Corn, Carbon, and Competition: The Low Carbon Fuel Standard's Effects on Imperfectly Competitive Corn Markets

Andrew C. Swanson

Selected Paper prepared for presentation at the 2022 Agricultural & Applied Economics Association Annual Meeting, Anaheim, CA; July 31-August 2

1 Introduction

Ethanol has played a prominent role in United States agricultural and energy policy since the passage of the Renewable Fuel Standard (RFS). California's Low Carbon Fuel Standard (LCFS) enhances ethanol's importance as a transportation fuel by distributing tradeable compliance credits to low-carbon ethanol producers. Ethanol is now the second largest source of compliance credits along with being the third largest fuel by volume (CARB, 2021a). By connecting compliance credits to plant-level emissions, LCFS takes a step beyond the RFS by actively incentivizing ethanol producers to reduce their carbon emissions so they can earn more credits. Additionally, as the RFS nears the end of its legislative mandate, policies like LCFS could serve as a model for the next evolution of biofuel policy (RFA, 2022).

Nevertheless, who actually gains from these subsidies is an open question. Subsidizing carbon mitigation by ethanol plants not only affects California's ethanol market, but also the local markets for corn and ethanol by-products. That is, a portion of the LCFS subsidies may pass-through to corn producers and distillers grains buyers-especially since increasing the ratio of wet to dry distillers grains production is a short-run means of reducing carbon emissions. The incentive for ethanol plants to further reduce their emissions will depend on how much of the subsidy they capture on the margin. Therefore, measuring the pass-through to local corn markets could provide key insights into the actual performance of California's most prominent transportation fuel policy.

However, the pass-through to local corn and feed markets will depend on the elasticities of local markets and any market power exerted by ethanol plants (Saitone et al., 2008). While dry distillers grains are exportable, wet distillers grains are quite perishable and difficult to transport, and as such, cattle feeders are limited to local sources. Moreover, while other corn buyers exist in local markets, the size of ethanol plants may enable them to exert a sizeable effect on local corn prices (McNew and Griffith, 2005; Jung et al., 2022). Ethanol plant market power could play a large role in determining the distribution of carbon mitigation subsidies and, hence, the ability of LCFS to incentivize carbon mitigation in ethanol markets. To that end, this project investigates the degree to which the LCFS credit values pass-through to corn producers and how ethanol plant market power affects the distributional impacts of paying biofuel producers to decrease their carbon emissions.

The intersection of market power and the pass-through of taxes has experienced a new general interest within the last decade, especially as these factors relate to energy markets. Weyl and Fabinger (2013) show that the degree of market power and the rate of pass-through co-determine the relative changes in deadweight loss and profits from changes in tax rates. Moreover, Pless and van Benthem (2019) show that empirical tests for more-than complete pass-through of a subsidy can be a reliable test of market power. In the case of liquid fuels, limitations on refinery capacity, state-level policies, and inventory constraints can constrain supply responses and reduce the pass-through of fuel taxes to prices (Marion and Muehlegger, 2011). For high-ethanol blends, reduced spatial competition can also reduce the size and speed of the pass-through of ethanol subsidies changes to retail prices (Lade and Bushnell, 2019). These studies, however, primarily focus on the pass-through of homogeneous policies to retail markets with market power while this study will focus on the effects of a heterogeneous subsidy on input procurement markets.

Moreover, measuring the pass-through of LCFS subsidies to corn markets makes significant contributions to literatures on LCFS, environmental policy, and market power in agriculture. Thus far, the literature on the LCFS has focused on its inefficiencies as compared to a carbon tax and how to address those inefficiencies with additional policy mechanisms like a consumption tax or credit price cap (Holland et al., 2009; Holland, 2012; Lade and Lin Lawell, 2021). This prospectus takes a more micro approach by structurally motivating the empirical estimation of the policy-relevant parameters of pass-through and market power in the input procurement markets for biofuel feedstocks. In environmental policy, addressing environmental externalities in markets with additional failures such as market power, leakage, or capital investments has become a key question (Fowlie et al., 2016; Fowlie, 2009, 2010). I contribute to this literature by estimating how the exertion of market power affects the welfare of polluters who receive subsidies to displace other producers with comparatively higher emissions. Finally, the effects of ethanol production on corn prices is not a new question (Babcock, 2008; Drabik et al., 2016; McNew and Griffith, 2005), and previous authors have also addressed concerns of ethanol producers exerting market power in local corn markets (Saitone et al., 2008; Jung et al., 2022). However, no existing research has explored the affects of the LCFS on the prices of corn or how differences in subsidy amounts for dry and wet distillers grains could affect local prices for farmers.

This paper is organized in the following manner. First, the institutional background for the LCFS policy, ethanol markets, and ethanol production is discussed. Then a model for an ethanol producer selling in the LCFS market place is developed. The model uses fixed-proportion technology and a conjectural elasticity framework to derive testable conditions for the pass-through of LCFS credit price changes to corn prices. Finally, an equilibrium displacement model is proposed. The equilibrium displacement model derives percentage changes in the endogenous variables for a shock in LCFS credit prices in terms of the elasticities and fixed-proportion parameters.

2 Institutional Background

All of the market agents affected by LCFS work to achieve their respective objectives within a particular set of constraints caused by policy, market, and technological factors. To understand these constraints, three categories will be studied in depth: the LCFS setting, ethanol market setting, and distillers grains market setting. All three of these topics have their own peculiar details and overlapping facts that must be explained to properly motivate any empirical and structural analysis of the markets modeled in this paper. This section provides the necessary institutional details for understanding and justifying the models used to study the effects of the LCFS on ethanol markets.

2.1 LCFS

In response to California AB 32, the California Air Resources Board (CARB) was tasked with reducing greenhouse gas (GHG) emissions from California's transportation sector. LCFS seeks to accomplish this goal by incentivizing a transition to fuels with lower emissions. The mechanism LCFS uses is a system of tradable compliance credits. CARB sets an annual standard for the carbon intensity (CI) of each kilojoule supplied by a fuel. The CI of each fuel is determined by each supplier's production process, emissions during feedstock production, and emissions during transportation. Wholesale fuel suppliers earn credits if their fuel is below the standard, and they incur a credit deficit if their fuel is above the standard. Fuel suppliers with an annual deficit must buy credits from fuel suppliers with credit surpluses at market prices on the LCFS credit exchange.[1] If the program is successful, then by 2030 the CI of the transportation sector will decrease by 20% as compared to 2010 levels (CARB, 2020a).

