Increasing Market Competition to Reduce the Level and Variability of Transportation Fuel Prices

A Case Study on California's Low Carbon Fuel Standard

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Executive Summary

First adopted in 2007 as part of California's clean energy law, also known as AB 32, the low-carbon fuel standard (LCFS) is a performance-based standard that sets pollution limits for transportation fuels sold in California. The program requires oil companies and other fuel providers to reduce the carbon pollution from gasoline and diesel by 10 percent by 2020. Companies can utilize any number of cleaner fuel technologies to meet the standard, including offering advanced biofuels made from agricultural waste and grasses, cleaner electricity, natural gas, hydrogen, or even cleaning up existing petroleum-based gasoline and diesel.

This brief evaluates spillover effects of the LCFS on the fuel market's structure, degree of input diversification, and input costs. We find that the LCFS is likely to:

- Increase the number of fuel suppliers and diversity of energy supplies for California's fuel market
- Reduce market power in the petroleum-based fuel sector
- Lower the average price of transportation fuels and bring greater stability to fuel prices in response to fluctuating crude oil prices, as the number of competitors selling in the wholesale fuel market increases as well as the diversity of fuel types.

The study provides an analysis of California's current fuels market followed by development of scenarios evaluating the spillover effects from a LCFS. For the main scenario developed, the LCFS spillover effects evaluated herein lower the level of average transportation fuel prices by 1.3 percent, or 4 cents per gallon gasoline and reduce the price variability, measured as the standard deviation, by 17 percent or from $0.70 to $0.58 per gallon. These benefits of the LCFS are in addition to the reduced damages from lowering greenhouse gas emissions (GHG) and will directly stimulate economic growth and employment. We estimate the spillover benefits of the lower fuel prices to consumers to be $837 million on an annual basis. There are also benefits from the reduction in price risk, which we do not quantify in this analysis. These effects are separate and additional to other direct and indirect benefits and costs evaluated by earlier studies of Low Carbon Fuel Standards.[1]

Introduction

How does California's LCFS work?

California's LCFS is one of a suite of policies designed to lower carbon emissions in the state to 1990 levels, as mandated by Assembly Bill 32. Adopted in 2007, California's LCFS requires regulated parties (e.g., oil producers and importers to CA)

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[1] For example, see *National Low Carbon Fuel Standard: Technical Analysis Report*, July 19, 2012. A Collaborative study by U.C. Davis, University of Illinois, University of Maine, Oak Ridge National Laboratory, International Food Policy Research Institute, and Carnegie Mellon University; *Low Carbon Fuel Standard 2011 Program Review Report*, December 8, 2011, California Air Resources Board. *A Low Carbon Fuel Standard in Washington: Informing the Decision*. February 18, 2011. TIAX; Chen, X and M. Khanna (2012). "The market-mediated effects of low carbon fuel policies." *AgBioForum*, **15** (1), 89-105.

to lower the carbon intensity of their fuel mix to 10% below a 2010 baseline by the year 2020. The program accounts for the full lifecycle greenhouse gas emissions of alternative and petroleum-based fuels, including direct and indirect land use change emissions associated with some types of biofuel feedstocks. Parties are expected to comply by blending more low-carbon fuels into gasoline products, reducing the carbon associated with their own production, and/or by purchasing credits from alternative fuel suppliers, such as biofuel producers, natural gas providers, electric utilities, and hydrogen producers. Low carbon fuel providers earn reduction credits for displacing higher carbon gasoline and diesel, and these credits can be traded and banked, offering regulated parties a flexible, market-based mechanism to meet their annual obligations in the most cost effective manner.

Are the LCFS goals attainable?

In the first two years of the program, low carbon fuels have replaced over 2.8 billion gallons of petroleum-based gasoline and diesel.[2] From 2011 through 3Q2013, the carbon intensity of the California fuel pool has decreased with 5.4 million tons of reduction credits generated (MT CO_2-equiv). A substantial number of credits have been banked, representing over compliance with the requirements by about 60% on average, or an excess of 2.0 million credits,[3] which is equivalent to over half of the amount needed to meet the current 2014 LCFS requirements. Over this period, both the volume and number of trades have increased, and credit prices have risen from an average of $13.50 in 2012 to approximately $65 in January 2014.[4] Overall, the market is working: through trading, parties are meeting compliance requirements.

