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Biodiesel Cross-Hedging Opportunities

We apply an encompassing framework to assess the viability of hedging spot biodiesel price risk for four U.S. markets with a conventionally used heating oil futures contract and a soybean oil futures contract based on the logic that supply shifts (i.e., price of soybean oil as an input) drive biodiesel prices when binding blending mandates are in place. Results indicate that soybean oil futures should in fact be part of a composite hedge, and that in some instances greater hedging weight should be placed on the soybean oil futures contract than the conventionally used heating oil futures contract.

Keywords: biodiesel, composite hedge, cross-hedge, encompassing, hedging effectiveness

Introduction

Renewable fuel mandates and high fuel prices have spurred U.S. biofuel production, with ethanol growing dramatically and biodiesel also experiencing substantial growth (Figure 1). Consistent with a corresponding growth in price volatility transmission between petroleum based energies and agricultural commodity biofuel inputs (Serra and Zilberman 2013), biofuels exhibit similar levels of price volatility as conventional fuels (U.S. Department of Energy, 2019). As such, scholars have investigated cross-hedging corn ethanol in unleaded gasoline futures prior to the listing of ethanol futures (Franken and Parcell 2003) and dried distillers grains (DDGs), an ethanol byproduct livestock feed, using corn and soybean meal futures (Brinker, et al. 2009). Similarly, Graf, McKenzie and Popp (2008) considered hedging soybean oil and poultry fat inputs to biodiesel production in soybean oil futures, noting insufficient biodiesel price data to consider an output hedge at that time.

Jess Hewitt, president of Gulf Hydrocarbon Inc., notes that without hedging, "… biodiesel producers take enormous risk every month selling biodiesel on fixed price contracts or on a price that they post daily." (Hewitt 2008). As such, industry practice is to hedge biodiesel about a month out using heating oil futures (Hewitt 2008), which the NYMEX transitioned to an ultra low sulfur diesel fuel (ULSD) futures contract starting with delivery in May 2013 (U.S. Energy Information Administration, 2013). However, Irwin (2015) presents a conceptual supply/demand model demonstrating that, as long as Renewable Fuel Standard (RFS) mandates are binding, supply shifts (i.e., input prices) and not demand shifts drive biodiesel prices—a point substantiated by the finding that soybean oil prices, the main biodiesel input cost, Granger cause biodiesel prices but not the reverse.

Irwin's (2015) biodiesel market model (Figure 2) features a standard upward-sloping supply curve that reflects marginal costs increasing with production and a perfectly elastic (horizontal) demand curve equivalent to the price of ultra low sulfur diesel (P_{ulsd}), assuming perfect substitution and that biodiesel is a small enough part of the diesel market that changes in biodiesel prices do not impact overall diesel fuel demand. If $Supply_1$ is normal production, then the equilibrium price and quantity without government intervention are P_{ulsd} and Q^*. Adding a tax credit to incentivize diesel blenders to blend in biodiesel, shifts demand vertically by the amount of the tax credit, resulting in P_{bd2} and $Q^{Tax\ Credit}$. Mandating that $Q2^M$ of biodiesel be blended raises the price to P_{bd1}. As is apparent from Figure 2, given any such binding mandate, the price of biodiesel is driven by shifts in supply (i.e., from $Supply_1$ to $Supply_2$ or $Supply_3$). Soybean oil, as the primary feedstock for biodiesel in the U.S., comprises 80% of the variable costs of production, and hence, is the main driver of shifts in the biodiesel supply curve (Irwin 2015). Thus, even while soybean oil futures are effective for hedging the cost of soybean oil used in biodiesel production (Graf, et al. 2008), they may also be useful in hedging biodiesel prices.

Though several measures of hedging effectiveness have been proposed (Pennings and Meulenberg 1997 list frequently used measures), the concept has not changed dramatically since Ederington's (1979) initial use of the correlation coefficient to measure the relationship between changes in cash and futures prices (Sanders and Manfredo 2004). Myers and Thompson (1989) suggest that conditioning hedging rules on all available information (e.g., past prices) improves upon the effectiveness of unconditional hedges.[1] However, conclusions about the hedging performance of futures markets vary little with the chosen measure (Floros and Vougas 2006). The effectiveness of a given futures contract and hedge ratio may vary with changes in numerous economic factors across time (Haigh and Holt 2000; Hauser, Garcia and Tumblin 1990; Mattos, et al. 2003; Pennings and Meulenberg 1997).

Sanders and Manfredo (2004, p.34) use the encompassing principle to determine if a particular contract "encompasses" the risk-reduction properties of an alternative contract, or if a using the competing contracts in a composite hedge would more effectively minimize residual basis risk. They illustrate their framework with empirical application to wheat futures contracts offered at competing exchanges, multiple cross-hedging alternatives, and proposed versus existing futures contracts. The advantage of their method over others is that it permits testing the statistical significance of the differences in the effectiveness of alternative hedging mechanisms.

