Invited Paper

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The Economic Effects of COVID-19 on the Producers of Ethanol, Corn, Gasoline, and Oil

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Abstract: The COVID-19 crisis created large economic losses for corn, ethanol, gasoline, and oil producers and refineries both in the United States and worldwide. We extend the theory used by Schmitz, A., C. B. Moss, and T. G. Schmitz. 2007. "Ethanol: No Free Lunch." *Journal of Agricultural & Food Industrial Organization* 5 (2): 1–28 as a basis for empirical estimation of the effect of COVID-19. We estimate, within a welfare economic cost-benefit framework that, at a minimum, the producer cost in the United States for these four sectors totals $176.8 billion for 2020. For U.S. oil producers alone, the cost was $151 billion. When world oil is added, the costs are much higher, at $1055.8 billion. The total oil producer cost is $1.03 trillion, which is roughly 40 times the effect on U.S. corn, ethanol, and gasoline producers, and refineries. If the assumed unemployment effects from COVID-19 are taken into account, the total effect, including both producers and unemployed workers, is $212.2 billion, bringing the world total to $1266.9 billion.

Keywords: COVID-19, ethanol, corn, gasoline, oil, refineries

1 Introduction

Sharply rising oil prices in the twenty-first century have incentivized the United States to seek energy self-sufficiency through increased domestic biofuel production. U.S. reliance on oil imports from the Middle East has been a major policy concern since the 1973 energy crisis. This concern led to the passage of the U.S. Energy Independence and Security Act of 2007, which has steadily increased the use of ethanol in the United States. In September 1995, ethanol represented 0.50% of total oil consumption in the United States; by August of 2008, ethanol use had risen to 3.36% of oil consumption; and by February of 2018, to 5.37% (Schmitz et al. 2020).

Biofuel production in the United States contributes to national energy security while supporting U.S. rural economic development. The COVID-19 pandemic in 2020 had a major negative impact on U.S. ethanol, gasoline, and oil prices and production. World oil prices and production also plummeted. By spring 2020, fossil fuel had become a liability, not an asset. A combination of low demand, overproduction in an intensely competitive market, and limited storage capacity created a "perfect storm" for the first-ever negative crude oil prices. For ethanol alone, from an industry perspective, Renewable Fuels Association (RFA) 2020 projected that the ethanol industry will contribute $30.1 billion to GDP in 2020, nearly one-third less than in 2019. From a biofuel company perspective, The Andersons Ethanol Group, for example, saw a $24 million decrease in its first quarter gross income for 2020 from biofuel production, with ethanol accounting for about 90% of the company's biofuel income (Voegete 2020). To counter economic losses to biofuel companies caused by the pandemic, the United States Department of Agriculture (USDA) has established $100 million in grants through the Higher Blends Infrastructure Incentive Program (HBIIP) as part of the USDA Rural Business-Cooperative Service.

In our empirical estimates, we recognize that there was a pre-pandemic crisis in the energy sector, including oil. The oil war between Russia and the OPEC partners led to a glut of oil on the world market. Similarly, the fracking industry had leveraged itself dangerously, and got hit by a repayment crisis. It increased production as prices were falling to meet repayment of loans. These two events created a perfect storm. Ethanol and oil prices were already very low in December 2019, well before COVID-19 created havoc. We incorporate the effect of OPEC in a later section dealing with the world oil market.

There are many published studies on the impact of ethanol fuel policy on the U.S. corn market, including Taheripour and Tyner (2014). These results are summarized

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in Taheripour, Cui, and Tyner (2019, p. 650). There are relatively few published results on the impact of the growth in ethanol on the U.S. and world gasoline and oil markets. Also, the 2020 studies on the effect of COVID-19 are generally confined to the corn–ethanol complex. These studies are discussed later in the empirical section.

We estimate the producer effects of COVID-19 by updating the economics of the corn–ethanol complex within a much broader framework that includes the ethanol–gasoline–oil complex. Welfare economics is used as the theoretical basis for these estimates, but we deal only with the producer effects of COVID-19. To do a complete benefit-cost analysis, which is beyond the scope of this paper, would also require estimates of the consumption impact. Within this context, the analysis of the effects of the U.S. energy policy is expanded to incorporate alternative specifications of supply price elasticities and trade. In the empirical analysis, we estimate both the short- and long-run impacts of COVID-19, along with the unemployment effects. Our cost estimates of producer losses from COVID-19 are based on the concept of producer surplus (well known in welfare economics literature). These cost estimates are lower than if we had used changes in total revenue instead as a measure.

2 Changes in the Ethanol–Corn–Gasoline–Oil Complex

Major changes have taken place in the U.S. ethanol–gasoline–oil complex since our 2007 paper. Changes include (1) significant increases in U.S. ethanol and corn production; (2) new oil exploration technologies; (3) fewer U.S. oil production regulations; (4) increased oil drilling on federal lands; (5) U.S. policy changes that affect ethanol production; (6) reduced U.S. reliance on foreign oil; (7) drop in demand for gasoline; and (8) significant reductions in oil and gasoline production due to COVID-19.

tThe U.S. ethanol energy policy had a major impact on fuel production, which was a factor that resulted in the United States becoming oil independent. In 2019, the United States produced roughly 16 billion barrels of ethanol from corn. In the same year, the United States produced 16 billion bushels of corn, of which 25–30% was used for ethanol production. Even so, the world oil market remains highly volatile. This is partly due to the uncertain behavior of OPEC. For example, the major drop in oil and gasoline prices in early-2000 was partly because OPEC did not curb crude oil production in light of the price drop. Later, in June 2020, two of the key members – Russia and Saudi Arabia – significantly cut oil production.

The consumption of blended motor fuel (reformulated blended gasoline) was relatively constant between September 2017 and March 2020, but declined dramatically with the onset of COVID-19 (Figure 1). In 2020, compared to 2019, per capita consumption fell by roughly 50%. The observed value of fuel consumption presented in Figure 1 is similar to the value estimated by Irwin and Hubbs (2020). Irwin and Hubbs predict a 40% decline in gasoline consumption in April 2020, from 11.6 to 7.7 billion gallons. Similarly, they predict a decline in gasoline production in May 2020 of 19%, from 12.3 to 10.2 billion gallons.

Three different phases of gasoline prices exist between 2010 and 2020 (Figure 2). From 2010 to mid-2014, the average price of gasoline was $3.57 per gallon. Between mid-2014 and July 2018, the blended gasoline price averaged $2.70 per gallon, while from July 2018 to March 2020, the blended gasoline price averaged $2.59 per gallon.

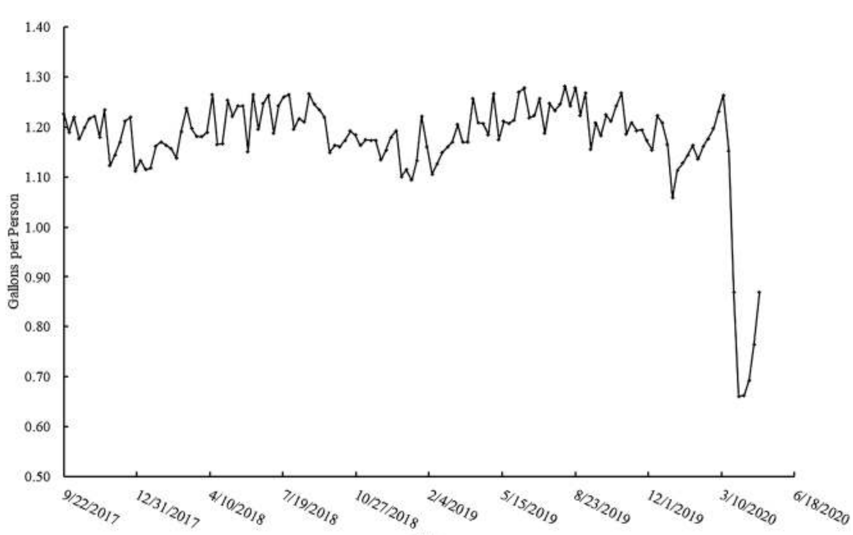

Figure 1: U.S. blended fuel consumption, 2017–2020.

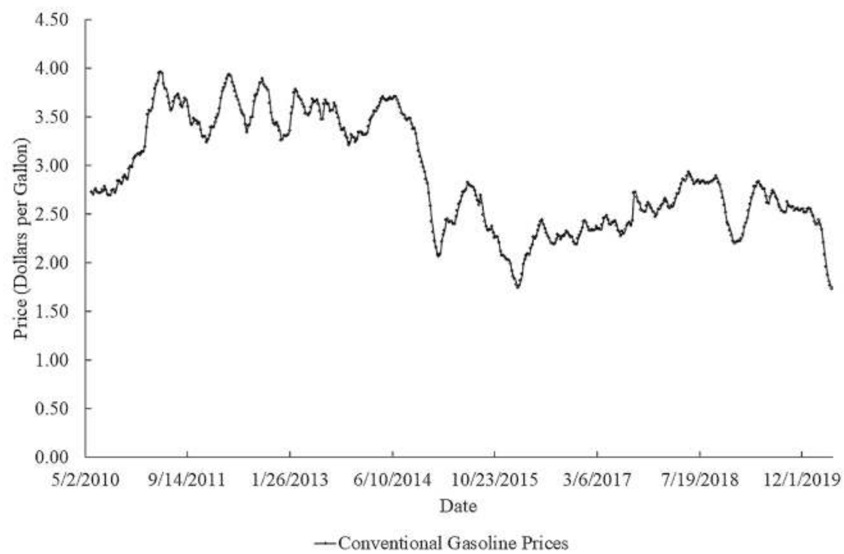

Figure 2: U.S. gasoline prices, 2010–2020.

Figure 3: U.S. WTI futures price, constant dollars, 1983–2020.
Source: Worldoil.com (2020).