As the standard becomes more stringent over time, regulated parties will comply with the LCFS in a variety of ways, many of which depend on the emergence of new markets for advanced biofuels and alternative non-petroleum based vehicles. The increasing diversity and range of potential compliance options gives most analysts, including ourselves, confidence that the LCFS goals are attainable. The doomsday scenarios put forward by some industry groups have been widely discredited.[5] In addition, and as a further backstop measure, the California Air Resources Board

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[2] Yeh, S. and J. Witcover, *Status Review of California's Low Carbon Fuel Standard*, January 2014 Issue, Institute of Transportation Studies, University of California, Davis 2014. Also see Yeh, S., J. Witcover and J. Kessler, *Status Review of California's Low Carbon Fuel Standard*, Spring 2013.

[3] Op cite.

[4] Based on LCFS reported data and conversations with ARB staff.

[5] Expert Evaluation of the Report *Understanding the Impacts of AB 32*, May 2013, UC Davis Policy Institute.
http://policyinstitute.ucdavis.edu/files/general/pdf/2013-05-09_Expert-Evaluation-of-BCG-Report.pdf
Review of the Boston Consulting Group "Understanding the impact of AB 32" report, TIAX, LLC, October 2012
http://www.ca-greenbusinessalliance.com/wp-content/uploads/2012/10/BCG-Final-Tiax-Report.pdf
Letter to Brad Tassel, Boston Consulting Group, from Professor Charles Mason, University of Wyoming, July 2012.

(CARB) has announced its intent to provide additional compliance flexibility through cost containment mechanisms.[6]

A recent report conducted by ICF International shows several ways in which compliance with the LCFS can be met with combinations of improved, lower carbon blended with gasoline and diesel and deployment of fuels used in alternative vehicle technologies (electric, hydrogen, natural gas).[7] While projections of future biofuel market developments remain uncertain, the diversity of biofuel sources and the economic stimuli from LCFS trades and Federal Renewable Fuel Standards (RFS2) provide strong economic incentives for robust development of low-carbon solutions.[8] The ICF scenarios indicate that the deployment of alternative fuels and transportation vehicles is likely to decrease the market share of petroleum-based fuels from over 90% to about 80%.

Economic Spillovers from the Low Carbon Fuel Standard program

Key features of the California wholesale market for transportation fuels make it a good candidate for modeling as a Cournot oligopoly. The market is dominated by a small number of firms producing relatively homogeneous products (gasoline and diesel fuel). There are also significant barriers to entering the oil refining business. While there is room for debate on whether the firms strategically choose output quantities (Cournot behavior) or prices (Bertrand behavior) in bringing fuel to the wholesale market, there is no doubt that they make prior choices about their refining capacities. In such instances of a two-stage game, Kreps and Scheinkman (1983) make a case that the Cournot model applies even if firms subsequently choose prices.[9]

Several authors have studied real-world markets using the Cournot model. The edited volume by Daughety (2005) contains some of the most prominent examples.[10] Applications of the Cournot model to energy markets are quite plentiful. Puller (2007) and Borenstein and Bushnell (1999) analyze the California electricity

[6] LCFS Regulatory Amendment Workshop, May 24, 2013, Discussion paper for the Cost Containment Provisions.
http://www.arb.ca.gov/fuels/lcfs/regamend13/20130522ccp_conceptpaper.pdf

[7] *California's Low Carbon Fuel Standard: Compliance Outlook for 2020*, Prepared for California Electric Transportation Coalition (CalETC), California Natural Gas Vehicle Coalition, Environmental Entrepreneurs, Advanced Biofuels Association, National Biodiesel Board, and CERES by ICF International, June 2013.
http://www.caletc.com/wp-content/downloads/LCFSReportJune.pdf

[8] The latest Annual Energy Outlook (AEO 2013). The Reference Case projects compliance of the LCFS in California with consumption of advanced renewable fuels increasing from 14 million barrels a day to over 100 million barrels a day by 2020.

[9] See Kreps and Scheinkman (1983) *Quantity Precommitment and Bertrand Competition Yield Cournot Outcomes.* Bell Journal of Economics 14: 326-337.

[10] Andrew Daughety (2005) Cournot Oligopoly: Characterization and Applications, Cambridge University Press.

market and find evidence of Cournot rivalry.[11] There are also studies applying the Cournot approach to gasoline markets. Ezeala-Harrison (1996) extends the Cournot model to a repeated game in order to explain the pricing of Canadian gasoline at the retail level. Kovac, Putzova, and Zemplinerova (2005) survey the theoretical and empirical literature on strategic interaction, including Cournot behavior, in gasoline markets.[12] Following this well-established path of Cournot modeling, we assume that firms producing in the California market for transportation fuels behave as rivals who maximize profits while taking other firms' output levels as given. In this context, we show that the fuel price will deviate from unit costs by a markup that depends on (1) the degree of market concentration and (2) the fuel price elasticity of demand, or the sensitivity of fuel demand to changes in price.