To comply with the program, each fuel supplier registers with CARB and receives a CI rating for its fuel. For gasoline and diesel producers, the CIs are calculated by CARB using an industry average(CARB, 2020a). Alternative fuel suppliers, on the other hand, receive more individualized ratings. Alternative fuel suppliers receive a CI rating based on the their feedstock, production process, plant energy source, carbon capture and sequestration, and by-products made during fuel production. Heterogeneity across these factors for firms also producers heterogeneity in the CI ratings of alternative fuel producers. For example, the 253 registered pathways for ethanol using corn starch as a feedstock have an average CI of 69.9 gCO_2e/MJ and a standard deviation of 6.9 gCO_2e/MJ (CARB, 2022a). These ethanol producers sometimes have multiple registered pathways depending on the type of co-products produced in conjunction with the ethanol. The most common distinction for ethanol producers is whether they produce dry, wet, or modified distillers grains.

Once a fuel supplier has received a CI rating, they must verify their transactions with CARB officials-or a third party-on a quarterly basis. Credit surpluses or deficits are then incurred based on the CI rating of the fuel, the annual standard, and the credit formula for that particular fuel.[2] Suppliers of gasoline and diesel

[1] To cap compliance costs, CARB offers credits at \$200 in 2015 dollars.

[2] The credit formula has the same basic form for all producers, but some of the scalar factors are fuel-type dependent (CARB,

fuels are the primary parties incurring credit deficits. While dozens of alternative fuel suppliers produce credit surpluses, the suppliers of renewable diesel and ethanol form the largest sources of credits (CARB, 2021a). At the end of the year, firms with deficits must meet compliance by supplying enough credits to cover their deficits. If a firm does not sell enough alternative fuels to offset their fossil fuel operations, then they must buy credits on the LCFS credit exchange or have a sufficient credit bank from over compliance in the past to meet current compliance. If enough credits are not available on the exchange to cover all of the deficits, then CARB supplies enough credits to meet compliance at the fixed price of $200 in terms of 2015 dollars.

Moreover, the LCFS's individualized pathways incentivizes alternative fuel producers to reduce the CI of their fuel over time. Whenever a change in production techniques occurs, the producer can apply for a new pathway certification and receive a new CI rating. For example, if an ethanol plants builds a gas connection to a source of landfill gas, that producer could apply for a renewed pathway certification recognizing the change in power source. This new pathway gives the producer a lower CI rating and more credits per gallon of ethanol sold. The opportunity to receive more credits thereby incentivizes alternative fuel producers to make long-term capital investments in GHG mitigation technology. Using the formula provided by CARB, ethanol plants can receive an additional $0.01 to $0.015 per gallon for every one-point reduction in their CI.[3]

2.2 Ethanol Market

Before the passage of RFS 1 and 2 in 2005 and 2007 respectively, ethanol played a small role as a fuel additive to boost the octane rating of gasoline. RFS 1 mandated a slight expansion beyond previous consumption levels, but RFS 2 mandated large increases of ethanol-both from corn and other sources-consumption over the ensuing decades. However, many of these mandates are technically and economically unfeasible, and the EPA has used discretionary authority to drastically cut consumption to more feasible levels(Lade et al., 2018a,b). As a result, conventional ethanol consumption has remained slightly below its 15 billion gallon by 2015 mandate while the consumption of ethanol from other sources is no where close to the mandated levels.

In addition to the RFS, another policy affecting ethanol consumption is the EPA's blend wall. For engine and environmental reasons, the blend wall prevents ethanol to be no more than 10% of the fuel for conventional gasoline-ethanol blended fuel called E10. Higher blends of ethanol such as 15% ethanol blends-E15-or 51-83% blends-E85-do exist, but their market share remains quite small. In California, E85

2020b). The credit formula for fuel i is: $\text{credits}_i = Q_i * (CI_s - CI_i) * ED_i * EER_i * C$ where Q_i is gallons sold of fuel i, CI_s is the standard set by CARB, CI_i is CI of fuel i, ED_i is energy density for fuel i, EER_i is energy economy ratio of fuel i, and C is a multiplicative constant that is the same for all fuel types equal to 10^{-6}.

[3] The exact formula for ethanol factors can be found on pages 70-73 of CARB (2020b), and I use a credit price of range of $125 to $200.

sales only totaled 40 million gallons in 2019 and 2020 (CARB, 2021b).[4] As a result of the 10% blend wall, the elasticity of demand for ethanol is quite elastic prior to the 10% threshold, but it then becomes highly inelastic after the threshold (Pouliot and Babcock, 2016). Thus, while policies like the LCFS can provide an additional incentive for the expansion of ethanol consumption, the blend wall may prevent any large scale expansion of ethanol consumption beyond 10% of total gasoline-ethanol consumption.

2.3 Ethanol Production and Distillers Grains

While ethanol itself is a homogeneous fuel, its production can differ in method and feedstock. The ethanol is produced from a variety of sources including corn, plant fibers, sorghum, sugarcane, and wheat, but corn remains the dominant feedstock because of its plentiful supply and ease of production. When RFS was first passed, lawmakers envisioned a world where the other feedstocks-particularly plant fibers-would supplant or at least rival corn. However, producing ethanol from the other sources at an industrial scale has proved to be economically infeasible (Lade et al., 2018a), and ethanol from corn has dominated the market. In California, corn ethanol accounts for almost 80% of consumption (CARB, 2022b), even though fiber ethanol has significantly lower CI ratings. As a result, corn ethanol will continue to dominate the market for the foreseeable future.

Furthermore, the nature of the corn kernel itself restricts ethanol production, and as a result it enables the use of a fixed-proportions model. A single kernel of corn consists of starch, oil, protein, fiber, and water. Starch is the largest component by mass, but the most variable component is moisture content which can fluctuate with harvest conditions and how long the farmer stores the grain in a drying bin.[5] Ethanol is produced from the fiber and starch portions by fermenting the corn grain. An efficient ethanol producer will strive to extract as much ethanol from the corn grain as possible, but only so much ethanol can be produced from a single bushel of corn because of the limitations on starch and fiber content.[6] As a result, data on ethanol yield from corn can be used to parametize a structual model of ethanol production, and USDA AMS biofuel by-product reports provide conversion ratios.

