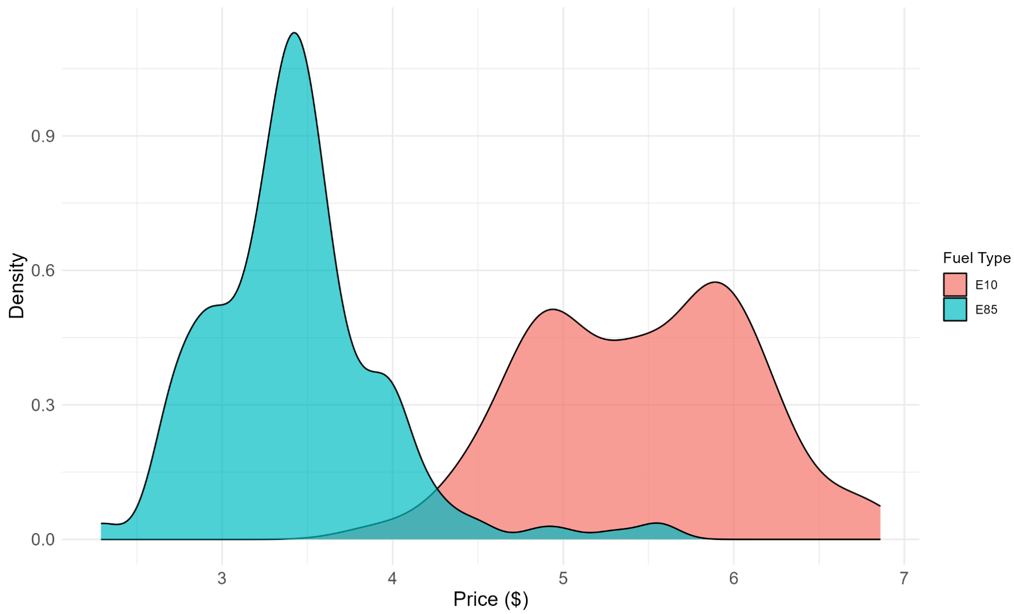
State	E15 ($)	E10 ($)	Price Spread ($)	% Diff. in Spread
PA	3.298017	4.165431	-0.86741	-20.82%
OH	3.01449	3.579796	-0.56531	-15.79%
NC	2.939126	3.433107	-0.49398	-14.39%

VA	2.996602	3.477864	-0.48126	-13.84%
WV	2.970952	3.409206	-0.43825	-12.85%
MD	3.35	3.665294	-0.31529	-8.60%
NY	3.49	3.69	-0.2	-5.42%
IA	3.228526	3.413347	-0.18482	-5.41%
MN	3.330167	3.502685	-0.17252	-4.93%
ND	3.483846	3.643462	-0.15962	-4.38%
AVERAGE	3.2101726	3.5980192	-0.387846	-10.64%

Figure 7 provides information on E10 and E85 prices in California, both over time (top) and densities of prices (bottom). Prices for each of these fuel blends follow nearly identical temporal patterns. However, E85 does exhibit a substantially narrower distribution compared to E10. This is likely due to several factors, including the more widespread availability of E10, leading to more spatial variation in prices, as well as different types of fuel consumers (and their associated vehicles).

Figure 6: Prices of E10 and E85 in California





B. Statistical Analysis

This section provides regression analyses to understand effects of some key characteristics of different fuels on their respective prices. We take a hedonic pricing approach, which breaks down the price of a good based on its individual attributes. This allows us to predict how the price of a good might change when the set of characteristics changes.

While E15 is not widely adopted, it includes a bundle of characteristics that can be compared with other fuel types, including both different ethanol blends as well as characteristics comparable to those found in gasoline (e.g. octane and fuel economy). We can use data on prices, octane levels, and fuel economy in each of these fuels to estimate the marginal effect of each of these characteristics on fuel price. Put differently, we can better understand how a one-unit change in octane (or fuel economy) affects price, and then use these estimates to predict how prices of E15 may differ compared to other fuel compositions by examining the overall composition of these characteristics in E15 compared with other fuels.

We conduct two primary sets of analyses. The first analysis, the results of which can be found in Table 2, uses the first set of data, which comes from the Motor Gasoline Price Survey (EIA-878). This analysis solely examines E10 gasoline, broken down by grade, which is translated into raw octane levels. Specifically, we estimate the following linear regression model:

(1) $$Price_{git} = \beta_1 Octane_g + \alpha_i + \delta_t + \epsilon_{git}$$

Where $Price_{git}$ represents the price of fuel grade g in location i in month-year t. $Octane_g$ is the octane rating by fuel grade. α_i represents location fixed effects (a binary variable corresponding to each different location), and δ_t are month-year fixed effects (a binary variable corresponding to each month-year, e.g. June 2024). β_1 is the predicted impact of one additional octane unit on fuel price. We estimate two separate models: one with Price as the dependent variable, and another with log(Price) as the dependent variable.