Figure 3 illustrates the volatility in U.S. oil prices. For example, in December 1998, the price of oil was roughly $20 per barrel. In 2008, the price of oil exceeded $160 per barrel. With the onset of COVID-19, the price of oil dropped to below $40 per barrel.

3 Theoretical Considerations

3.1 Alternative Ethanol Energy Programs

U.S. energy policy has had a significant effect on the U.S. oil–gasoline–ethanol complex. The magnitude of oil and gasoline production that existed prior to COVID-19 was in part due the U.S. energy policy. The complexity of the ethanol component of the U.S. energy policy is illustrated in Table 1. The Volumetric Ethanol Excise Tax Credit (VEETC) was created as part of the 2004 American Jobs Creation Act to subsidize ethanol production by giving the producers of motor fuel a 51.5 cents per gallon tax credit on ethanol blended with gasoline for sale in the United States. Ethanol use targets, including the mandated Renewable Fuels Standard (RFS), were introduced in the Energy Policy Act of 2005 and the Energy Independence and Security Act of 2007. Neither of these acts (e.g., the Energy Policy Act of 2005 or the Energy Independence and Security Act of 2007) explicitly prescribed a mechanism for enforcing the targets – implicitly relying on VEETC. However, in 2010, shortly before the VEETC expired in 2011, the United States Environmental Protection Agency announced a new rule to meet the RFS. This rule created the concept of a Required Volume Obligation, where refiners were obliged to purchase the rights to a level of ethanol that would meet the RFS when they produced gasoline. To meet this obligation,

Table 1: U.S. federal ethanol energy legislation and standards, 2004–2007.

Year	Policy
2004	American Jobs Creation Act of 2004 (PL 108-357): Created the Volumetric Ethanol Excise Tax [VEETC]
2005	Energy Policy Act of 2005 (PL 109-58): Created the initial Renewable Fuel Standard [known as RFS1]
2007	Energy Independence and Security Act of 2007: Extended the Renewable Fuel Standard [known as RFS2]
2010	Rule change by Environmental Protection Agency (75 FR 14673, March 26, 2010): Created the Required volume Obligation [RVO] and the Renewable Identification Numbers [RIN] to meet the RFS2 standards.

refineries would purchase the right to a certain level of ethanol. The mechanism for this right is the Renewable Identification Number (RIN) credit. The gasoline is then sold with the RIN to a blender who purchases the ethanol, blends the gasoline and the ethanol, and retires the RIN.

To compare the impact of the VEETC with the RFS mandate, consider the profit maximization function (Equation (1)) for producers of gasoline:

$$\pi = \max p_G f(x_{CO}, x_{Et}, x_L) - w_{CO}x_{CO} - (w_{Et} - \tau_{Et})x_{Et} - w_L x_L + \lambda\left(R - \frac{x_{Et}}{x_{CO}}\right), \quad (1)$$

where x_{CO} is the quantity of crude oil used to produce blended gasoline, x_{Et} is the quantity of ethanol used, x_L is the amount of labor used, w_{CO} is the price of crude oil, w_{Et} is the price of ethanol, τ_{Et} is the subsidy on ethanol used to produce blended gasoline (the VEETC), w_L is the price of labor, and R is the required blend ratio. If we ignore the required blend ratio (i.e., $R - x_{Et}/x_{CO}$), the first-order conditions imply that the marginal rate of substitution at the optimal combination of crude oil and ethanol becomes

$$\frac{\partial x_{CO}}{\partial x_{Et}} = \frac{w_{Et} - \tau_{Et}}{w_{CO}}. \quad (2)$$

Figure 4 depicts this solution under two scenarios. In case 1, $\tau_{Et} = 0$. No ethanol is blended with gasoline; hence, $x^0_{CO} > 0$ and $x^0_{Et} = 0$ (i.e., the optimal combination of crude oil to ethanol is the corner solution on the crude oil axes). This is compared to the case where a VEETC subsidy exists. The quantity of ethanol used to produce blended gasoline increases from zero to $x'_{Et} > 0$, while the amount of crude oil used to produce blended gasoline declines to $x'_{CO} < x^0_{CO}$. This point is determined by the new price ratio k''. Note that the cost of producing this fixed level of blended fuel falls (Equation (1)).

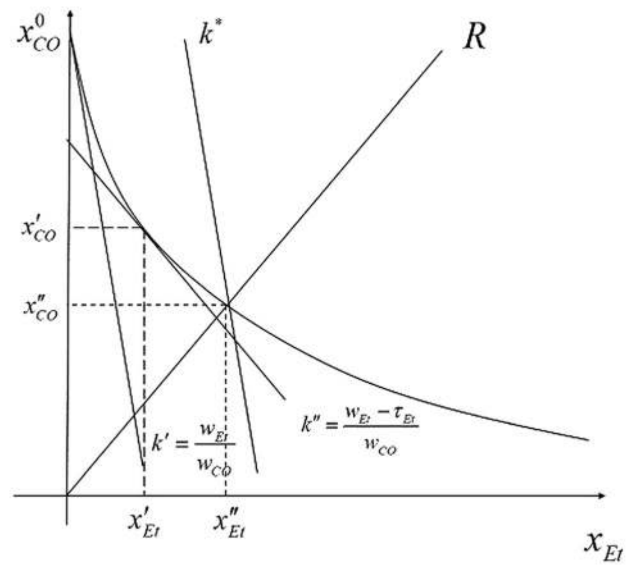

Figure 4: Economic choice of crude oil and ethanol.

Consider now the case where the blend ratio is mandated, but the subsidy on ethanol is eliminated (i.e., re-insert the constraint $R - x_{Et}/x_{CO}$, and set ($\tau_{Et} = 0$). Thus, there is no choice between crude oil and ethanol – the blend is mandated by policy.

In Figure 4, this mandated blend is depicted by the ray R. The quantity of crude oil used under the mandate is x''_{CO}, while x''_{Et} of ethanol is used in the production of blended gasoline. We define the price lines k' and k'' as iso-cost lines. The cost of producing the required blend increases the cost of producing the blended fuel. Thus follows the original (unsubsidized) solution; that, given flexibility, producers of blended fuel would choose to produce no ethanol.

Figure 5 extends the analysis to include the crude oil, ethanol, and blended fuel markets. Under the initial solution, we assume that there is neither a subsidy for ethanol production nor a required blend. Under these assumptions, the initial supply curve (S^0_G) and demand curve (D_G) give rise to a quantity of y^0_G at a price of p^0_G. At this solution, no ethanol is produced for fuel, and the quantity of crude oil used to produce fuel is x^0_{CO} at a market price of w^0_{CO}. Next, we assume that ethanol production is subsidized. Given a subsidy of τ_{Et}, the quantity of ethanol produced for blended fuel market increases to x'_{Et}. The supply of blended fuel shifts out to S'_G, resulting in a lower fuel price of p'_G and an increased quantity of fuel consumed. Given the introduction of ethanol, the demand for crude oil shifts inward to D'_{CO}, resulting in a lower price for crude oil and a smaller quantity of crude oil demanded (x'_{CO}).

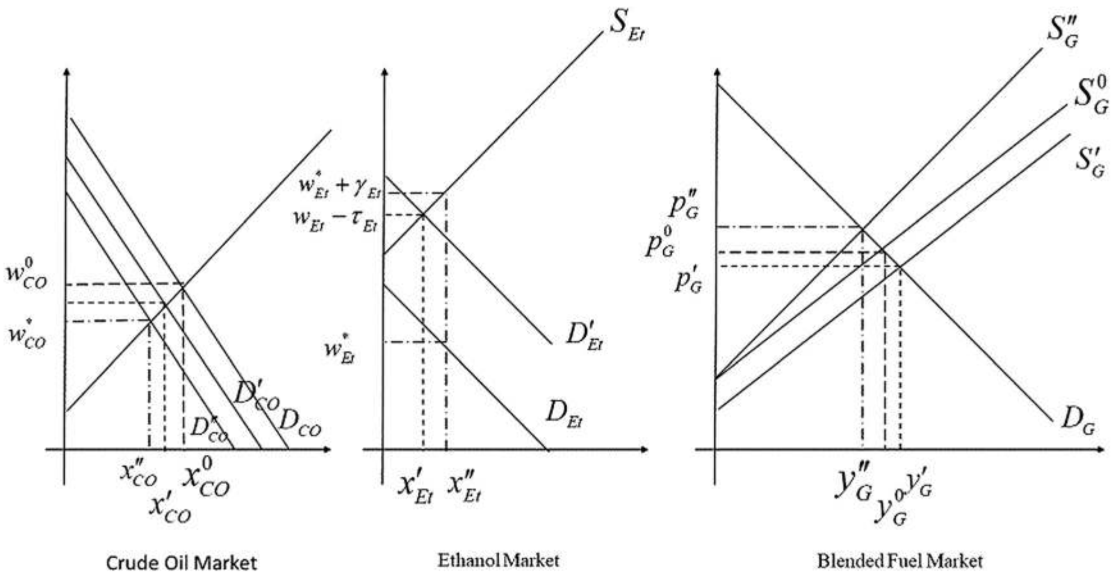

Figure 5: Ethanol market under various ethanol policies.

With the required mandate, the supply function shifts from S_G^0 to S''_G (Figure 5). Blenders now use a more costly blend of ethanol and crude oil. Further, the effect of this misallocation increases as the quantity of blended gasoline increases. Tracing the blend requirement back into the market for ethanol, fuel producers are required to increase the amount of ethanol to x''_{Et} to meet the blend requirements. Given these blend requirements, ethanol is only worth w''_{Et} to the blenders (i.e., the value of marginal product for the use of x''_{Et} is only (w''_{Et}). However, since they are required to use this quantity under the mandated blend ratio, they must pay a price of $w''_{Et} + \gamma_{Et}$ to acquire this quantity of ethanol. Under the current program, the premium (γ_{Et}) is the price of the RIN purchased by gasoline distillers when they create a barrel of gasoline (a Renewable Volume Obligation – RVO). The blend requirement results in an increased demand for ethanol (x''_{Et}) In addition, the mandatory blend ratio results in a higher price of blended fuel (e.g., increasing from p_G^0 to (p''_G) and a lower quantity of fuel consumed. Further, the introduction of a mandatory blend ratio reduces the demand for crude oil (to x''_{CO}) and crude oil prices.