An efficient ethanol producer will also make use of the other components of the corn kernel, but the co-products will depend on plant type and manager decisions. Ethanol plants come in two varieties: wet wills and dry mills. The decision to build either a wet mill or dry mill is a non-reversible, capital intensive choice that is made prior to the building of the plant itself. Wet mills are more expensive to build, and they can produce other products from the starch instead of ethanol such as corn sugars while dry mills are cheaper

[4]Ethanol and pure gasoline combined for 15 billions in the state of California in 2019 (CARB, 2022b).

[5]Grain buying companies such as cooperatives and ethanol plants will dock farmers for high-moisture corn to account for the higher weight of wet corn and the need to dry the corn for storage and/or processing.

[6]Seed companies have developed corn varieties that are more efficient for ethanol production, but to my knowledge these varieties do not represent a significant portion of the seed market.

to build but are limited to producing only ethanol from the starch(Hoffman and Baker, 2010). Wet mills can also produce corn gluten feed, corn gluten meal, and corn germ meal, and dry mills produce distillers grains and a small portion of corn oil.[7] In terms of corn consumed, dry mills have a much larger share of the ethanol market. In January 2022, dry mills consumed 438.3 million bushels of corn for ethanol while wet mills only consumed 35.7 million bushels(NASS, 2022).[8]

Because wet mills comprise only a small portion of the total ethanol market, the structural analysis will focus on the production processes of dry mills. One of the most important decisions a dry mill can make is what type of distillers grains to produce. Dry mills can produce three types of distillers grains: dried, modified, and wet. The only difference between the three types is the water content. Dried is 10% moisture, wet is 65-70% moisture, and modified is 40-65% moisture. Dry comprises between 50-55% of distillers grains production, wet comprises 30-35%, and modified has the smallest share at 10-15% (NASS, 2022). During the production process, the ethanol is separated from the leftover solids, oil, and water. Ethanol plant managers can then choose to dry down the solids to produce dried or modified distillers grains or sell the grains as wet with little to no drying.

While the three types of distillers grains have some differences in use as an animal feed, the LCFS creates a clear advantage for wet over dried and modified. Cattle feeders will use either dried, modified, or wet as feed, and the primary nutritional difference is the water content. One primary advantage for dry production is the ability to export the commodity. The high moisture content of modified and wet make these forms more expensive to transport and more difficult to store if the weather is hot and humid, so dried is the preferred form for export. Nevertheless, the extra energy used to produce dry distillers grains also increases its carbon emissions as compared to wet and dried. As a result, wet and modified generate more credits for each gallon of ethanol sold.[9]

3 Ethanol Market Model

This section builds an ethanol market model to analyze the decisions made by ethanol producers serving the LCFS market. The markets for fuels are quite complex with multiple markets interacting together while market agents simultaneously face multiple policy constraints. The market for ethanol is no different. The prices of blended fuel, pure gasoline, corn, and distillers grains-among others-all affect the market for ethanol, and policies like LCFS and RFS expand the demand for ethanol while policies like the EPA's blend wall restrict demand for ethanol. Simplifying assumptions are necessary to build a general model that is both

[7] Both wet and dry mills can include structures to capture carbon dioxide during production, but this requires additional capital investment beyond what a typical plant includes.

[8] Wet mills consumed an additional 40.8 million bushels for non-ethanol starch products (NASS, 2022).

[9] For example, KAPPA Ethanol in Ravenna, Nebraska has a CI of 73.75 for dried distillers grains and a CI of 63.46 for wet.

useful and tractable.

First, the forms of supply and demand functions that cannot be derived from the ethanol producers' problem are defined. Next, a fixed proportions production model is used to derive equilibrium conditions on corn consumption and distillers grains production from producers' objective functions. The equilibrium levels of corn consumption and wet distillers grain production are derived in terms of elasticities, market power parameters, LCFS parameters, prices, and marginal costs. Taking the total differential of these conditions with respect to the LCFS credit price enables derivation of the pass-through to corn and wet distillers prices in terms of the parameters. Finally, taking the same differential of the other equations builds a model for deriving equilibrium changes in prices and quantities.

3.1 Principle Supply and Demand Curves

The LCFS market is modeled as an isolated market from global trade and from the national RFS market. A finite number of ethanol producers N have heterogeneous carbon-intensity levels that are drawn from a bivariate distribution. Ethanol plants only have market power in the corn and ethanol by-product markets. Assumptions on the structure of production and costs for ethanol producers will be discussed in subsection on ethanol production. The assumptions and function forms of demand and supply curves that are not explicitly derived in the main body are defined below.

Blended fuel is produced in fixed proportions of gasoline to ethanol. The EPA's blend wall prevents conventional E10 from having more than 10% ethanol while the RFS mandates total consumption of ethanol to be between 10 and 12% of total gasoline consumption. As a result, weekly ethanol production is consistently between 9 to 12% of gasoline consumption (RFA, 2022).[10] Thus, blended fuel is produced in the fixed proportion of: $f = .1e + .9g$, where f,e, and g are blended fuel, ethanol, and gasoline, respectively.

Ethanol producers are assumed to have no market power in the market for ethanol. Thus, each ethanol producer faces a perfectly elastic demand for its ethanol. The industry demand for ethanol, however, is assumed to be a decreasing function in the price of ethanol. The industry demand for ethanol is written as

$$E = D_E(P_E, P_{LC}, \sigma, Z). \tag{1}$$

P_{LC} is the price of LCFS credits, and σ is the LCFS carbon-intensity standard. It is assumed that $\frac{\partial D_E}{\partial \sigma} > 0$ and $\frac{\partial D_E}{\partial P_{LC}} < 0$.[11] Z is a vector of exogenous supply shifters for factors related to blended fuel demand, gasoline prices, and the costs of blending gasoline and ethanol.

[10] E85 and other higher blends enable blenders to meet the RFS consumption mandates, but they comprise a small percentage of total blended fuel demand (CARB, 2021b).

[11] Because of the fixed-proportions between ethanol and gasoline, blended-fuel faces a net-credit deficit. Therefore, increases in the credit price increase the defacto tax on blended fuel, and a tightening of the carbon-intensity standard also increases the defacto tax on blended fuel.