The estimation of this model leverages nearly 150,000 gasoline price observations at the grade-by-location-by-week level, allowing us to obtain significant predictive power in understanding the impact of octane level on price. The model also exhibits an extremely strong fit to the data, as indicated by an R-squared value of nearly 1.

Table 2: Effect of Octane Rating on Gasoline Price

	Real Price	**Log Real Price**
Octane	0.112***	0.032***
	(0.002)	(0.001)
Num.Obs.	145999	145999
R2	0.954	0.956
R2 Adj.	0.954	0.956
R2 Within	0.447	0.477
R2 Within Adj.	0.447	0.477
RMSE	0.20	0.06
Std.Errors	by: Location	by: Location
FE: Location	X	X
FE: Month_Year	X	X

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

Our results indicate that one additional unit of octane is worth approximately 11 cents (3.2%), all else equal. This estimate is statistically significant at a >99.9% confidence level. Since the octane level of E15 is 88, while E10 has an octane rating of 87, E15 maintains a value premium of 11 cents (3.2%) compared with E10 solely based on its higher octane level.

Table 3: Effect of Ethanol Blend, Energy Content, and GHG Intensity on Blended Fuel Price

	Price	**Price**	**Price**	**log(Price)**	**log(Price)**
E85	−0.986***				
	(0.089)				
E15	−0.267***				
	(0.063)				
Energy Content Normalized		0.040***			
		(0.004)			
GHG Intensity			0.029***		
			(0.003)		
Log Energy Content Normalized				1.105***	
				(0.071)	
Log GHG Intensity					0.777***
					(0.050)
Num.Obs.	7720	7720	7720	7720	7720
R2	0.805	0.792	0.792	0.775	0.775
R2 Adj.	0.803	0.791	0.791	0.773	0.773
R2 Within	0.610	0.586	0.586	0.593	0.593
R2 Within Adj.	0.610	0.585	0.586	0.593	0.593
RMSE	0.33	0.34	0.34	0.11	0.11
Std.Errors	by: State	by: State	by: State	by: State	by: State
FE: State	X	X	X	X	X
FE: Month_Year	X	X	X	X	X

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

The second set of analyses, which can be seen in Table 3, leverages the data from E15prices.com. While this dataset only dates back to 2022, it provides much more detailed locational and temporal information on prices, broken down by E10, E15, and E85 fuel blends. We accomplish several objectives with this analysis. First, we can empirically estimate the average price spread between E10, E15, and E85 across all locations and time periods. Next, we are able to use the same approach as the first analysis to predict the effect of energy content (fuel economy) on fuel prices. Once again, this allows us to infer how a marginal change in energy content affects price, all else equal, which we can use in conjunction with overall fuel economy differences between E15 and other fuels. We are able to leverage this same approach to estimate the impact of greenhouse gas (GHG) intensity in an identical manner.

The set of estimated models is similar in structure to equation (1), and we estimate five different specifications, all of which are found in Table 3. Specification 1 estimates the average price differential between E85, E15, and E10 (the omitted category). One can see that on average, the price of a gallon of E85 is nearly $1 less than the price of a gallon of E10, and E15 is about $0.27/gallon cheaper than E10.

Specification 2 estimates the predicted effect of a one unit increase in energy content on price, finding the effect to be about $.04/gallon. Because a one unit increase in energy content is not intuitive, Specification 4 presents this estimation in logs. We can interpret the coefficient in that regression as follows: for a 1% increase in energy content of a fuel, prices increase by about 1.1%. The same approach can be used in interpreting the effect of GHG intensity on price using specifications 3 and 5, respectively. We find that a 1% increase in GHG intensity of a fuel leads to a predicted price increase of approximately 0.78%.

Similar to Table 2, all of these specifications include location (state) and month-year fixed effects. We also observe a relatively high R-squared value indicating a good fit between each of these predictive models and the data.

C. *Discussion of Results and Policy Implications for California*

Table 3 includes data from 33 states across the US. Table 4 below estimates the same specifications as Table 3, but focusing exclusively on gasoline stations in California. The results are intuitive when interpreted in the context of the significantly higher average prices of fuel in California compared with the other states in our sample. Of course, E15 is not available in California, and so we do not estimate a price per gallon differential between E10 and E15.