Our main argument is straightforward. **In response to the LCFS mandate, more firms will enter the transportation fuel market and the markup above unit variable costs will become smaller**. Entry by rival firms will reduce each market participant's ability to influence market price through its choice of output. That is, each firm's market power declines. The firms behave more like price takers, and the market works more like Adam Smith's invisible hand with price gravitating downward toward marginal cost. But a smaller markup is only part of the LCFS story. **We demonstrate that, for very reasonable scenarios, the LCFS brings about a decline in the price of transportation fuel.**

The *markup*, as we define it, can be high while the *profit margin* is considerably lower. Our model's markup, which implies wholesale price will be a certain percentage above *marginal cost* differs from the notion of a profit margin, which gives price as a certain percentage above or below *average cost*. Average cost includes fixed costs (e.g., plant and equipment) that do not vary with output, whereas marginal costs include only the costs that vary as output varies. For gasoline and diesel refining, we consider the price of crude oil (calibrated in units per gallon of gas) to be a reasonable proxy for marginal cost. Our model yields a predicted current markup of 1.33, which says that the wholesale price of gasoline is predicted to be 33 percent above the market price of crude oil. Indeed, this prediction is remarkably close to the historical relationship between the prices of California wholesale gasoline and world crude oil.[13] The markup is a useful concept, in part, because it plays a key role in pricing. Also, one can more easily empirically measure and verify the markup as opposed to the profit margin, which companies

[11] Steven Puller (2005). Pricing and Firm Conduct in California's Deregulated Electricity Market, *Review of Economics and Statistics,* February 2007, 89(1): 75-87*.* Severin Borenstein and James Bushnell (1999). An Empirical Analysis of the Potential for Market Power in California's Electricity Industry, *Journal of Industrial Economics*, September, V. XLVII, 285-323.

[12] Ezeala-Harrison (1996) *New Brunswick Gasoline Industry: An Oligopoly with Tacit Collusion under Consistent Conjectures? http://www.cjrs-rcsr.org/archives/19-2/ezeala-harrison.pdf* . Kovac, Putzova, and Zemplinerova (2005) *Survey of Collusion in Gasoline Markets* http://home.cerge-ei.cz/zemplinerova/pub%5Cdp_eugen.pdf

[13] See: http://energyalmanac.ca.gov/gasoline/margins/

can influence by reallocating costs between operational activities, by amortizing sunk costs, and by employing other forms of creative accounting.

In addition to offering a lower average fuel price, **the LCFS is likely to deliver another positive economic spillover: greater stability of transportation fuel prices in response to fluctuating input prices (e.g., variations in the price of crude oil).** This increased price stability results from both the lower markup and the diversification of fuel sources.

Various analyses have shown that firms are complying with the LCFS program by introducing more diverse fuels with lower carbon intensity.[14] This fuel diversification leads to lower variability in fuel input costs as long as input prices are not perfectly positively correlated. Even inputs that are close substitutes almost never have perfectly correlated prices. One would not expect, for instance, the sources of crude oil price volatility (e.g., civil war in Syria) to be perfectly correlated with the sources of volatility in electricity or corn prices (e.g., weather in Corn belt and hydroelectric conditions).

Conclusions

Transportation accounts for 40% of California's annual greenhouse gas emissions. Before the implementation of the LCFS, petroleum-based fuels accounted for the vast majority (about 96%) of the transportation fuel pool.[15] Designed primarily to reduce the carbon intensity of transport fuels and GHG emissions, the LCFS program will generate additional and significant economic benefits. It will introduce diversity of fuel supplies and lower the market power of a petroleum-based fuel sector, changes that will likely reduce transportation fuel prices and lessen their variability in response to petroleum supply-side shocks. We estimate the spillover effects of the standard to reduce fuel prices by 1.3 percent, or 4 cents per gallon gasoline, while reducing price variability, as measured standard deviation, by 17 percent or from $0.70 to $0.58 per gallon. Both of these spillover effects will benefit California consumers.

The spillover effect of lowering the price of transportation fuel will benefit consumers by saving them expenses on their current vehicle miles traveled. The estimated annual benefit to consumers from the LCFS under this scenario is $837 million annually. This effect is separate and additional to other direct and indirect benefits and costs evaluated by earlier studies of Low Carbon Fuel Standards.[16]

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[14] Califor*nia's Low Carbon Fuel Standard: Compliance Outlook for 2020*, Prepared for CalETC and other sponsors by ICF International, June 2013 and Yeh, Sonia, Julie Witcover and Jeff Kessler, 'Status Review of California's Low Carbon Fuel Standard, Spring 2013'. Institute of Transportation Studies, University of California, Davis 2013.