The primary input for ethanol and its by-products is corn. The corn supply function is defined as an increasing function in its own price. The supply curve also includes a vector of exogenous shifters Y. The corn supply faced by each ethanol plant is then

$$C = S_C(P_C, Y). \tag{2}$$

Distillers grains are by-products from ethanol production that are produced in fixed proportion to ethanol. Distillers grains are produced in two types: wet W and dry D. Demand curves for both wet and dry are assumed to be decreasing functions with respect to their own prices.[12] They also are assumed to be substitutes for each other, so demand for each type will have a positive relationship with the other price. Each demand function will have its own vector of exogenous shifters. The wet distillers grains and dry distillers grains demand functions respectively are

$$W = D_W(P_W, P_D, X), \tag{3}$$

$$D = D_D(P_D, P_W, V). \tag{4}$$

Wet and dry distillers grains are assumed to have the same nutritional value apart from water weight, but dry distillers grains is easier to ship and store, especially in summer. Thus, cattle feeders have a strict preference for dry distillers grains by usable volume. That is, $P_D > P_W$ for $W = D$.[13]

3.2 Residual Credit Demand for Ethanol Industry

In the presence of a blend-wall constraint, the number of credits generated from the sale of ethanol may not equal the deficit created by the sale of gasoline. That is, the blend wall prevents a gallon of blended fuel from having a positive credit balance.[14] Despite the credit shortfall created by the blend wall, equilibrium in the credit market can be reached through alternative sources of credits.

LCFS also regulates the diesel market, as diesel is a liquid fossil fuel for ground transportation. Renewable diesel is a major source of credits, and it is gaining in market share in the total diesel market because it is not hampered by a blend wall (CARB, 2022b). Moreover, CARB also allows for non-liquid fuels such as biogas from methane capture and electric vehicle infrastructure to generate credits, but these sources of credits are relatively minor in volume than renewable diesel and ethanol.[15] Finally, since CARB allows credit banking, current demand can be met from compliance in previous years.

[12] A large portion of dry distillers grains are exported. Since the model does not account for international trade, the dry distillers grains demand curve is local demand only.

[13] USDA Agricultural Marketing Service has daily prices for distillers grains, and their data show that dry prices are consistently higher than wet (AMS, 2022).

[14] This result is explicitly derived in Appendix A.

[15] The infrastructure credits can be no more than the previous quarter's credit deficit (Bushnell et al., 2020).

Combining the diesel pool, blended fuel pool, and secondary credit sources creates the conditions for equilibrium in the market for LCFS credits. Horizontally summing across all sources of demand and all sources of supply yields the market level demand and supply curves. The relevant credit demand to the ethanol industry is found by subtracting the other suppliers from the total demand curve. Thus, the residual demand curve for ethanol industry is

$$LC_e = D^e_{LC}(P_{LC}, \sigma, U), \tag{5}$$

where U is a vector for exogenous shifters for factors that affect supply and demand in the other markets. (5) is assumed to be downward sloping in the price of credits P_{LC}.

The multiple sources of credit demand and supply preclude the possibility of ethanol plants exerting any market power on credit markets. Therefore, each ethanol plant faces a perfectly elastic demand curve for its credits.

3.3 Ethanol Supply and the LCFS Credit Market

This subsection analyzes the decisions of a profit maximizing ethanol producer when they have the ability to earn emission credits. The ethanol plant acquires corn and converts corn to ethanol using a fixed-proportion technology, and they also produce distillers grains in fixed proportion to ethanol, as distillers grains are a by-product of ethanol production(Saitone et al., 2008; Cui et al., 2011). That is, a bushel of corn has a fixed conversion of $\gamma c = e$, where γ is the conversion factor from bushels of corn to gallons of ethanol.[16] A pound of distillers grains has a fixed conversion factor of $dg = \mu c$, where μ is the conversion factor from bushels of corn to pounds of distillers grains dg. The costs of converting corn to ethanol are assumed to be constant in e (Saitone et al., 2008; Cui et al., 2011).

The ethanol producer can also choose how much of the dg to convert from wet to dry. The relationship between dry d and wet w is $dg = \delta w + d$, where δ is a conversion factor that accounts for the differences in dry matter between wet and dry. The costs for producing wet or dry are assumed to be constant in their respective quantities, but converting wet to dry requires additional energy, and therefore, the dry distillers grains production costs more than wet.

The ethanol produced with either wet or dry distillers grains is identical in consumptive properties, but CARB differentiates between ethanol produced from either type because of differences in carbon emissions. Therefore, ethanol can be be decomposed as $e = e_w + e_d$, where e_w is ethanol with wet co-production and e_d is ethanol with dry co-production. Because of the fixed proportions between corn and ethanol and corn and distillers grains, wet ethanol and dry ethanol can be expressed in terms of their respective co-products:

[16] Lower case variables indicate individual quantities.

wet or dry distillers grains. That is, using $\gamma c = e_w + e_d$ and $\mu c = d + \delta w$, $e_w = \frac{\gamma\delta}{\mu} w$ and $e_d = \frac{\gamma}{\mu} d$.

Ethanol plants are assumed to have two carbon intensity ratings: CI_w for wet and CI_d for dry. The pair of carbon intensity ratings (CI_w,CI_d) is drawn from a continuous, bivariate distribution with strictly positive supports such that $a_w \leq CI_w \leq b_w < \sigma$ and $a_d \leq CI_d \leq b_d < \sigma$. Moreover, for each ethanol plant i, $CI^i_w < CI^i_d$.[17]

Ethanol plants earn credits per gallon of ethanol if their carbon intensity is below the standard. The credits are sold at a market-determined price P_{LC}.[18] The formula for the number of credits for wet ethanol and dry ethanol sales only differs in the carbon intensity rating of each product. The number of carbon credits for each firm i is written as[19]

$$lc = B[[\sigma - CI^i_w]e_w + [\sigma - CI^i_d]e_d] \tag{6}$$

where B is constant for equalizing the differences in gasoline and ethanol energy content per gallon, and σ is the carbon intensity standard set by CARB.

The objective function for the ethanol producer will have five prices: P_E the price of ethanol, P_W the price of wet distillers grains, P_D the price of dry distillers grains, P_C the price of corn, and P_{LC} the price of LCFS credits. Ethanol plants are assumed to face downward-sloping demand curves for wet and dry and an upward-sloping supply curve for corn. Thus, the prices for corn, wet distillers grains, and dry distillers grains are endogenous to the production decisions of ethanol plants. The only assumption on the relativity of prices, however, is $P_D \geq P_W$ to account for dry's higher costs and the fact that dry has advantages in storage and transport.

The fixed proportions enables the objective function to be expressed in terms of two decision variables: c and w.[20]. All curves for which the ethanol plant may exert some market power are included in their inverse form. The objective function for the ethanol producer is then

$$\begin{aligned} \max_{c,w} \quad \pi^i = P_E\gamma c + P_D(D)[\mu c - \delta w] + P_W(W)w - P_C(C)c - c_e\gamma c - c_d(\mu c - \delta w) - c_w w \\ + P_{LC}B((\sigma - CI^i_w)\frac{\gamma\delta}{\mu}w + (\sigma - CI^i_d)(\frac{\gamma\mu c - \gamma\delta w}{\mu})) \end{aligned} \tag{7}$$

where σ is the LCFS carbon intensity standard and B is a constant to account for the energy content differences between ethanol and gasoline.