3.2 Welfare Economics Framework

We use welfare economics as a framework for theoretical and analytical purposes to assess U.S. ethanol policy and the impact of COVID-19 on the ethanol-gasoline-oil complex.

3.2.1 Zero trade

We analyze the energy policy in a zero trade framework.

- We discuss the effect of ethanol subsidies (Figure 6). The ethanol supply curve is S_E, the gasoline supply curve is S_G, the demand for gasoline (or a combination of gasoline and ethanol) is D, the price of gasoline is p_0, and the quantity of gasoline consumption is q_0. With an ethanol per unit subsidy, the ethanol supply curve shifts to S'_E. The ethanol produced under the subsidy is q_1 to meet the demand q_0 (a blend of gasoline and ethanol). The quantity of gasoline consumption is q_2 while the quantity of ethanol consumption is q_1.
- Consider now the case where a mandatory blend is combined with a subsidy. In the simplest case, assume that the mandate requires that q_1 of ethanol be blended

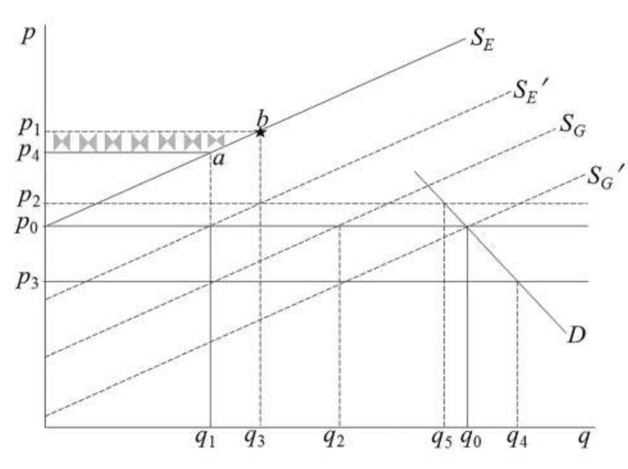

Figure 6: Ethanol subsidy and mandatory blend ratio.

with gasoline. The blenders purchase this quantity of ethanol at price p_0, as is the case with an ethanol subsidy only. With a combination of a subsidy and a mandatory blend, the solution need not be different than in the case of a subsidy alone.

- If the ethanol subsidy is removed and only the mandatory blend remains, the blenders are required to purchase a quantity of ethanol q_1 at price p_4. This results in a higher price for the combination of gasoline and ethanol. Because gasoline blenders are required to purchase both ethanol and gasoline, the higher cost for ethanol causes the blend price to increase from p_0 to p_2, and fuel consumption to fall from q_0 to q_5. Consider now the effect of the change in the blend requirements. Suppose that under the blend, the purchase of ethanol by blenders is q_3 at price p_1. Ethanol producers gain (p_1p_4ab), but the overall price of fuel increases.
- The above assumes that S_E and S_G are upward sloping in contrast to de Gorter and Just (2009) where, in their seminal paper on the effect of a blend ratio policy, they assume both that S_G is perfectly elastic and zero trade. This assumption is of critical importance, especially in view of our empirical analysis later, where supply is shown to be highly price inelastic (Figure 7).
- Assume in case 1 that the supply of gasoline is S_1, the supply of ethanol is S_E, and D is demand for fuel (either blended or unblended). Without the mandate, the gasoline price is p_1, and q_1 is the amount of gasoline produced. Now suppose a mandate q_m is imposed, giving rise to an ethanol price of p_2. In response, the gasoline price falls to p_3 and gasoline production falls to q^* ($q_m + q^*$ now equals q_1). Gasoline producers lose (p_1p_3ab) from the mandate, and ethanol producers gain rents (p_2p_1c). Note that the blended fuel price need not change due to the fuel mandate.
- Now assume in case 2 that supply is S_0 rather than S_1. Here, the blend ratio has no effect on the economic rents of gasoline producers (i.e., there are no gross rents above S_0 and, in equilibrium, the fuel blend price has to be higher than p_1).
- Due to COVID-19, the demand for gasoline dropped significantly worldwide. Prior to the fall in demand, Figure 8 shows the equilibrium price and quantity within a mandated blend framework. The supply of ethanol is S_E and the supply of gasoline is S_G. Without the mandate, the gasoline price is p_0, quantity demand is q_0, and the entire demand is made up of gasoline. We now add a blending constraint of q_1. In order to keep the fuel blend price equal to p_0, U.S. gasoline production falls to q_w and the producer price falls to p_w. As a result, ethanol producers gain ($p_1p^{**}ef$) while U.S. gasoline producers lose (p_0p_wac). Consider now a drop in fuel demand shifts from D to D'. Given the blend constraint of q^{**}, U.S. producer gasoline prices fall to p_w^* and production falls to q_1. For ethanol, the price falls from p_1 to p_w^* and production falls to q^{**}. As a result of the drop in demand for fuel, ethanol producers lose ($p_1p^{**}ef$) and gasoline producers lose ($p_wp_w^*ba$).

3.2.2 Non-Zero Trade

To expand the scope of the above analysis, we discuss energy policy in a trade framework.

- Consider Figure 9, where S_G is the U.S. supply of gasoline and S_E is the ethanol supply curve. U.S. demand is ($D_G + D_E$). Given the world price of gasoline P_W, the

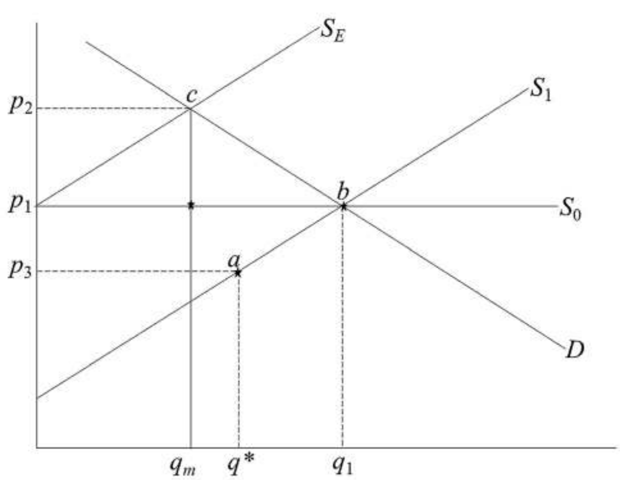

Figure 7: Effect of a blend ratio policy.

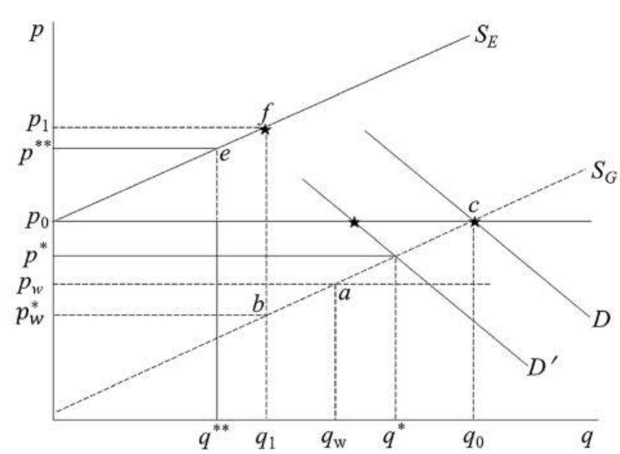

Figure 8: Falling gasoline demand.

United States produces q_1 of gasoline and imports q_1q_2. In the absence of an ethanol subsidy on production, given the supply curve S_E, no ethanol is produced.
- If a subsidy is given to ethanol producers, the supply of ethanol shifts from S_E to S_S, and ethanol production increases to q_4. The total of the gasoline and ethanol supply is $(S_G + S_S)$. As a result, due to the increase in the total production of the gasoline-ethanol blend, imports are reduced to q_3q_2. The cost of the U.S. government subsidy to ethanol producers is $(g'ebc)$.
- What are the effects of the collapse in world and U.S. gasoline prices due to falling world demand caused by COVID-19? The U.S. demand shifts to D' Gasoline prices fall from P_W to $S_E{}'$.
  1. Ethanol production falls from q_4 to q_5.
  2. U.S. government ethanol subsidies are reduced to $(g'efg)$.
  3. Ethanol producers lose $(g'hfb)$ from the drop in world gasoline prices.
  4. U.S. gasoline production falls from q_1 to q_7.
  5. U.S. gasoline producers lose $(g'hji)$.
  6. The combined loss to U.S. ethanol and gasoline producers totals $(g'hkl)$.
  7. U.S. imports of gasoline total q_1q_6.