Table 4: Effect of Ethanol Blend, Energy Content, and GHG Intensity on Blended Fuel Price in California

	Price	Price	Price	log(Price)	log(Price)
E85	−2.031***				
	(0.112)				
Energy Content Normalized		0.090***			
		(0.005)			
GHG Intensity			0.066***		
			(0.004)		
Log Energy Content Normalized				1.777***	
				(0.078)	
Log GHG Intensity					1.251***
					(0.055)
Num.Obs.	392	392	392	392	392
R2	0.880	0.880	0.880	0.884	0.884
R2 Adj.	0.871	0.871	0.871	0.876	0.876
R2 Within	0.864	0.864	0.864	0.869	0.869
R2 Within Adj.	0.863	0.863	0.863	0.868	0.868
RMSE	0.40	0.40	0.40	0.09	0.09
Std.Errors	by: Month_Year	by: Month_Year	by: Month_Year	by: Month_Year	by: Month_Year
FE: Month_Year	X	X	X	X	X

+ p < 0.1, * p < 0.05, ** p < 0.01, *** p < 0.001

In summary, the results suggest that a gallon of E85 is on average $2.03 cheaper than a gallon of E10, a one unit increase in energy content (GHG intensity) is expected to increase predicted prices by $0.09 ($0.066) per gallon. In percentage-change terms, a one percent increase in energy content (GHG intensity) is expected to increase predicted prices by 1.78% (1.25%).

Our empirical analysis examines the carbon intensity levels of different fuels and the impact of reductions in carbon intensity on fuel prices. The LCFS in California rewards low-carbon fuels, and thus we should expect to see more carbon-intensive fuels have higher prices than lower-carbon fuels, holding energy content constant.

Focusing on Table 4, specification (3) suggests that for a one unit increase in GHG intensity, predicted fuel prices increase by 6.6 cents on average in California, holding all else constant. Interpreting this effect in the opposite direction, we estimate that a 1 unit *decrease* in GHG intensity is expected to decrease predicted prices by 6.6 cents on average.

Specification (5) predicts this effect in percentage-change terms, estimating that a 1% increase in GHG intensity increases predicted prices by 1.25%, all else equal. This is interesting when compared to the same parameter estimated in Table 3, which suggested a 0.78% increase in prices for every 1% increase in GHG intensity. The larger percent impact in the California-only estimation suggests that low-carbon fuels fetch an additional value premium in California. Put differently, a higher percent reduction in price for a percent reduction in GHG intensity may be attributed to California-specific policies that incentivize lower carbon fuels.

Given a GHG intensity of ethanol of 60.06gCO2e/MJ and a GHG intensity of CARBOB of 101.92,[37] then the carbon intensities of E10, E15, and E85 (assuming an 83% ethanol blend) are 97.73, 95.64, and 67.18, respectively. Thus, holding all else equal, moving from E10 to E15 is expected to save approximately 2 units of GHG intensity, which translates into approximately 13.2 cents savings per gallon on average.

V. Preliminary Lessons for California and Future Work

Even with limited data, we find that consumers have the potential to gain significantly from the introduction and purchase of E15. We estimate the effects of energy intensity and octane level on fuel prices, finding meaningful premiums for higher levels of these characteristics. We also find significant price reductions for lower GHG intensity levels; in California, price savings for lower GHG intensity fuels are larger, likely due to California-specific policies incentivizing low carbon fuels.

The results show that in comparison to E10, E15 generates economic benefits with respect to higher octane and engine efficiency, as well as lower GHG intensity, that outweigh marginal reductions in energy content.Given California's annual fuel consumption of 13.5[38] billion gallons, this translates into potential consumer savings of up to $2.7 billion annually, which is particularly beneficial for low-income commuters. Our analysis also finds that a unit increase in octane level results in a value premium of about 11 cents per gallon. In light of the presence of the LCFS, an analysis focused solely on California further shows that transitioning from E10 to E15 could save approximately 13.2 cents per gallon on average due to the lower carbon intensity of E15.

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[37] These estimates were provided by Scott Richman.

[38] Based on April 2024 CARB Low Carbon Fuel Standard (LCFS) summary. There were 12.11 billion gal of CARBOB and 1.38 billion gal of ethanol consumed

Future work will consider several important additional factors for California, primarily associated with market structure and changes to existing infrastructure. Considerations include adoption by branded vs. unbranded stations and modifications to pump infrastructure (i.e. will there be separate E15 nozzles or will E10 be replaced?), among others.