The analysis henceforth assumes that both ethanol and distillers grains have some positive economic

[17] This restriction matches data patterns for U.S. corn ethanol registered pathways (CARB, 2022a).

[18] CARB allows banking of credits, but I will not include that dynamic decision.

[19] Notation distinguishing heterogeneous decision variables such as w or d is suppressed to prevent notational clutter. All exogenous parameters are assumed to be constant across all ethanol producers unless explicitly stated otherwise such as CI^i_w.

[20] $\gamma c = e$, $d = \mu c - \delta w$, $e_w = \frac{\gamma\delta}{\mu}w$, and $e_d = \frac{\gamma}{\mu}d$ from the defined relations.

value, though distillers grains could be wet or dry only. That is, only the cases of $c > 0$, and $w \geq 0$ will be considered. Therefore, complementary slackness conditions on w will be included with the first-order conditions. The Kuhn-Tucker first-order conditions are

$$\frac{\partial \pi^i}{\partial c}: \quad P_E\gamma + P_D(D)\mu + P_D'(D)[\mu c - \delta w] - P_C(C) - P_C'(C)c - c_e\gamma - c_d\mu + P_{LC}B(\sigma - CI_d^i)\gamma = 0, \quad (8)$$

$$\frac{\partial \pi^i}{\partial w}: \quad P_W(W) + P_W'(W)w - P_D(D)\delta - P_D'(D)[\mu c - \delta w] + c_d\delta - c_w + P_{LC}B((CI_d^i - CI_w^i)\frac{\gamma\delta}{\mu} \leq 0, \quad (9)$$

$$\frac{\partial \pi^i}{\partial w} \leq \ 0, \qquad w \geq 0, \qquad w\frac{\partial \pi^i}{\partial w} = 0. \quad (10)$$

Three possible scenarios can arise from the solving the first-order conditions. Since the quantity of corn procured and ethanol produced are strictly positive by assumption, only the distillers grains mix varies. First, equation (1.9) is slack, and thus only dry distillers grains are produced. Second, equation (1.9) holds with equality and $\mu c = w$, and therefore, ony dry is produced. Finally, (1.9) holds with equality and $\mu c > w$, and thereby, both dry distillers grains and wet distillers grains are produced. The primary case being considered is the third, when both wet and dry distillers grains are produced in positive quantities.

Equations (1.8) and (1.9) can be solved to find the optimal amounts of ethanol production c^* and wet distillers grains w^* for each producer in terms of the prices and parameters. From the fixed relations, the optimal amounts of ethanol e^* and dry distillers grains d^* are found from equations (1.8) and (1.9) as well. The optimal number of credits for each producer lc^* is then calculated using (1.6) and c^* and w^*.

The indefinite forms of the corn supply curve and distiller grains demand curves prevent the derivation of closed form solutions for the endogenous decision variables, but (1.8) and (1.9) can be rearranged to yield equilibrium conditions in terms of elasticities and market power parameters. This form enables a clearer interpretation of the first-order conditions. Rearranged (1.8) and (1.9) are

$$\frac{\partial \pi^i}{\partial c}: \quad \gamma(P_E + P_{LC}B(\sigma - CI_d^i) - c_e) + \mu(P_D(D)(1 + \frac{\xi_d}{\eta_d}) - c_d) = P_C(C)[1 + \frac{\theta}{\epsilon}], \quad (11)$$

$$\frac{\partial \pi^i}{\partial w}: \quad P_W(W)(1 + \frac{\xi_w}{\eta_w}) - c_w + P_{LC}B(\sigma - CI_w^i)\frac{\gamma\delta}{\mu} = \delta P_D(D)(1 + \frac{\xi_d}{\eta_d}) - c_d\delta + P_{LC}B(\sigma - CI_d^i)\frac{\gamma\delta}{\mu}, \quad (12)$$

θ, ξ_w, and ξ_d are measures of market power that account for each ethanol plant's share of corn consumption and distillers grains production. $\theta \in [0, 1]$ is the oligopsony power in the corn market, $\xi_w \in [0, 1]$ is oligopoly power in the wet distillers grains market, and $\xi_d \in [0, 1]$ is oligopoly power in the dry distillers grains market.[21] Evaluated at the equilibrium quantities, ϵ is the elasticity of corn supply function, η_d is the elasticity of the wet distillers grains demand function, and η_w is the elasticity of the dry distillers grains

[21] $\theta \to 0$ leads to a competitive market while $\theta = 1$ results in a monopsony, analogous interpretations hold for the oligopoly parameters ξ_w and ξ_d. Each term is defined in terms of firm i's share of the respective market.

demand function. That is,

$$\epsilon = \frac{1}{\frac{\partial P_E}{\partial E}\frac{E}{P_E}}, \tag{13}$$

and η_d and η_w have analogous forms.

Equations (1.11) and (1.12) allow the first-order conditions to be interpreted in a straight-forward manner. Equation (1.11) shows that the profit maximizing ethanol plant will equate its marginal procurement costs of corn with the sum of the net value marginal product of ethanol-including the economic value of the credits-and the net marginal revenue product of distillers grains production. That is, the profit maximizing ethanol will at the margin equate its costs of additional corn procurement with its total net benefits from additional production, including any changes in prices caused by the expansion of output. Equation (1.12) shows that the profit maximizing ethanol plant will equate its net marginal revenue product of wet distillers grains production and the value of the credits from wet production to the net marginal revenue product of dry production also with the value of the credits from dry production. Therefore, the profit maximizing ethanol plant will equate its net benefits of wet distillers grains production to its nets benefits from dry distillers grains production, including any effects on prices.