3.2.3 Interaction Effects: Refineries, and Ethanol, Gasoline, and Oil Producers

We now link oil refineries with ethanol, gasoline, and oil producers. Refineries blend gasoline and ethanol and market it as "blend gasoline" using the blend requirement set forth in the Renewable Fuels Act.
- The supply of blend fuel in Figure 10a is S_G and demand is D_G. The supply of ethanol in Figure 10b is S_E, while demand for ethanol by refineries is D_E. Ethanol is

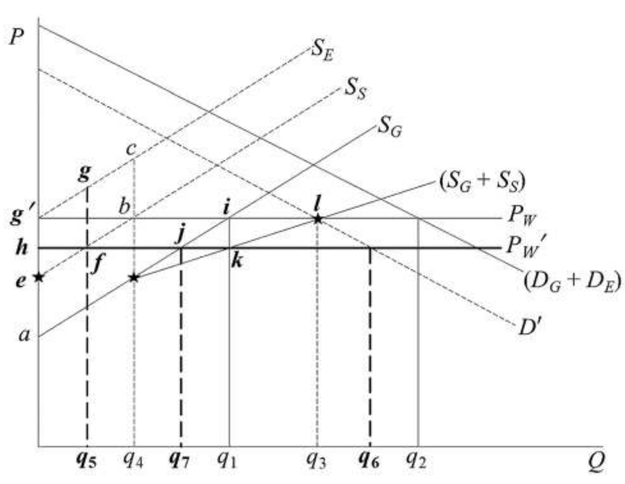

Figure 9: Gasoline–ethanol production and trade (imports).

sold to the refineries at price p_0 for quantity q_0. A shift in the demand for blend gasoline from D_G to $S_E{}'$ causes the price and quantity to fall to p_2 and q_2, respectively. Correspondingly, the derived demand for ethanol by the refineries shifts from D_E to D_E', causing the price of ethanol to fall to p^* and the quantity purchased by refineries to fall to q^*. Because of the blend ratio, refineries reduce ethanol purchases given consumer fuel demand of q_2. Due to the drop in gasoline prices, ethanol producers lose (p_0p^*ec), and government ethanol subsidies are reduced from $(abcd)$ to $(abef)$.
- Consider now the case where gasoline prices are affected by shifts in the supply of ethanol. In Figure 11, S and D are derived given the price of corn – a major component in the cost of producing corn ethanol. We consider three cases: a decrease in corn prices, an increase in corn prices, and a joint decrease in gasoline and corn prices.
- *Decrease in Corn Prices*: A decrease in corn prices shifts ethanol supply from S to S'. The unrestricted price and quantity is $p_2,\ q_2$. With the blend ratio constraint, the maximum ethanol quantity is q_1. Given S' and a fixed quantity of ethanol q_1, price falls to p_3. Based on $\{(p_1ab) = (p_3cd)\}$, ethanol producers lose from the drop in the price of corn, while refineries gain from the drop in ethanol prices.
- *Increase in Corn Prices*: We take S' as the ethanol supply curve before the rise in corn prices. In this case, the price of ethanol increases to p_1 and quantity is reduced to q_1 given the new supply curve S. To produce q_2 to meet the blend requirement, the price of ethanol has to increase to p^*. Interestingly, ethanol producers are unaffected by the increase in corn prices as $(p_2cf) = (p^*ae)$.
- *Joint Decrease in Gasoline and Corn Prices*: Gasoline prices fall from p_0 to p_1 and quantity demanded falls to q_1 (Figure 12a). The derived demand for ethanol shifts from D^* to D^{**} (Figure 12b). Due to falling corn prices, the supply of ethanol shifts from S_E to S_E' (Figure 12b). With the current blend requirement, refineries pay the low ethanol price of p_1. Ethanol producers do not gain from the drop in corn prices. The net change in economic rent is zero as $\{(p_ecb) = (p_1da)\}$.

4 Empirical Analysis

To estimate the impact of COVID-19 on producers operating within the ethanol-gasoline-oil complex, we use the data

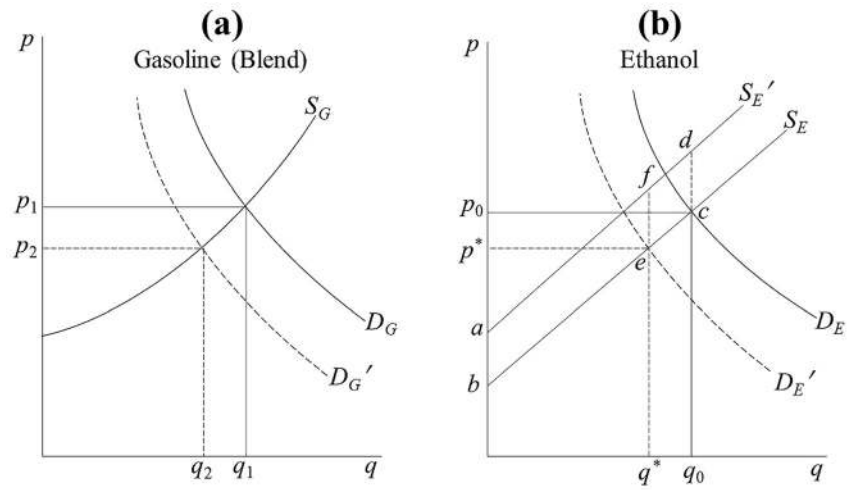

Figure 10: Blend gasoline and ethanol.

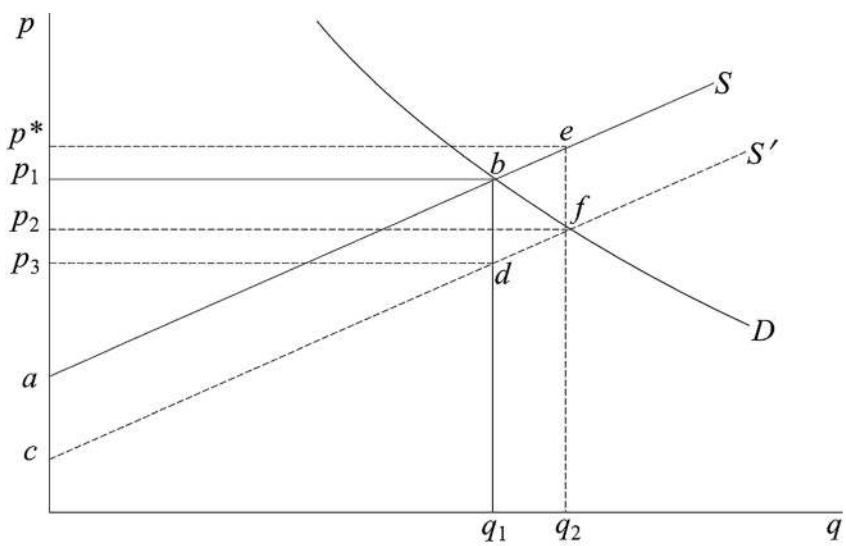

Figure 11: Ethanol profitability and corn prices.

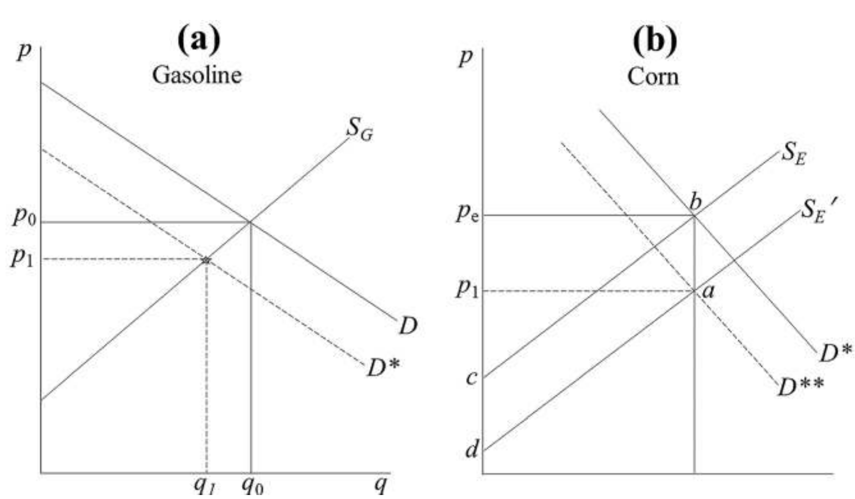

Figure 12: Combined gasoline and ethanol prices.

for the combined years 2018 and 2019 and compare this with 2020. For the latter, we use data for January through June, and projections for July through December.

4.1 Corn–Ethanol Complex

To empirically estimate of the effect of falling ethanol prices on the corn market, data are used from corn prices and quantity of corn used to produce ethanol (USDA's Feed Grains Database); ethanol rack prices in dollars per gallon (Nebraska Department of Energy); gasoline prices (U.S. Department of Energy); 500-lb feeder cattle (USDA/Quickstats); household wages earned and the Personal Consumption Expenditures chained price index (U.S. Department of Commerce).

To estimate the effect of changes in ethanol production on the corn market, (1) the real ethanol price is regressed on real gasoline prices, wages, and two sinusoid terms to account for seasonality, and (2) the estimated ethanol prices are used to estimate the quantity of corn used to produce ethanol in addition to real corn prices, real prices for feeder cattle, a time trend, and two sinusoids to adjust for seasonality. The estimated parameters for the logarithmic specification of the demand for corn to produce ethanol are given in Table 2.

The price of ethanol fell from $1.15/gallon in December 2019 to $0.59/gallon between December 2019 and May 2020, at a rate of 0.667 (Nebraska Energy Statistics 2020). Using the estimated effect of ethanol on the demand for corn in Table 2 implies a reduction in the corn demanded to produce ethanol of 0.473, or 728.298 million bushels per quarter (Table 3). Given corn consumption in 2019:Q2, the share of corn used to produce ethanol is set at 0.307 of overall corn production. The decrease in ethanol prices implies a 0.145 decline in the overall demand for corn. Assuming an exponential form of both the supply and demand relationships, the producer surplus loss is given in Table 4. With a demand price elasticity of −0.250 and a supply price elasticity of 0.250, the price of corn falls to 2.196, or 31.4% with the decline in the demand for corn to produce ethanol. This results in a loss of producer surplus of $15.46 billion. To test the sensitivity of these results to changes in supply and demand elasticities, we multiply both the elasticity of supply and demand by 1.5. The price of corn falls to $2.53/bushel, while producer surplus declines by only $10.31 billion.