[15] California Energy Commission website : http://energyalmanac.ca.gov/petroleum/

[16] For example, see *National Low Carbon Fuel Standard: Technical Analysis Report*, July 19, 2012. A Collaborative study by U.C. Davis, University of Illinois, University of Maine, Oak Ridge National

Methodology

In this section, we develop a theoretical model that highlights key elements of the market structure, strategic interactions, and uncertainty characterizing the California market for transportation fuels. The model abstracts from many market nuances but offers a simple framework for making qualitative and quantitative predictions. Our modeling approach is not novel. As noted above, other investigators have modeled regional gasoline markets as Cournot rivalries, but, to our knowledge, nobody has applied the Cournot approach to the California market for transportation fuels.

The qualitative predictions of our model are quite robust. In the scenario analyses below, we also derive quantitative predictions that are sensitive to the values taken by the model's parameters. We use parameter values that are based on other researchers' conservative findings that in some instances (e.g., the assumption of constant price elasticity across scenarios) provide bias favoring alternative conclusions to our own.

Suppose that *N* firms have identical cost functions and produce a homogeneous good to sell in a market. Assume that the firms behave as Cournot rivals, each choosing its own output level to maximize profits while taking as given the other firm's output levels and the market demand function. Let $P(Q)$ be the market inverse demand function, showing market price as a decreasing, continuously differentiable function of the aggregate market output level $Q = \sum_{i=1}^{N} q_i$, the sum of the output levels of the *N* firms. Denote each firm's cost function by $C(q_i)$, which is assumed to be increasing, convex, and twice continuously differentiable.

Firm $i's$ profits are given by

$$\pi_i = P(Q)q_i - C(q_i), \tag{1}$$

and the first-order condition for maximizing (1) is:

$$\frac{\partial \pi_i}{\partial q_i} = \frac{\partial P}{\partial q_i} q_i + P - \frac{\partial C}{\partial q_i} = 0. \tag{2}$$

Denote

Laboratory, International Food Policy Research Institute, and Carnegie Mellon University; *Low Carbon Fuel Standard 2011 Program Review Report*, December 8, 2011, California Air Resources Board. *A Low Carbon Fuel Standard in Washington: Informing the Decision*. February 18, 2011. TIAX; Chen, X and M. Khanna (2012). "The market-mediated effects of low carbon fuel policies." *AgBioForum*, **15** (1), 89-105.

$$\eta_i = -\frac{\partial Q}{\partial P}\frac{P}{q_i} \tag{3}$$

as firm *i's* own price elasticity of demand. Divide (2) by P and substitute (3) into (2) to get

$$P = \left(\frac{1}{1-\frac{1}{\eta_i}}\right)\frac{\partial C}{\partial q_i}, \tag{4}$$

which shows that market price is a markup of $\left(\frac{1}{1-\frac{1}{\eta_i}}\right)$ times the marginal cost of production for firm *i*.

Next, write the market price elasticity of demand as

$$\eta = -\frac{\partial Q}{\partial P}\frac{P}{Q}. \tag{5}$$

Substitute $q_i = \frac{Q}{N}$ into (3) and get firm *i*'s demand elasticity as *N* times the market demand elasticity:

$$\eta_i = -\frac{\partial Q}{\partial P}\frac{NP}{Q} = N\eta. \tag{6}$$

Substitute (6) into (4) to get the markup price equation, showing market price as a function of the market demand elasticity, the number of firms in the market, and marginal cost:

$$P = \left(\frac{1}{1-\frac{1}{N\eta}}\right)\frac{\partial C}{\partial q_i}. \tag{7}$$

The Herfindahl index, widely used as a measure of market power, is defined as $H = \sum_{i=1}^{N} S_i^2$, where S_i is the market share of firm *i,* i.e., $S_i = \frac{q_i}{Q}$. Since the firms have identical cost functions, they will have identical market shares $S_i = \frac{q_i}{Nq_i} = \frac{1}{N}$ in the Cournot equilibrium. The Herfindahl index for the model as described takes the value

$$H = N\left(\frac{1}{N^2}\right) = \frac{1}{N}. \tag{8}$$

Equation (8) yields the well-known result that the reciprocal of the Herfindahl index is the number of equivalent-sized firms in the market that would yield the particular value of the index. For example, if $H = \frac{1}{5}$, then 5 firms having equal market shares would generate that level of market power.