Moreover, the pass-through of LCFS credit prices and additional comparative statics can be drawn from (1.11) and (1.12) by differentiating these with respect to the price of LCFS credits. No ethanol plants can individually affect the price of LCFS credits, so an exogenous shock to credit prices can be used to determine the pass-through of the LCFS subsidies to corn prices-provided that the shock induces an expansion of corn procurement. The effects on the prices between wet and dry distillers grains can also be observed via the same means. Totally differentiating (1.11) and (1.12) with respect to the credit price and subsequent rearrangement yields the following

$$\frac{\partial P_C}{\partial C}\frac{dC}{dP_{LC}} = \left(\gamma\frac{dP_E}{dP_{LC}} + \gamma dP_{LC}B(\sigma - CI_d^i) + \mu\frac{\partial P_D}{\partial D}\frac{dD}{dP_{LC}}\left(1+\frac{\xi_d}{\eta_d}\right)\right)\left(1+\frac{\theta}{\epsilon}\right)^{-1}, \tag{1.11*}$$

$$\frac{\partial P_W}{\partial W}\frac{dW}{dP_{LC}} = \left(\delta\frac{\partial P_D}{\partial D}\frac{dD}{dP_{LC}}\left(1+\frac{\xi_d}{\eta_d}\right) - dP_{LC}B(CI_d^i - CI_w^i)\frac{\gamma\delta}{\mu}\right)\left(1+\frac{\xi_w}{\eta_w}\right)^{-1}. \tag{1.12*}$$

Equation (1.11*) shows that the total pass-through of LCFS credit prices to corn prices will depend on changes in the price of ethanol the price of dried distillers grains and the value of the credits themselves. The size of the pass-through to corn prices, however, depends on ability of ethanol plants to affect corn prices. If $\theta > 0$ and ethanol plants have some market power, then the pass-through to corn prices will be reduced. If $\theta = 0$ and corn markets are perfectly competitive, then the pass-through will be complete.

Determining whether the pass-through from (1.11*) is complete generates a testable condition for determining the market power of ethanol plants. After accounting for changes in distillers grains and ethanol prices, the change in subsidy will fully explain changes in corn price-if perfect competition in the local corn market holds. If $dP_{LC}\gamma B(\sigma - CI_d^i)$ can be isolated from the other terms, then a regression analysis could determine the pass-through specifically from this term. Since the policy parameters and fixed conversion ratios are known, $\frac{\theta}{\epsilon}$ can be determined from the results of that analysis. Moreover, θ could be directly measured as well if a reliable estimate for ϵ can be obtained from the literature.

Equation (1.12*) tells a similar story for changes in the spread between wet and dry distillers grain prices. If changes in the price of credits induces a different output mixture between wet and dry distillers grains, then the pass-through to wet distiller prices will depend on changes in the price of dry distillers grains and the size of the shock to price of credits-given the difference in CI's between wet and dry. Similar to equation (1.11*), if the oligopoly parameter $\xi_w > 0$, the decrease in wet distillers grain prices from an expansion of output caused by the credit price change will not be complete. Furthermore, if the direct effect of the subsidy can be isolated from changes in other prices, then determining the size of the market power parameter xi_w is possible given knowledge of the elasticity eta_w.

Finally, in the case that an ethanol plant is producing at full capacity, the pass-through of LCFS credit prices can still be measured through equation (1.12*). If the ethanol market is operating near the blend wall, then a change in the credit price could result in little to no change in the total ethanol sold. This lack of output expansion could result in little to no change in corn demand, and as a result, little to no change in corn prices via equation (1.11*). However, as long as the change in the price of credits produces a different production mix of distillers grains, then equation (1.12*) still holds. As a result, an empirical estimation of (1.12*) can be used to detect market power through measuring the pass-through of LCFS credit price changes to distillers grain prices in the case that the blend wall holds.

3.4 Equilibrium

Although (1.11*) and (1.12*) include the individual components CI_w^i and CI_d^i, all ethanol plants will meet these conditions at their optimal levels of production. Because of the common fixed proportions technology between all ethanol plants, (1.11*) then establishes an equilibrium condition between ethanol supply, distillers grain supply, ethanol-sector credit supply, and procurement for corn. (1.12*) likewise establishes an equilibrium condition for dry distillers grains supply, wet distillers grains supply, and credit supply from the ethanol sector.

The technology for supplying credits, however, is not homogeneous across ethanol plants because each ethanol plant has a random draw for the pair (CI_w^i, CI_d^i). Thus, ethanol-sector supply will be defined explicitly using equation (1.6). Using the optimal quantities d_i^* and w_i^*, a weighted-average carbon intensity rating for wet and dry can be calculated at the market level. Once the weighted-average carbon intensities are calculated, summing across all $i \in N$ yields the number of credits generated by the ethanol market

$$LC_E = \sum_{i=1}^{N} B((\sigma - CI_w^i)\frac{\gamma\delta w_i^*}{\mu} + (\sigma - CI_d^i)(\frac{\gamma d_i^*}{\mu})) = \frac{\gamma B}{\mu}((\sigma - \bar{C}I_w)\delta W + (\sigma - \bar{C}I_d)D)), \tag{1.6'}$$

where $\bar{C}I_w$ and $\bar{C}I_d$ are the weighted-average carbon intensities for wet and dry respectively. (1.6') depends implicitly on the price of LCFS credits P_{LC} through the equilibrium values of corn and wet distillers grains.

The equilibrium for the endogenous parameters E, C, W, D, LC_E, P_E, P_C, P_W, P_D, and P_{LC} are then determined by the equations (1.1), (1.2), (1.3), (1.4), (1.5), (1.6'), (1.11*), (1.12*), and the homogeneous fixed relations $\gamma C = E$ and $\mu C = D + \delta W$. Comparative statics can then be generated by differentiating the equations by exogenous parameters. Because the price of credits P_{LC} is independent from the actions of individual ethanol plants, it creates an exogenous means by which to define the pass-through of the subsidy to the price of corn in terms of other exogenous parameters. The credit price itself can be changed via an exogenous shock to the demand parameter U in equation (1.5). Using the inverse demand functions for (1.1), (1.3), (1.4), and (1.5) and the inverse supply function of (1.2), comparative statics for a change in U are found by totally differentiating the equations

$$\frac{dP_e}{dP_{LC}} = \frac{\partial D_E^{-1}}{\partial E}\frac{dE}{dP_{LC}} + \frac{\partial D_E^{-1}}{\partial P_{LC}}dP_{LC} + \frac{\partial D_E^{-1}}{\partial Z}\frac{dZ}{dP_{LC}}, \tag{1.1*}$$

$$\frac{dP_C}{dP_{LC}} = \frac{\partial S_C^{-1}}{\partial C}\frac{dC}{dP_{LC}} + \frac{\partial S_C^{-1}}{\partial Y}\frac{dY}{dP_{LC}}, \tag{1.2*}$$