Our predicted decline in corn used for ethanol is somewhat larger than that predicted by Irwin and Hubbs (2020). In addition, our estimate of the impact of COVID-19 on corn prices is larger than that estimated by Hart et al. (2020). This difference is due to the methodology; we use supply and demand elasticities where Hart et al. (2020) use changes in futures prices to estimate the effect of COVID-19 on corn prices. Our overall estimate of the effect of COVID-19 on corn prices in the United States is similar to Beghin and Timalsina (2020) who predict that corn prices have fallen from $3.74/bushel in December 2019 to $2.94/bushel in May of 2020, which represents a 24.1% decline. This result is less than the 0.209% decline, which is our minimum estimate, but larger than the 25.1% reduction, which is our mid-range estimate of the effect of COVID-19 on corn prices.

Table 2: U.S. demand for corn to produce ethanol.

Parameter	Estimate
Constant	−260.1004***
	(8.1193)[a]
Ethanol price	0.7084***
	(0.0968)
Corn price	−0.0125
	(0.0978)
Cattle price	0.2157
	(0.2278)
Trend	0.1319***
	(0.0043)
Sine (seasonality)	−0.0422
	(0.0297)
Cosine (seasonality)	0.1529***
	(0.0420)

[a]Numbers in parentheses denote standard errors.
***Denotes statistical significance at the 0.01 level of confidence.
Source: Authors' computations.

4.2 U.S. Ethanol Complex

In 2007, we published a paper "Ethanol: No Free Lunch" in honor of Professor Bruce Gardner that gave a theoretical

Table 3: Levels of corn production and ethanol demand.

Item	Value
Log change in ethanol price	−0.667
Log change in corn consumption for ethanol	−0.473
Corn consumption of ethanol in 2019:Q2 (million bushels)	1381.400
New corn consumption for ethanol (million bushels)	728.298
Reduction in ethanol demand (million bushels)	2.324
Share of ethanol to total corn use	0.307
Log change in corn consumption holding other uses constant	−0.145

Source: Corn consumption data – USDA feed grains database, remaining values – Authors' computations.

Table 4: Impact of reduced ethanol demand on U.S. corn prices, equilibrium demand, and producer surplus.

Demand elasticity	Supply elasticity	Equilibrium corn price (dollars/bushel)	Equilibrium corn quantity (billion/bushels)	Change in corn price (dollars/bushel)	Percent change in price (dollars/bushel)	Change in producer surplus (billion USD)
−0.250	0.250	2.196	14.792	−1.004	−0.314	−15.457
−0.375	0.250	2.396	15.026	−0.804	−0.251	−12.490
−0.250	0.375	2.396	14.562	−0.804	−0.251	−12.270
−0.375	0.375	2.530	14.792	−0.670	−0.209	−10.305

Source: Authors' computations.

framework and empirical results on the effect of the U.S. Energy Policy that promotes the production and use of corn ethanol. We concluded that

> The sharp rise in energy prices in the 1980s triggered a strong interest in the production of ethanol as an additional energy component. Economists are divided as to the payoffs from ethanol-derived corn in part because of the complex interrelationship between energy produced from ethanol and energy from fossil fuels. Using a welfare economic framework, we calculate that there can be treasury savings from ethanol using tax credits as these subsidies can be smaller than direct payments to corn farmers, which are essentially eliminated from the expansion of ethanol. Also, to the extent that ethanol dampens fuel prices there can be a net welfare gain from ethanol production in the presence of ethanol subsidies (Schmitz, Moss, and Schmitz 2007).

This paper has a different focus in that there is no benefit-cost assessment of the U.S. ethanol program. Rather the focus is on the producer effect of COVID-19 on the U.S. ethanol-corn-gasoline-oil complex, taking into account the many changes that have occurred in this complex.

U.S. production, consumption, and trade of ethanol has changed over the years (Figure 13). Prior to 2020, U.S. ethanol production expanded significantly, with the largest increase occurring between 2006 and 2010 (introductory period of the U.S. ethanol program). Between 2007 and 2019, ethanol production roughly doubled, and then collapsed in 2020 due to COVID-19. As a result, over 70 ethanol plants in the United States have significantly reduced operations and their labor force because of decreased demand due to COVID-19.

Prior to COVID-19, the United States produced approximately 16 billion gallons of ethanol per year, with five companies producing 45% of the total U.S. ethanol production: Poet, Archer Daniels Midland, Valero Energy Corporation, Green Plains Renewable Energy, and Flint Hills Resources (FarmProgress.com 2016). COVID-19 has had a major impact on ethanol production, such that U.S. ethanol sales in 2020 could fall by more than $10 billion (Colombini 2020).

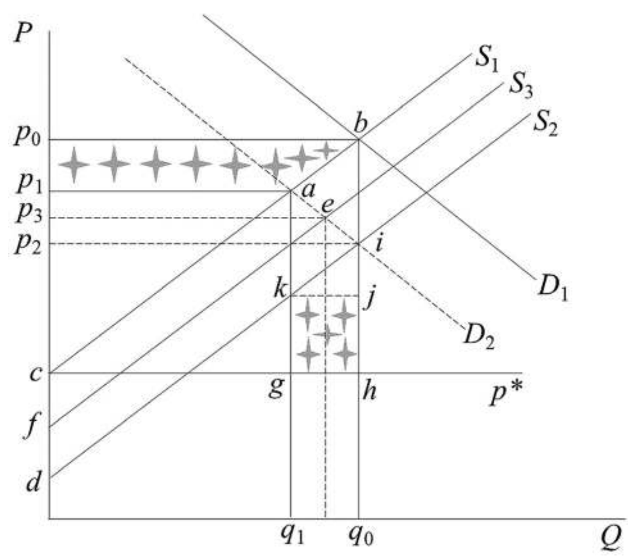

Figure 14: COVID-19 and U.S. ethanol production.

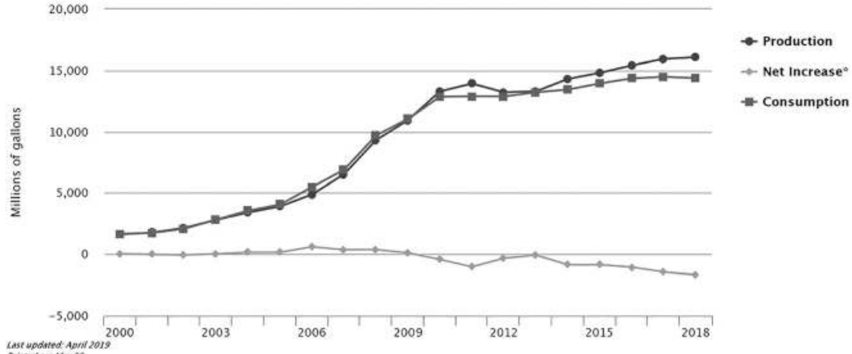

Figure 13: U.S. production, consumption, and trade of ethanol, 2000–2018. Source: U.S. Energy Information Administration (USEIA) 2019.

The theory underlying the effects of the crisis on U.S. ethanol producers is extended in Figure 14. The supply prior to COVID-19 is S_1 and demand is D_1. Prices and quantities are given by p_0 and q_0. In the presence of COVID-19, demand shifts from D_1 to D_2, causing the price to fall to p_1 and quantity to fall to q_1. The loss to ethanol producers is (p_0p_1ab).

Because of the interaction between ethanol and corn prices, a fall in corn prices causes the supply of ethanol to shift from S_1 to S_2. As a result, while COVID-19 has no effect on ethanol production, the price of ethanol falls from p_0 to p_2. Also, producers are unaffected by COVID-19: $(p_0cb) = (p_2di)$.

While inputs may be perfectly elastic in supply – except for the fixed factor that gives rise to the economic rent portion of the model – what happens if they are not? COVID-19 triggered high global unemployment levels. Our model, like the one in Figure 14, should account for this by calculating the size of $(aghb)$ and taking a percentage of this amount to account for unemployment due to COVID-19. For example, the loss of $(kghj)$ implies the total loss from COVID-19, given S_1, is $\{(p_0p_1ab) + (kghj)\}$.

In our empirical analysis, we simplify the theoretical base. The supply and demand for ethanol are S_G and D_E (Figure 15a), where prior to COVID-19, the price of ethanol is p_1 and the quantity produced is q_1. The corresponding quantity of labor employed in production is q_L and the wage rate is p_L (Figure 15b), where prior to COVID-19, labor supply is S_L and demand is D_L. With COVID-19, the demand for ethanol shifts from D_E to D^*. The price of ethanol falls to p_2 and output falls to q_2. The price of labor falls to p_W and quantity demand falls to q_W. As a result, producers lose (p_1p_2ba) and labor costs fall by $(p_Lp_Wcq_Wq_Ld)$.

In the analysis, ethanol producers reduce their variable costs by (abq_2q_1) because of the ethanol price drop. If part of this cost is labor, this creates a situation of unemployment if labor is sector-specific and immobile. Therefore, at least a percentage of (abq_2q_1) is an economic cost due to COVID-19 (e.g., economic loss of $(abfg)$. In this case, economic damage from COVID-19 is $\{(p_1p_2ba)+(abfg)\}$. If all of the variable inputs become unemployed (or unused), the total cost of COVID-19 is $(p_1p_2bq_2q_1a)$. But note that this is equal to the change in lost total revenue from a fall in ethanol production.

4.3 Ethanol Empirics

According to the Renewable Fuels Association (RFA 2020, p. 2), "the impact on the ethanol industry has been swift and sharp. Deeply negative operating margins and falling consumption have led to dramatic cuts in ethanol production. For the week ended April 10, ethanol production was 44% below the same time in 2019, hitting the lowest level since the EIA began reporting statistics in 2010… Approximately 70 ethanol facilities with an annual production capacity of 6.1 billion gallons have been fully idled, and nearly 70 more plants have reduced their operating rates by a combined 1.9 billion gallons annualized." Taheripour and Mintert (2020), also note that "ethanol production could be expected to fall by approximately 3 billion gallons in 2020 for supply and demand to balance—a severe cutback of nearly 20%" (RFA 2020, p. 3).