Using (8), substitute $N = \frac{1}{H}$ into (7) to obtain

$$P = \left(\frac{1}{1-\frac{H}{\eta}}\right)\frac{\partial C}{\partial q_i}. \tag{9}$$

Equation (9) shows the Cournot market equilibrium price as a markup on marginal cost, where the size of the markup depends directly on market power (H) and inversely on the market price elasticity of demand (η). The assumptions of the model guarantee that $H < \eta$, so the markup is greater than one.[17]

To examine the empirical implications of Cournot rivalry for price variation of fuels used in California ground transportation, it is useful to add the assumption that each firm's marginal cost is independent of its output level but varies directly with a random variable such as the price of a key input (e.g., the world price of crude oil). As a consequence, and with the addition of time subscripts, (9) becomes

$$P_t = \left(\frac{1}{1-\frac{H}{\eta}}\right)c_t, \tag{10}$$

[17] Note that $\eta > \frac{1}{N}$ is necessary for firms to choose positive output levels to maximize profits and that $H \in [0,1]$, with $H = 0$ being the limiting case as $N \to \infty$ (perfect competition) and $H = 1$ being the case where $N = 1$ (monopoly).

where c_t is a random variable representing marginal cost. Further assume that c_t is distributed normally with mean $\bar{c}$ and standard deviation σ, and assume that firms make their output choices after the realization of c_t. Equation (10) directly yields the following results:

Results for the fuel price level

(i) The level of fuel price increases with the Herfindahl index, ceteris paribus, as

$$\frac{\partial P_t}{\partial H} = \frac{c_t}{\left(1-\frac{H}{\eta}\right)}\frac{H}{\eta^2} > 0.$$

(ii) The level of fuel price decreases with the market price elasticity of demand, as

$$\frac{\partial P_t}{\partial \eta} = -\frac{c_t}{\left(1-\frac{H}{\eta}\right)^2}\frac{H}{\eta^2} < 0.$$

(iii) The level of fuel price increases with the realized value of marginal cost, since

$$\frac{\partial P_t}{\partial c_t} = \left(\frac{1}{1-\frac{H}{\eta}}\right) > 0.$$

Results for the variance of fuel price

From (10), the variance of fuel price can be computed as:

$$VAR(P_t) = \left(\frac{1}{1-\frac{H}{\eta}}\right)^2 \sigma^2, \qquad (11)$$

where σ^2 is the variance of marginal cost. Equation (11) shows that the variance of fuel price

(iv) is increasing in the Herfindahl index.

(v) is decreasing in the price elasticity of demand.

(vi) is increasing in the variance of marginal cost.

The LCFS is expected to lower H and raise η. These two effects both work in the direction of lowering market price. However, the effect of the LCFS on $\bar{c}$ is less clear. The LCFS credits will increase marginal cost for petroleum refineries but decrease marginal cost for low-carbon fuel providers. Our results above suggest that even if the net effect is to increase $\bar{c}$, the impact on the market price of fuel will be at least partly countered, and perhaps reversed, by the effects on market power and demand elasticity.

The LCFS is also predicted to decrease σ (due to increased diversification of inputs), which according to (vi) above will reduce the variance of fuel price. Similarly, the anticipated changes in the Herfindahl index and price elasticity of demand will lower the variance of fuel price according to (iv) and (v).

Scenario analysis

To make predictions about the level and variance of transportation fuel price and to illustrate the model's robustness, we simulate the model using scenario analysis. We estimate some key parameters of equations (10) and (11) using 5-years of monthly data on prices for crude oil, ethanol, natural gas, and electricity[18] (from May 2008 to May 2013). We begin by considering three scenarios. The first is without the LCFS, while the other two are with 10% and 20% reduction in carbon intensity, respectively. To bolster the thrust of our overall argument, we assume that the market price elasticity of demand remains unchanged in each scenario. In scenarios 2 and 3, we assume that petroleum-based firms mix biofuels with gasoline and diesel to meet a significant portion of the LCFS mandate. We conservatively assume this fuel blending does not affect the market concentration of transportation fuel suppliers. However, we posit that some portion of LCFS compliance does involve new low-carbon entrants to the transportation fuels market, namely, firms providing electricity, natural gas, and hydrogen. As of early 2014, we note that there were over one hundred and fifty parties reporting transactions under the LCFS with many of these companies representing low-carbon entrants to the California market.[19]

Scenario 1: without the LCFS

The Herfindahl index for the California petroleum-based fuel market has been estimated by Robert McCullough, Analysis of West Coast Gasoline Prices, June 2012,

[18] Crude oil prices from the World Bank, http://www.indexmundi.com/commodities/?commodity=crude-oil&months=60&commodity=rbob-gasoline

Ethanol prices from US Bioenergy Statistics, Table 14, http://www.ers.usda.gov/data-products/us-bioenergy-statistics.aspx#.Udne7D75kr8

Prices for biodiesel, CNG, and Hydrogen are from U.S. Department of Energy, *Clean Cities Alternative Fuel Price Report*, April 2013.