$$\frac{dP_W}{dP_{LC}} = \frac{\partial D_W^{-1}}{\partial W}\frac{dW}{dP_{LC}} + \frac{\partial D_W^{-1}}{\partial P_D}\frac{dP_D}{dP_{LC}} + \frac{\partial D_W^{-1}}{\partial X}\frac{dX}{dP_{LC}}, \tag{1.3*}$$

$$\frac{dP_D}{dP_{LC}} = \frac{\partial D_D^{-1}}{\partial D}\frac{dD}{dP_{LC}} + \frac{\partial D_D^{-1}}{\partial P_W}\frac{dP_W}{dP_{LC}} + \frac{\partial D_D^{-1}}{\partial V}\frac{dV}{dP_{LC}}, \tag{1.4*}$$

$$dP_{LC} = \frac{\partial D_{LC}^{e-1}}{\partial LC_e}\frac{dLC_e}{dP_{LC}} + \frac{\partial D_{LC}^{e-1}}{\partial U}dU, \tag{1.5*}$$

$$\frac{dLC_E}{dP_{LC}} = \frac{\gamma B}{\mu}\left((\sigma - \bar{C}I_w)\delta\frac{dW}{dP_{LC}} + (\sigma - \bar{C}I_d)\frac{dD}{dP_{LC}}\right), \tag{1.6*}$$

$$\gamma\left(\frac{dP_E}{dP_{LC}} + dP_{LC}B(\sigma - CI_d^i)\right) + \mu\left(\frac{\partial D_D^{-1}}{\partial D}\frac{dD}{dP_{LC}}\left(1 + \frac{\xi_d}{\eta_d}\right)\right) = \frac{\partial S_C^{-1}}{\partial C}\frac{dC}{dP_{LC}}\left(1 + \frac{\theta}{\epsilon_c}\right), \tag{1.11*}$$

$$\frac{\partial D_W^{-1}}{\partial W}\frac{dW}{dP_{LC}}\left(1 + \frac{\xi_w}{\eta_w}\right) + dP_{LC}\frac{B\gamma\delta}{\mu}(CI_d^i - CI_w^i) = \delta\frac{\partial D_D^{-1}}{\partial D}\frac{dD}{dP_{LC}}\left(1 + \frac{\xi_d}{\eta_d}\right), \tag{1.12*}$$

$$\gamma \frac{dC}{dP_{LC}} = \frac{dE}{dP_{LC}}, \tag{14}$$

$$\mu \frac{dC}{dP_{LC}} = \delta \frac{dW}{dP_{LC}} + \frac{dD}{dP_{LC}} \tag{15}$$

This system makes two primary assumptions. First, the elasticity parameters do not change with respect to the price of credits. This assumption will hold if the shock to the credit prices is relatively small and the demand curve is well-behaved. Second, the weighted-average carbon intensity for wet and dry do not change with the shock in credit prices. This assumption is the most stringent, and it requires that the output response from each firm is scaled by the same value.

Using the system of equations, I derive differential changes in terms of percentage changes. These percentage changes enable the differentials to be defined in terms of elasticities and fixed-proportion parameters. These elasticities will provide more intuitive interpretations for the parameters defining the differentials. In the equations below, asterisks, i.e. E*, indicate a percentage change from the initial equilibrium. η's indicates elasticities for demand functions, and ϵ's indicate elasticities for supply functions. Finally, $\kappa's$ indicate shares of the initial total market equilibrium.

$$\frac{P_e*}{P_{LC}*} = \frac{1}{\eta_E}\frac{E*}{P_{LC}*} + \frac{P_{LC}}{\eta_{E,P_{LC}}} P_{LC}* + \frac{1}{\eta_{E,Z}}\frac{Z*}{P_{LC}*}, \tag{16}$$

$$\frac{P_C*}{P_{LC}*} = \frac{1}{\epsilon_C}\frac{C*}{P_{LC}*} + \frac{1}{\epsilon_{C,Y}}\frac{Y*}{P_{LC}*}, \tag{17}$$

$$\frac{P_W*}{P_{LC}*} = \frac{1}{\eta_W}\frac{W*}{P_{LC}*} + \frac{1}{\eta_{W,D}}\frac{P_D*}{P_{LC}*} + \frac{1}{\eta_{W,X}}\frac{X*}{P_{LC}*}, \tag{18}$$

$$\frac{P_D*}{P_{LC}*} = \frac{1}{\eta_D}\frac{D*}{P_{LC}*} + \frac{1}{\eta_{D,W}}\frac{P_W*}{P_{LC}*} + \frac{1}{\eta_{D,Y}}\frac{Y*}{P_{LC}*}, \tag{19}$$

$$P_{LC}* = \frac{1}{\eta_{LC_e}}\frac{LC_e*}{P_{LC}*} + \frac{1}{\eta_{LC_e,U}}\frac{U*}{P_{LC}*}, \tag{20}$$

$$\frac{LC_E*}{P_{LC}*} = \kappa_{LC,W}\frac{W*}{P_{LC}*} + \kappa_{LC,D}\frac{D*}{P_{LC}*}, \tag{21}$$

$$\gamma\left(\frac{P_E*}{P_{LC}*}P_E + P_{LC}^2 B(\sigma - CI_d^i)P_{LC}*\right) + \mu\left(\frac{P_D}{\eta_D}\frac{D*}{P_{LC}*}\left(1+\frac{\xi_d}{\eta_d}\right)\right) = \frac{P_C}{\epsilon_C}\frac{C*}{P_{LC}*}\left(1+\frac{\theta}{\epsilon_c}\right), \tag{22}$$

$$\frac{P_W}{\eta_W}\frac{W*}{P_{LC}*}\left(1+\frac{\xi_w}{\eta_w}\right) + P_{LC}^2\frac{B\gamma\delta}{\mu}(CI_d^i - CI_w^i)P_{LC}* = \delta\frac{P_D}{\eta_D}\frac{D*}{P_{LC}*}\left(1+\frac{\xi_d}{\eta_d}\right), \tag{23}$$

$$\gamma^2 \frac{C*}{P_{LC}*} = \frac{E*}{P_{LC}*}, \tag{24}$$

$$\mu^2 \frac{C*}{P_{LC}*} = \kappa_W \frac{W*}{P_{LC}*} + \kappa_D \frac{D*}{P_{LC}*} \tag{25}$$

The system of equations can be solved using Cramer's rule. From Cramer's rule, the pass-through rate of LCFS credit prices to corn prices can defined in terms of the elasticities, fixed proportions parameters, and market power parameters. Moreover, changes in the relative prices of distillers grains from LCFS credit prices can be derived as well in terms of elasticities and parameters.