Falling oil and gasoline prices due to COVID-19 negatively affect the demand for ethanol and thus the corn market in the United States. The overall consumption of fuel ethanol reached a maximum of 1095 thousand barrels per day in January 2019, but fell roughly 30% in early 2020. Figure 16 gives the theoretical basis for our analysis, along with ethanol prices and quantities used in estimating the

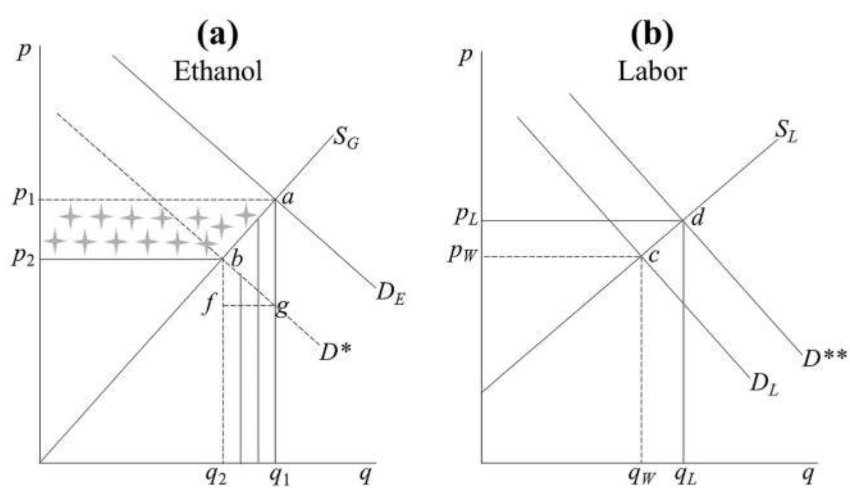

Figure 15: Ethanol production and labor inputs.

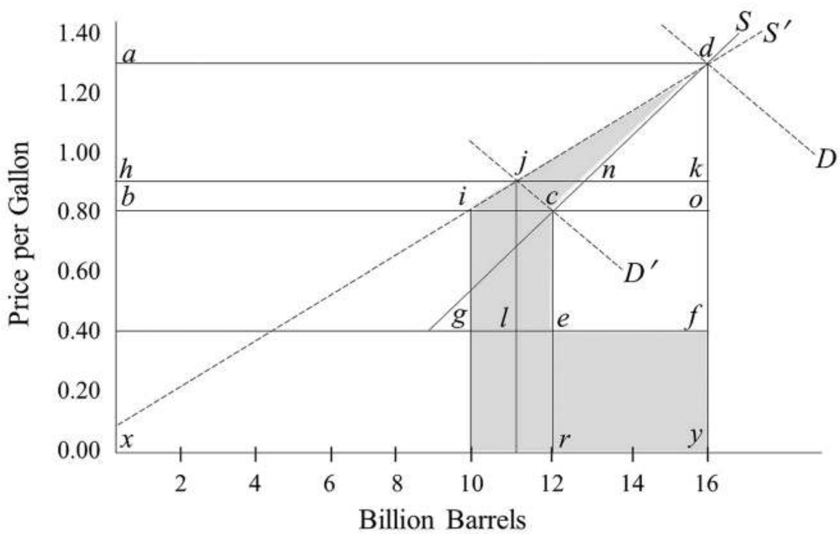

Figure 16: Ethanol empirics.

Table 5: Impact of COVID-19 on ethanol (zero unemployment effect) in U.S. billion dollars.

Variable	(Supply curve *S*)	Loss (USD)
Producers		
Producer surplus	(*abcd*)	$7.0 billion
Variable input cost	(*cefd*)	$2.6 billion
Change in total revenue	{(*axyd*) − (*bxrc*)}	$11.2 billion

Table 6: Impact of COVID-19 (unemployment effect) in U.S. billion dollars.

Variable	(Supply curve *S*)	Loss (USD)
Producers		*Shutdown price $0.40*
Producer surplus	(*abcd*)	$7.0 billion
Variable input cost	(*cefd*)	$2.6 billion
Unemployment effect 1	(*cefo*)	$1.6 billion
Unemployment effect 2	(*ncok*)	$405 million
Total cost 1	{(*abcd*) + (*cefo*)}	$8.6 billion
Total cost 2	{(*abcd*) + (*ncok*)}	$7.4 billion
Variable	**(Supply curve *S′*)**	**Loss (USD)**
Producers		*Shutdown price $0.40*
Producer surplus	(*ahjd*)	$5.4 billion
Variable input cost	(*igfd*)	$5.5 billion
Unemployment effect 1	(*jlfk*)	$2.5 billion
Unemployment effect 2	(*iokj*)	$608 million
Total cost 1	{(*abcd*) + (*jlfk*)}	$7.9 billion
Total cost 2	{(*abcd*) + (*iokj*)}	$6.0 billion

impact of COVID-19 on the ethanol sector. Because we do not consider the impact of COVID-19 on the distiller's grain industry, our estimates understate the cost of COVID-19 (see Moss, Schmitz, and Schmitz 2014). Due to COVID-19, the demand for ethanol shifts from *D* to D′. The supply of ethanol is *S* (derived from the actual price and quantity data). It is price inelastic. The ethanol price falls from $1.30/gallon to $0.80/gallon due to COVID-19. The quantity produced before and after COVID-19 is 16 billion gallons and 12 billion gallons, respectively. The analysis applies to 2019 as compared to 2020. Therefore, the price and quantity used for 2020 are essentially forecasts based on data from January 1, 2020 to June 1, 2020.

The results, given supply (e_s<1), for a price drop from $1.30/gallon to $0.80/gallon, are given in Table 5. The producer loss due to COVID 19 is $7 billion. Total revenue falls by $11.2 billion.

Suppose now that the producers' reduction in variable input cost is associated with unemployment. In this case, a percentage of the workers laid off cannot find jobs elsewhere. In Table 6, given supply curve *S*, if unemployment is measured by (*cefo*) with a shutdown price of $0.40 per gallon, the total cost of COVID-19 is $8.6 billion. If the unemployment effect is measured by (*ncok*), the economic loss from COVID-19 is much smaller, falling to $405 million.

In Table 6 we also show the COVID-19 unemployment effect given the supply curve S' (e_s>1). If the unemployment effect is measured by (*jlfk*), the total cost of COVID-19 is $7.9 billion. However, if the unemployment is measured by, for example, (*iokj*), the economic loss falls to $608 million.

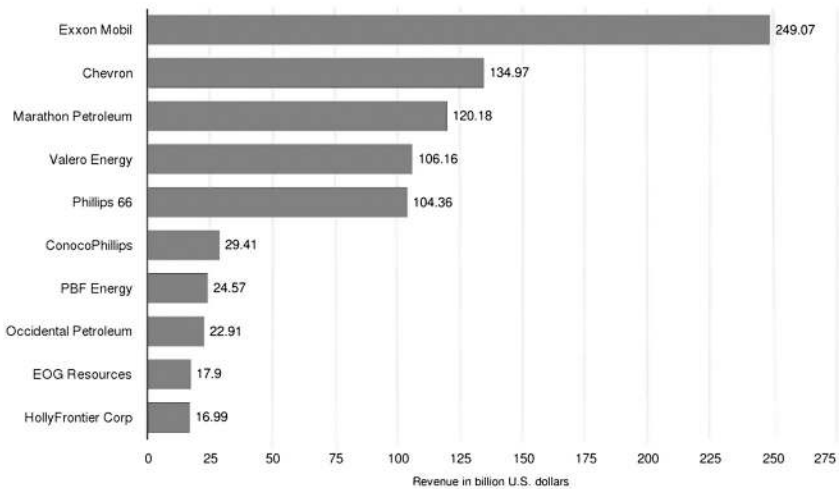

Figure 17: Top 10 U.S. oil companies based on revenue in 2019 (U.S. billion dollars). Source: Statista (2020).

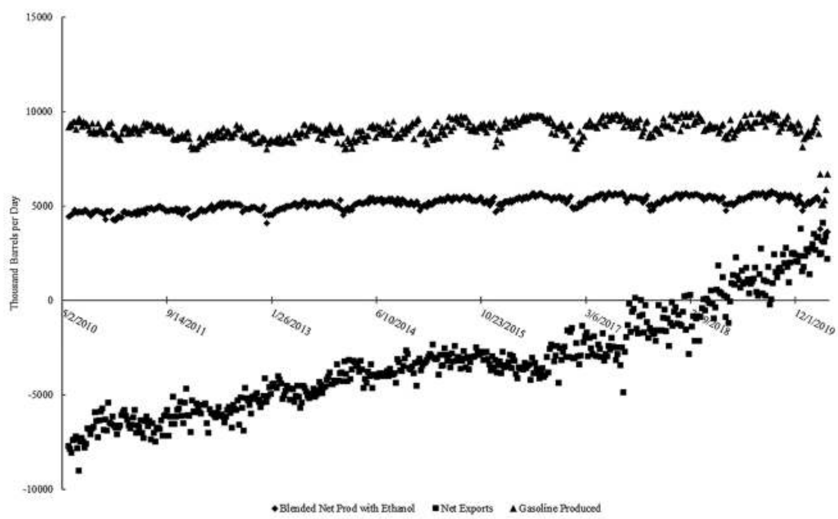

Figure 18: Blended fuel, net exports, and gasoline production, 2010–2019. Source: USEIA (2020a).

4.4 U.S. and World Oil

4.4.1 Producers

The top three U.S. oil production areas are Texas (Permian Basin), North Dakota (Bakken Formation), and the Gulf of Mexico (offshore drilling). Oil companies operating in the United States are classified as integrated or independent (non-integrated) based on their operational activities within the energy value chain (Figure 17). U.S. integrated oil producers, such as Exxon Mobil and Chevron, are involved in all facets of the energy value chain: oil exploration, production, refinement, distribution, storage, and marketing. Operation of these companies comprises three segments: upstream (exploration and production), midstream (distribution and storage), and downstream (refinement and marketing).