Electricity prices are from the U.S. Energy Information Administration, Wholesale Market data, (http://www.eia.gov/electricity/wholesale/).

[19] "LRT Registered Parties," as of February 3, 2014. http://www.arb.ca.gov/fuels/lcfs/lcfs.htm

to be above 0.2.[20] We, however, compute the Herfindahl index to be 0.18637, assuming nine major firms and fourteen refineries serving California's market and representing 95% of the refining capacity.[21] (Note on HHI measure: though others sometimes do, we do not multiply the HHI index by 10,000.) To err on the side of obtaining a conservative estimate of the markup, we shall use the lower estimate of $H_1 = 0.18637$ in the present scenario. We conduct the analysis at the producer level (here the firms engaged in refining), as opposed to terminal facility level, distributor level, or retail station level because the analysis focuses on the concentration of suppliers as opposed to distribution channels.

Many authors have estimated the market price elasticity of the retail demand for gasoline, and those estimates generally fall between 0.1 and 0.9 and depend on the time period and geographical region of the analysis. Long-term estimates from several studies average around $\eta = 0.8$. The midpoint of medium-term estimates is $\eta = 0.4$.[22] Both sets of estimates are based on data prior to 2002. Subsequently, crude oil prices and gasoline prices have risen significantly, with retail gasoline prices in 2013 plateauing at levels about 50 percent higher than their 2002 levels. Higher prices are generally associated with higher price elasticities of demand. Also, the previously-estimated elasticities are at the retail, rather than wholesale level. Taking these factors into account, and in order to calibrate the model to fit current data, we choose $\eta = 0.75$.

From data on crude oil prices, we find for May 2013 that the price of crude oil used in one gallon of gasoline was $c_1 = \$2.37$. Plugging the values $c_1 = \$2.37$, $H_1 = 0.18637$, and $\eta = 0.75$ into (10), we obtain $P_1 = \$3.15$ as the predicted wholesale price per gallon of gas for scenario 1 for May 2013.

With the posited parameter values, the model seems reasonably calibrated. It predicts an absolute markup per gallon of gasoline for California refineries in May 2013 of $P_1 - c_1 = \$3.15 - \$2.37 = \$0.78$, which is somewhat higher than the average markup, called *margin*, of $0.55 reported by California refineries for May 2013. It should be noted that the California margin has exceeded $0.78 on several occasions.[23]

Small disparity between the model's predicted prices and the actual transaction prices can be expected because the Cournot model simplifies and abstracts away from some external market influences. California refineries face some potential

[20] *Analysis of West Coast Gasoline Prices*, page 5, Robert McCullough June 2012.
[21] Source: California Energy Commission. California Oil Refinery Locations and Capacities, *October 2012). http://energyalmanac.ca.gov/petroleum/refineries.html.* We note that BP's Carson refinery was recently purchased by Tesoro and that companies may consider separate facilities listed as a single refinery.
[22] See *Analyzing Gasoline Demand Elasticities: a survey*, Carol Dahl and Thomas Sterner, 1991, Energy Economics. Also, see Table 15, *Understanding Transport Demands and Elasticities*, Todd Litman, Victoria Transport Policy Institute, March 2013 http://www.vtpi.org/elasticities.pdf
[23] Source: http://energyalmanac.ca.gov/gasoline/margins/

competition from rivals who can export gasoline to the state. Gasoline can flow into California from regional trading hubs and from refineries in the Pacific Northwest and Gulf Coast. Longer term, these fringe rivals set upper bounds on the margin that can be charged within California. That margin, in the long run, cannot exceed the cost of transporting and reformulating gasoline to California specifications. Yet, as we shall argue below, nothing about fringe competition prevents wholesale gasoline price from being lowered in California.

Scenario 2: with the LCFS requiring a 10 percent reduction in carbon intensity

The report suggests a plausible pathway for achieving the LCFS, wherein non-petroleum based firms provide 7.5 percent of the fuel market (in gallons of gas equivalents) in 2020.[24] To compute the Herfindahl index for this scenario, let us suppose that incumbent petroleum-based firms serve 92.5% of the market for transportation fuel and that 30 firms serve the remaining 7.5% (all with equal submarket shares).[25] The index is then computed as $H_2 = 0.1597$. We again use $\eta = 0.75$.