4 Discussion

Once the endogenous variables are defined in terms of parameters, estimations for these parameters can be drawn from the literature. Simulations over values of the market power parameters would determine how sensitive the pass-through rate to corn prices and the relative distillers grains prices are to degrees of market power. Moreover, edge cases,such as when the blend wall binds and the overall quantity of ethanol purchased remains largely fixed, could be explored.[22] Once the simulations are complete, the results on welfare changes can be interpreted to reveal the incentives to innovate for ethanol plants because of the ability to earn and sell LCFS compliance credits.

References

Agricultural Marketing Service (AMS). (2022). Usda daily ethanol report, wed. march 29, 2022. Technical report, United States Department of Agriculture.

Babcock, B. A. (2008). Distributional implications of u.s. ethanol policy. *Review of Agricultural Economics*, 30:533–542.

Bushnell, J., Mazzone, D., Smith, A., and Witcover, J. (2020). Uncertainty, innovation, and infrastructure credits: Outlook for the low carbon fuel standard through 2030. *Institute of Transportation Studies, Working Paper Series qt7sk9628s*. Institute of Transportation Studies, UC Davis.

California Air Resources Board (CARB). (2020a). Lcfs basics. *Arb.ca.gov*. Accessed at:`https://ww2.arb.ca.gov/resources/documents/lcfs-basics`.

California Air Resources Board (CARB). (2020b). Unofficial electronic version of the low carbon fuel standard

[22]In such a case, the elasticity of demand for ethanol could be highly inelastic and approaching 0.

regulation. *Arb.ca.gov*. Accessed at:https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf.

California Air Resources Board (CARB). (2021a). 2020 LCFS Reporting Tool (LRT) Quarterly Data Summary: Report No. 4. *Arb.ca.gov*. Accessed at:https://ww3.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm.

California Air Resources Board (CARB). (2021b). E85 annual volumes chard. *Arb.ca.gov*. Accessed at:https://ww2.arb.ca.gov/resources/documents/alternative-fuels-annual-e85-volumes.

California Air Resources Board (CARB). (2022a). Current fuel pathways. *Arb.ca.gov*. Accessed at:https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities.

California Air Resources Board (CARB). (2022b). Lcfs quarterly data spreadsheet. *Arb.ca.gov*. Accessed at:https://ww3.arb.ca.gov/fuels/lcfs/lrtqsummaries.htm.

Cui, J., Lapan, H., Moschini, G., and Cooper, J. (2011). Welfare impacts of alternative biofuel and energy policies. *American Journal of Agricultural Economics*, 93(5):1235–1256.

Drabik, D., Ciaian, P., and Pokrivčák, J. (2016). The effect of ethanol policies on the vertical price transmission in corn and food markets. *Energy Economics*, 55:189–199.

Fowlie, M. (2009). Incomplete environmental regulation, imperfect competition, and emissions leakage. *American Economic Journal: Economic Policy*, 1(2):72–112.

Fowlie, M. (2010). Emissions trading, electricity restructuring, and investment in pollution abatement. *American Economic Review*, 100(3):837–69.

Fowlie, M., Reguant, M., and Ryan, S. P. (2016). Market-based emissions regulation and industry dynamics. *Journal of Political Economy*, 124(1):249–302.

Hoffman, L. and Baker, A. (2010). Market issues and prospects for u.s. distillers' grains supply, use, and price relationships. Technical report, United States Department of Agriculture, Economic Research Service, ers.usda.gov.

Holland, S. P. (2012). Emissions taxes versus intensity standards: Second-best environmental policies with incomplete regulation. *Journal of Environmental Economics and Management*, 63(3):375–387.

Holland, S. P., Hughes, J. E., and Knittel, C. R. (2009). Greenhouse gas reductions under low carbon fuel standards. *American Economics Journal: Economic Policy*, 1:106–46.

Jung, J., Sesmero, J., and Siebert, R. (2022). A structural estimation of spatial differentiation and market power in input procurement. *American Journal of Agricultural Economics*, 104(2):613–644.

Lade, G. E. and Bushnell, J. (2019). Fuel subsidy pass-through and market structure: Evidence from the renewable fuel standard. *Journal of the Association of Environmental and Resource Economists*, 6(3):563–592.

Lade, G. E., Cynthia Lin Lawell, C.-Y., and Smith, A. (2018a). Designing climate policy: Lessons from the renewable fuel standard and the blend wall. *American Journal of Agricultural Economics*, 100(2):585–599.

Lade, G. E. and Lin Lawell, C. C. (2021). The design of renewable fuel mandates and cost containment mechanisms. *Journal of Environmental Resource Economics*, 79:213–247.

Lade, G. E., Lin Lawell, C.-Y. C., and Smith, A. (2018b). Policy shocks and market-based regulations: Evidence from the renewable fuel standard. *American Journal of Agricultural Economics*, 100(3):707–731.

Marion, J. and Muehlegger, E. (2011). Fuel tax incidence and supply conditions. *Journal of Public Economics*, 95(9):1202–1212.

McNew, K. and Griffith, D. (2005). Measuring the impact of ethanol plants on local grain prices. *Applied Economic Perspectives and Policy*, 27(2):164–180.

National Agricultural Statistical Service (NASS). (2022). Grain crushings and co-products production 03/01/2022. usda.library.cornell.edu. Accessed at: `https://usda.library.cornell.edu/concern/publications/n583xt96p`.

Pless, J. and van Benthem, A. A. (2019). Pass-through as a test of market power: An application to solar subsidies. *American Economic Journal: Applied Economics*, 11:367–401.

Pouliot, S. and Babcock, B. A. (2016). Compliance path and impact of ethanol mandates on retail fuel market in the short run. *American Journal of Agricultural Economics*, 98(3):744–764.

Renewable Fuels Association (RFA). (2022). Low Carbon, Clean Fuel Policies: Building Upon the RFS with Low Carbon, Clean Fuel Policies. *Ethanolrfa.org*. Accessed at: `https://ethanolrfa.org/policy/low-carbon-clean-fuel-policies`.

Saitone, T. L., Sexton, R. J., and Sexton, S. E. (2008). Market Power in the Corn Sector: How Does It Affect the Impacts of the Ethanol Subsidy? *Journal of Agricultural and Resource Economics*, 33:169–194.

Weyl, E. G. and Fabinger, M. (2013). Pass-through as an economic tool: Principles of incidence under imperfect competition. *Journal of Political Economy*, 121(3):528–583.