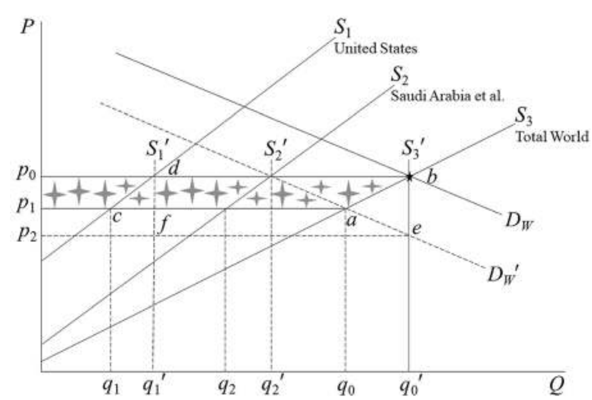

Figure 19: Oil supply (United States, Saudi Arabia et al., and total world).

Independent oil producers, such as ConocoPhillips and EOG Resources, are non-integrated companies involved in the exploration and production of oil – usually with no marketing, transportation, or refining operations. There are about 9000 independent producers in the United States, operating in 33 U.S. states and offshore, and producing about 83% of the oil in the United States.

Expanded oil production in the United States has led to a significant increase in net exports of crude oil (or reduction in net imports). While the United States is still a net importer of crude oil, it has become a net exporter in energy with increased exports of refined gasoline and other fuels (Figure 18).

Globally, the two largest oil-producing countries are the United States and Saudi Arabia. In 2018, the United States produced 17.87 million barrels per day (18% of global production) and Saudi Arabia produced 12.42 million barrels per day (12% of global production). The dependency of the United States on obtaining oil from foreign countries has dropped sharply over the years (USEIA 2020a).

Consider Figure 19, where S'_1, S'_2, and S'_3 are the short-run oil supply schedules for the United States, Saudi Arabia et al., and total world, respectively. Given the shift in demand from D_W to D'_W due to COVID-19, the world oil price falls to p_2. The loss in world oil producer surplus is (p_0p_2eb). Also, for example, the loss to U.S. producers is (p_0p_2fd).

Consider now in Figure 19, where the supply schedules are not perfectly inelastic. In this example, S_1, S_2, and S_c are the supply curves for the United States, Saudi Arabia et al., and total world supply of oil, respectively. Before COVID-19, world oil production was q'_0 and price was p_0. With COVID-19, world demand for oil shifted from D_W to D'_W. The price fell to p_1 and production fell to q_0. The total loss in world producer rent is (p_0p_1ab), of which the loss to the United States is (p_0p_1cd).

4.4.2 Impact of COVID-19 on Global Crude Oil Producer Welfare

We estimate the impact of the COVID-19 event on global crude oil producer welfare for the year 2020. Monthly data on the production of "crude oil, including lease condensate", by country, for January 2019 through March 2020 were obtained from the U.S. Energy Information Administration (USEIA 2020a). Monthly crude oil production in millions of barrels per day (Mb/d) for each country was multiplied by the number of days in each month and then aggregated over 12 months to obtain crude oil production for the United States, Russia, and Saudi Arabia for 2019 (represents the baseline for a typical year in the absence of the COVID-19 event). Next, the combined crude oil production for the United States, Russia, and Saudi Arabia was subtracted from the world total to create a fourth region for the Rest of the World (ROW). According to the U.S. Energy Administration (USEIA) (2020b), the United States was the largest producer of "crude oil, including lease condensate" in the world at 4.46 billion barrels (Bb) in 2019, followed by Russia (3.96 Bb) and Saudi Arabia (3.59 Bb). In addition, data on average monthly spot prices for WTI crude in Cushing, Oklahoma were obtained from the U.S. Energy Administration (USEIA 2020b) for January 2019 through May 2020. The average of the monthly WTI crude spot prices for 2019 was $56.98 per barrel.

The U.S. Energy Administration has data available on monthly crude oil production for January through March 2020, and average monthly WTI crude spot prices for January through May 2020. In order to obtain predictions for June through December 2020, we make the following simplifying assumptions regarding future monthly prices and production levels. First, rather than attempting to forecast prices for the rest of 2020, we assume that the price of crude oil from June through December will be equal to the five-month average WTI crude spot price of $36.48 per barrel (which is also approximately equal to the spot price of WTI crude on June 15, 2020). Second, we assume that the quantity of crude oil produced by each country in April and May 2020 is equal to the actual quantity produced during the corresponding months in 2019. Third, due to the announcement in June 2020 that OPEC (including Russia and Saudi Arabia) will cut back crude oil production by 30%, we assume that the quantity of crude oil produced in each country from June 2020 through December 2020 will be equal to 70% of what each country produced in 2019.

4.4.3 Impact of COVID-19 on World Oil (Positively Sloped Supply Curves)

We consider two possible scenarios from which we obtain estimates of the welfare implications of COVID-19 for the crude oil market. In the first scenario, we assume the

Table 7: Impacts of COVID-19 for crude oil producers (yearly aggregated supply curves).

Variable	United States	Russia	Saudi Arabia	ROW	Total
Price ($/barrel)	−21.0	−21.0	−21.0	−21.0	−21.0
Quantity (billion barrels)	−700	−689	−630	−3182	−52.0
Producer Surplus (billon USD)	−117	−54	−49	−485	−706

Source: Authors' calculations.

supply curves (S_1–S_3 in Figure 19) for each country are linear and use the actual price and aggregate quantity for 2019 as one point on their inverse supply curve, and the predicted price and aggregate quantity for 2020 to obtain the second point on their inverse supply curves. Using these two points to derive the inverse aggregate supply curves for each country, we can then calculate producer surplus in 2019 and 2020 as the area above the inverse supply curve, bounded by the X-axis from below and the price from above (Just, Hueth, and Schmitz 2004).

The estimated welfare impacts of COVID-19 for crude oil producers associated with Scenario 1 (using aggregate supply curves across 2019 and 2020) are provided in Table 7. The average yearly crude oil price is projected to drop by $20.51 per barrel (36%) due to COVID-19. Crude oil production is predicted to drop in the United States by 700 Mb (16%), Russia by 690 Mb (17%), and Saudi Arabia by 630 Mb (18%) in 2020 as compared to 2019 data. U.S. crude oil producers are projected to lose $117 billion, followed by Russia ($54 billion) and Saudi Arabia ($49 billion). ROW crude oil producers are projected to lose $485 billion. The total predicted loss under Scenario 1 from COVID-19 in 2020, compared to 2019, is $706 billion for all world crude oil producers combined.

4.4.4 Impact of COVID-19 on World Oil (Both Inelastic and Positively Sloped Supply Curves)

In the second scenario, we assume the supply curve for each country in 2019 is perfectly inelastic. For 2020, the supply curve for each country is separated into two periods (January through May and June through December), representing before and after the decision by OPEC to cut oil production by 30%. We assume the supply curve for each country in 2020 is perfectly inelastic in Period 1, and unitarily elastic in Period 2. The price of crude oil from June 2020 through December 2020 is assumed to be equal to the five-month average WTI crude spot price of $36.48 per barrel. The quantity of crude oil produced by each country in April and May 2020 is assumed to be equal to the actual quantity produced during the corresponding months in 2019, and the quantity of crude oil produced in each country from June 2020 through December 2020 is predicted to be equal to 70% of what each country produced in 2019.

The estimated welfare impacts of COVID-19 for crude oil producers associated with Scenario 2 (which separates the 2020 supply curves into two periods) are provided in Table 8. In Period 1, comparing 2019 to 2020, predicted losses for crude oil producers in each region are as follows: United States ($34b), Russia ($35b), Saudi Arabia ($33b), and world crude oil producers combined ($263b). In Period 2, predicted losses for crude oil producers in each region are as follows: United States ($151b), Russia ($135b), Saudi Arabia ($123b), and world crude oil producers combined ($768b). On aggregate, we predict that COVID-19 will result in losses to crude oil producers in the United States ($151b),

Table 8: Impacts of COVID-19 for crude oil producers (two periods).

	Change from 2019 to 2020 (January–May)				
	United States	**Russia**	**Saudi Arabia**	**ROW**	**Total**
Price ($/barrel)	−21.36	−21.36	−21.36	−21.36	−21.36
Quantity (million barrels)	98.56	6.37	−7.12	−18.79	79.03
Producer surplus (billion USD)	−34.89	−34.62	−32.71	−160.50	−262.72
	Change from 2019 to 2020 (June–December)				
	United States	**Russia**	**Saudi Arabia**	**ROW**	**Total**
Price ($/barrel)	−19.90	−19.90	−19.90	−19.90	−19.90
Quantity (million barrels)	−798.81	−695.45	−623.27	−3163	−5281
Producer Surplus (billion USD)	−116.12	−101.10	−90.60	−459.88	−767.70
	Change from 2019 to 2020 (total)				
	United States	**Russia**	**Saudi Arabia**	**ROW**	**Total**
Price ($/barrel)	−20.51	−20.51	−20.51	−20.51	−20.51
Quantity (million barrels)	−700.25	−689.08	−630.39	−3182	−5202
Producer surplus (billion USD)	−151.02	−135.72	−123.31	−620.37	−1030

Source: Authors' calculations.

Table 9: Five largest U.S. refining companies in 2020.

Ranking	Corporation	Barrels/day	Number of refineries
1	Marathon	3.0 million	16
2	Valero energy	2.1 million	13
3	Phillips 66	1.9 million	10
4	Exxon Mobil	1.7 million	5
5	Chevron	1.0 million	5

Source: United States Energy Information Administration (2020).