Next, we estimate the effect of the 7.5% market displacement on the unit cost of transportation fuel in gallons of gasoline equivalent (gge). To generate this estimate, we take a weighted average of the current prices of crude oil, ethanol, wholesale electricity in California, and wellhead natural gas (in gge) where the weights are the market shares predicted for 2020 for each input.[26] On a gge basis, the May 2013 prices are \$2.37 for crude oil, \$3.96 for ethanol, \$0.34 for wholesale electricity, \$3.35 for wellhead natural gas, \$3.72 for Hydrogen, \$3.75 for Biodiesel (B20), and \$3.75 for remaining (assumed). [27] The weighted average unit cost is computed as:[28]

$$\begin{aligned} c_2 &= (.8362)2.37 + (.0510)3.96 + (.0142)0.34 + (.0598)3.35 + (.0012)3.72 \\ &\quad + (.0168)3.75 + (.0129)3.75 = \$2.45 \end{aligned}$$

Substituting $H_2 = .1597$, $\eta = 0.75$ into (10), and $c_2 = \$2.45$, we find: $P_2 = \$3.11$. The price of wholesale transportation fuel is lower than in the first scenario by 1.3% or 4 cents per gge because the effect of the Herfindahl index dropping. This drop thereby lowers the markup, outweighing the effect of the increase in average input price.

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[24] This percentage is computed "Scenario 1 Results," in Califor*nia's Low Carbon Fuel Standard: Compliance Outlook for 2020*, Prepared for CalETC and other sponsors by ICF International, June 2013.

[25] Our results are robust to the assumption of how many new firms enter the market to provide alternative fuels. For example, with one new entrant, $H_2 = 0.1651$.

[26] This scenario can be interpreted as presenting the counterfactual of what the market outcomes would have been today if the LCFS had been adopted 7 years sooner than it was.

[27] Note that we are treating crude oil, ethanol, wholesale electricity, hydrogen, and wellhead natural gas as inputs into production of transportation fuel.

[28] The input prices are from the sources in footnote 18 and are for May 2013. We note that the blenders, prior to 2012, received a tax credit for blending ethanol equivalent to about \$0.45 per gallon ethanol, which is a transfer payment not included here.

Scenario 3: with the LCFS requiring a 20 percent reduction in carbon intensity

To compute the Herfindahl index for this scenario, we suppose that incumbent firms serve 85% of the market for transportation fuel and that 60 new entrants serve the remaining 15% (all with equal submarket shares). The index is then computed as $H_3 = 0.135$. We again use $\eta = .75$. We further assume that the market shares of non-petroleum fuel types increase in proportion to their shares in scenario 2. For this new scenario, then, the weighted average unit fuel cost is

$$\begin{aligned} c_3 &= (.7362)2.37 + (.0837)3.96 + (.0233)0.34 + (.0982)3.35 \\ &\quad + (.0020)3.72 + (.0276)3.75 + (.0212)3.75 = \$2.52 \end{aligned}$$

Substituting the values for this scenario into (10), we find $P_3 = \$3.07$. The price of transportation fuel drops further due to the strength of Herfindahl effect.

To summarize briefly, we expect that an LCFS requirement of a 20 percent reduction in carbon intensity would reduce the price of transportation fuel. In our illustrative example, we generate a 2.5% drop, from $3.15 to $3.07/gge, for a difference of $0.08/gge due to the lowering of market power (i.e., increased competition).

We now investigate the effect of the LCFS on price risk by computing the standard deviations of marginal cost and transportation fuel price. These standard deviations are likely to differ across the three scenarios because the LCFS serves to diversify the input portfolio, and generally speaking, diversification lowers risk. We use historical data on fuel input prices to estimate the standard deviations of input prices and the correlation coefficients between the pairs of price series. We begin by computing the variance and standard deviation of marginal cost:

For scenario 1, we use 8 years of monthly data on crude oil prices to compute the standard deviation of crude oil price per gallon of gas equivalent (gge):

$$\sigma(c_1) = 0.53$$

For scenarios 2 and 3, we use 8 years of monthly data on prices for crude oil, wellhead natural gas, ethanol, and wholesale electricity along with portfolio weights consistent with the ICF study scenarios.[29] Our computation involves the following matrix multiplication:

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[29] Our constructed portfolio of fuels leaves out hydrogen, biodiesel, and *other* fuels because of insufficient data. There are not enough years of data on these prices to compute meaningful covariances. To adjust our input portfolio so that the weights still add to 1, we spread the market share of those three fuels evenly amongst the market shares of crude oil, natural gas, ethanol, and electricity.

$$\sigma(c_k)=\left\{\begin{bmatrix} w_1\sigma_1 & w_2\sigma_2 & w_3\sigma_3 & w_4\sigma_4 \end{bmatrix}\times\begin{bmatrix} 1 & \rho_{12} & \rho_{13} & \rho_{14} \\ \rho_{21} & 1 & \rho_{23} & \rho_{24} \\ \rho_{31} & \rho_{32} & 1 & \rho_{34} \\ \rho_{41} & \rho_{43} & \rho_{43} & 1 \end{bmatrix}\times\begin{bmatrix} w_1\sigma_1 \\ w_2\sigma_2 \\ w_3\sigma_3 \\ w_4\sigma_4 \end{bmatrix}\right\}^{\frac{1}{2}} \tag{12}$$

where $k=1,2,3$ represents the three scenarios; w_i $(i=1,2,3,4)$ is the market share of input i, with 1=crude oil, 2=natural gas, 3=ethanol, and 4=electricity; σ_i is the standard deviation of input *i*'s price, and ρ_{ij} is the correlation coefficient between input *i* and input *j*. We calculate standard deviations of marginal cost for scenarios 2 and 3 as:

$$\sigma(c_2)=0.46$$

$$\sigma(c_3)=0.44$$

As shown, the estimated standard deviation of marginal cost falls from scenario 1 to scenario 2 and from 2 to 3, illustrating the role of input diversification in reducing marginal cost variations.

Now, we turn to the analysis of variation in transportation fuel price. Since fuel price is the markup multiplied by marginal cost, the standard deviation of fuel price is given by

$$\sigma(P_k)=\left(\frac{1}{1-\frac{H_k}{\eta}}\right)\sigma(c_k) \tag{13}$$

Substituting parameter values from the three scenarios into equation (13), we find

$$\sigma(P_1)=0.70$$
$$\sigma(P_2)=0.58$$
$$\sigma(P_3)=0.54$$

These results indicate that the LCFS can be expected to reduce substantially the variation in transportation fuel price. Overall, the standard deviation in fuel price falls over the three scenarios from $0.70 to $0.54. The implementation of scenario 2, or a 10% reduction in carbon-intensity, reduces the standard deviation by 17 percent. The implementation of scenario 3, or a 20% reduction in carbon-intensity, reduces the standard deviation by 23 percent.

The LCFS reduces the riskiness (or variability) of fuel price for two reasons. First, it diversifies fuel sources, which lowers the variation in marginal cost. Secondly, it increases market competition, thereby reducing the markup, which lowers the multiplier (in equation 13) of the marginal cost variation.

It is important to point out that the LCFS reduces price risk even though the prices of some of the alternative fuels (specifically, ethanol and natural gas) have more individual variation than does the price of crude oil. Indeed, $\sigma_{\text{natural gas}} = 2.08$ is four times the level of $\sigma_{\text{oil}} = 0.53$. The statistical elements underpinning the risk-reducing property of diversification are the correlations between input prices. As long as those correlations are strictly less than 1, some diversification of the portfolio will reduce risk, a well-known result in the finance literature.

Estimate of Overall Benefits for Consumers

Since the LCFS is predicted to result in a lower transportation fuel prices that have less variation, it is intriguing to think about the potential dollar benefits to California consumers. The benefits of lower price risk are difficult to measure because they require positing a utility function that exhibits risk aversion, and the specific choice of utility function would be rather ad hoc. We instead choose to focus exclusively on the benefits of the lower fuel price, keeping in mind that our prediction will understate the full gain in consumer surplus.

The lower price of transportation fuel will benefit consumers by saving them expenses on their current vehicle miles traveled. In theory, there may be additional consumer benefits if a downward-sloping demand curve is assumed and greater demand for driving is met. The estimated total amount of gasoline and diesel consumed in California in 2011 was 17.18 billion gallons, and the average price of gasoline in California for that year was $3.73 per gallon.[30] If we apply the price elasticity of demand $\eta = .75$ and our predicted percentage decline of 1.3 percent in transportation fuel price under scenario 2, while assuming the demand curve is approximately linear in that range, then the estimated annual benefit to consumers from the LCFS in scenario 2 is $837 million. Doing a similar estimate for scenario 3, we obtain $1,625 million.

[30] The gasoline consumption data are from
http://www.fhwa.dot.gov/policyinformation/statistics/2011/33ga.cfm
Diesel consumption data are from
http://www.boe.ca.gov/sptaxprog/reports/Diesel_10_Year_Report.pdf
Gasoline price data are from
http://www.californiagasprices.com/retail_price_chart.aspx