Russia ($135b), Saudi Arabia ($123b), and ROW ($620b), so that the total loss to the global crude oil market in 2020, compared to 2019, is predicted to be approximately $1 trillion.

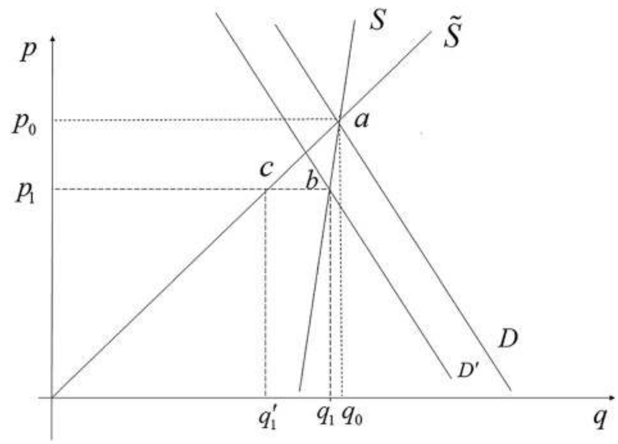

Figure 20: Effect of reduction in demand from COVID-19 on refineries.

Table 10: U.S. prices and quantities of conventional (blended) motor fuel.

Variable	Price dollars/ gallon	Equilibrium quantity	
		Barrels/ month	1000 gallons/ month
December 19, 2019 (Observed)	2.1816	55,627	2336
March 20, 2020 (Observed)	1.8540	46,684	1961

Source: United States Department of Energy, Petroleum & Other Liquid data (https://www.eia.gov/petroleum/data.php).

5 Refineries

The United States is the largest exporter of refined oil, with most of its refineries located in the Gulf Coast region (the largest refinery is in Port Arthur, Texas). The five top U.S. companies refine between 1.0 and 3.0 million barrels of oil per day (Table 9). Although more than 50% of U.S. oil refineries have closed since 1982 (301 in 1982 vs. 132 in 2020), production volume has increased (USEIA 2019).

To estimate the effect of changes in policy or events (such as COVID-19) on the combination choice between crude oil and ethanol, we start with a general differential multiproduct model (Suh and Moss 2017). This formulation is based on changes in the first-order conditions of the firm as.

$$\bar{y}_t\bar{g}_{rt}\Delta\ln(y_{rt}) = \sum_{r=1}^{n}\alpha_{rs}\left(\Delta\ln(p_{st}) - \sum_{i=1}^{m}\theta_i^s\Delta\ln(w_{it})\right) + \phi_r\Delta\ln(z_t) + \delta_r D_t$$

$$\bar{f}_{it}\Delta\ln(x_{it}) = \bar{y}_t\sum_{r=1}^{n}\theta_i^r\bar{g}_{rt}\Delta\ln(y_{rt}) + \sum_{j=1}^{m}\pi_{ij}\Delta\ln(w_{jt}) + \phi_i\Delta\ln(z_t) + \delta_i D_t \quad (3)$$

where $\bar{y}_t = \sqrt{R_t R_{t-1}/C_t C_{t-1}}$, R_t is the firm's revenue, C_t is the cost, $\bar{g}_{rt}$ is the average output revenue share (between periods t and t–1) for output r, y_{rt} is the output level for output r, p_{rt} is the output price for output r at time t, w_{it} is the input price for input i at time t, z_t is the level of a quasi-fixed variable at time t, D_t is a dummy variable that is one after the volumetric ethanol excise tax credit was allowed to expire, $\bar{f}_{it}$ is the average input share (between periods t and (t–1) for input i, and x_{it} is the level of input i used at time t. In this formulation $\Delta\ln(y_{it}) = \ln(y_{it}) - \ln(y_{i,t-1})$.

To estimate this model, we used information from the United States Department of Energy (2020) to construct a dataset in thousands of barrels per month for blended gasoline, jet fuel, distillates, and residual oil. The price of crude oil is dollars per barrel while the price of ethanol is dollars per gallon. United States Bureau of Labor Statistics data are used for labor prices and quantities. Labor prices are wages per hour for all workers in the refinery sector (34,110). Quantity of labor is derived by multiplying hours worked per week times the number of workers in the sector. We use refining capacity as a quasi-fixed variable, with all prices deflated using the Personal Consumption Expenditures component of the Implicit Gross Domestic Product deflator from economic data at the Federal Reserve Bank of St. Louis.

Equation (3) is estimated using maximum likelihood. Because the unconstrained estimation may violate concavity, we impose concavity by constraining the matrix of $[\alpha_{rs}]$ to be convex and restricting the minimum eigenvalue of the matrix to be positive. Similarly, we constrain the maximum of the $[\pi_{ij}]$ matrix to be negative.

For the estimated parameters of the multiproduct differential model, the demand for crude oil increases significantly when blended gasoline production increases, while the demand for ethanol does not increase significantly when blended gasoline production increases. From the output choice parameters, the amount of blended gasoline increases with an increase in the price of blended gasoline. However, there appears to be only one substitution relationship (i.e., only one of

Table 11: Impact of COVID on refinery surplus in the short and long run.

	Equilibrium quantity		Loss in producer surplus	
	1000 barrels/ month	1000 gallons/ month	Million dollars/ month	Billon dollars/ year
Stage I	*Stage I (Short-Run)*			
Producer surplus (p_0p_1ba) (derived from actual quantity price data)	46,684	1961	703.86	
Producer Surplus (p_0p_1ba) (based on estimated supply elasticity)	55,296	2322	763.11	
Stage II	*Stage II (Long-Run)*			
Producer Surplus (p_0p_1ca) (unitary elasticity)	47,274	1985	707.92	
Total producer surplus loss				8.5 8.7

the α_{rs} is negative). This may be the result of a fixed-proportion output structure. For example, there may be little that a refinery can do to change the proportion of products produced from a barrel of crude oil. The exception is the negative coefficient for the choice between jet fuel and distillates.

Two elasticities are statistically significant. Specifically, the elasticity of crude oil production with respect to an increase in the price of blended gasoline is 0.05324, while the elasticity of ethanol demand with respect to an increase in the price of blended gasoline is 0.05712. However, the estimated demand elasticity of the quantity of crude oil demand is negative, but not statistically significant at any conventional confidence level. Similarly, the elasticity of demand for ethanol is negative, but not statistically significant. Further, the cross-price elasticity indicates that the quantity demanded of crude oil is rather inelastic with respect to a change in ethanol prices, while the price of ethanol is inelastic, but somewhat more responsive, with respect to changes in crude oil prices.

Estimates on the impact of COVID-19 on the U.S. oil refinery sector are given in Figure 20. The short-run supply curve is S and the long-run supply curve is $\tilde{S}$. The analysis considers two periods. Period 1 (December 2019 through March 2020) is based on supply curve S. Period 2 (April 2020 through December 2020) is based on supply curve $\tilde{S}$.

Table 12: Producer's economic losses (conservative estimates) from COVID-19, ethanol–gasoline–oil complex, 2020 (billion USD).

Producer loss (producer surplus)	Billion USD	Producer loss plus unemployment*	Billion USD
United States		United States	
U.S. corn producers	10.3	U.S. corn producers	12.4
U.S. ethanol producers	7.0	U.S. ethanol producers	8.4
U.S. oil producers	151.0	U.S. oil producers	181.2
U.S. refineries	8.5	U.S. refineries	10.2
Total	176.8	Total	212.2
World		World	
World oil producers	1030.0	World oil producers	1236.0
Total [corn producers, ethanol, oil, and refineries]	1055.8	Total [corn producers, ethanol, oil, and refineries]	1266.9

* Based on 20% of producer surplus
Source: Authors' calculations.

Given a drop in demand from D to D', producer loss for refineries is (p_0p_1ba) in the first period and (p_0p_1ca) in the second period. Total producer loss is $\{(p_0p_1ba) + (p_0p_1ca)\}$.

Due to COVID-19, the consumption of gasoline dropped from 2336 thousand gallons in December of 2019 to 1961 thousand gallons in March of 2020 (Table 10). Gasoline prices declined from $2.18/gallon in December 2019 to $1.85/gallon in March of 2020. The loss in producer surplus from the COVID-19 event is between $703.9 million and $763.1 million per month (Table 11). This loss increases under a different elasticity assumption to $763.1 million per month. The monthly produce surplus loss is $9.2 billion.

In the second stage, the supply curve is unitarily elastic, the loss in producer surplus $707.9 million per month, or $8.5 billion per year. This gives rise to a total loss to refineries of between $16.9 and $17.6 billion.

6 Summary: COVID-19 Producer and Unemployment Effects

The costs to U.S. producers of corn, ethanol, and oil, and refineries are given in Table 12. For the year 2020, the total cost is $176.8 billion. When the world oil producers are taken into account, the cost rises to $1055.8 billion. Also, it is necessary to include the unemployment effects from COVID-19 (see Section 4.2, U.S. Ethanol Complex).

In Table 12, we assume that the unemployment effect due to COVID-19 is 20% of the producer surplus values. For the United States, now the cost of the virus is $212.2 billion. When world oil is included, the total loss (producers and unemployed workers) is $1266.9 billion.

7 Conclusions

Our estimates focus on the impact of COVID-19 on producers using classical welfare economics, where the key measure of losses is producer surplus. Commonly though, many studies report estimates based on changes in total producer revenue. Generally, these estimates overstate economic losses.

The economic cost from COVID-19 for oil producers is huge, exceeding $1 trillion. The cost to the U.S. oil producers alone is $151 billion. The total oil producer cost is $1.03 trillion, which is roughly 40 times the cost to U.S. corn, ethanol, and gasoline producers, and refineries of $26 billion. Therefore, for example, if our estimate of the cost is 20% too high for the ethanol producers, the total world picture changes very little.

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