The objective of this study is to apply Sanders and Manfredo's (2004) encompassing framework to assess cross-hedge relationships between four biodiesel spot markets and heating oil/diesel futures and soybean oil futures over a four-week hedging horizon. The advantage of this approach over others (e.g., Anderson and Danthine 1981) is that it permits testing the statistical significance of the differences in the hedging effectiveness of alternative futures contracts. End of week (Friday) biodiesel spot prices for Iowa are obtained from USDA Agricultural Marketing Service reports and for Thursdays in Chicago, New York, and the Gulf of Mexico from Oil Price Information Service's (OPIS) Ethanol and Biodiesel Information Service for January 25, 2007 through February 7, 2020. Corresponding nearby close of day futures prices, rolled over on the first day of contract maturity, are obtained from Barchart.com for the period.

The paper is organized as follows. The next section describes the data. The empirical methods and procedures are then discussed, followed by the results and conclusions sections.

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[1] Myers and Thompson (1989) also note that conditional hedge ratios closely approximate unconditional hedge ratios estimated with price changes.

Data

The analysis utilizes weekly data on spot prices for biodiesel and futures prices for soybean oil and heating oil/ultra low sulfur diesel from January 26, 2007 through February 7, 2020. Iowa biodiesel prices on Fridays are reported by the US Department of Agriculture (USDA). Biodiesel prices for Chicago, New York, and the Gulf of Mexico are available on Thursdays from the Oil Price Information Service (OPIS). Spot price series for the Gulf of Mexico and New York, respectively, start on February 23, 2007 and October 12, 2012. Nearby close of day futures prices, rolled over on the first day of contract maturity, are obtained from Barchart.com on Thursdays and Fridays corresponding to the cash price series.

Biodiesel prices at each location trade at similar levels and patterns over the study period (Figure 3), and exhibit similar means around $3.60/gallon (gal), with the exception of New York, which reflects its shorter sample period (Table 1). The Iowa and Chicago markets seem to exhibit similar levels of volatility, based on standard deviations and maximum and minimum statistics, with the Gulf of Mexico exhibiting a bit more variability. In comparison, the heating oil/diesel futures price exhibits a lower average of $2.25/gal and less variability. The soybean oil futures price averages about ¢39.40/pound (lb) or equivalently $39.40/hundredweight (cwt). Prior to subsequent analysis, soybean oil futures prices are converted from cents per pound to dollars per gallon, consistent with the pricing of heating oil futures and biodiesel (e.g., ¢39.40/lb × 7.55 lb/gal ÷ 100¢/$ = $2.97/gal).

In the interest of space, correlations are described briefly here with details available from authors upon request. The lowest correlation among the spot price series is 0.97 between Iowa and New York, which again attests to how similar the series are. Notably, spot biodiesel prices are somewhat more correlated with soybean oil futures (>0.90) than heating oil/diesel futures (>0.72), which is suggestive of opportunities to hedge spot biodiesel price risk with soybean oil futures.

As expected, Augmented Dickey-Fuller (ADF) tests are unable to reject the null hypothesis of nonstationarity for each of the data series at conventional levels. Differencing the data yields stationary series, and is consistent with the empirical approach outlined below.

Empirical Methods and Procedures

Leuthold, Junkus and Cordier (1989) state that ex-post minimum variance hedge ratios are commonly estimated with ordinary least squares regression as

$$\Delta CP_t = \alpha + \Delta\beta FP_t + e_t, \quad (1)$$

where Δ represents changes in cash prices CP_t and futures prices FP_t, α is the trend in cash prices, β is the ex-post minimum variance hedge ratio, and e_t is residual basis risk.[2]

[2] Despite dispute over whether such models should be estimated in price levels, price changes, or percentage changes, the price change formulation in equation (1) is a common approach to estimating unconditional hedge ratios.

Following Sanders and Manfredo (2004), the standard minimum variance regression can be used to identify the relative hedging effectiveness of two competing contracts and/or their combination. Equations (2) and (3) respectively represent hedging with the incumbent or original contract (e.g., heating oil/diesel futures) and an alternative or competing contract (e.g., soybean oil futures).

$$\Delta CP_t = \alpha_0 + \beta_0 \Delta FP_t^0 + e_{0,t}, \quad (2)$$

$$\Delta CP_t = \alpha_1 + \beta_1 \Delta FP_t^1 + e_{1,t}. \quad (3)$$

As in Harvey, Leybourne, and Newbold's (1998) regression test of forecast encompassing, a modified version of the *J*-test of nonnested hypotheses (Maddala 1992) enables testing the null hypothesis that the incumbent contract *encompasses* the proposed alternative contract. Fitted values from equations (2) and (3), represented by y_0 and y_1 respectively, and actual values of the dependent variable, represented by y, can be inserted into equation (4):

$$y - y_0 = \Phi + \lambda(y_1 - y_0) + v. \quad (4)$$

The $y - y_0$ term is the residual basis or spread risk of the first model, and $y_1 - y_0$ is the difference in fitted values of the two models. Here, we are not concerned with conventional basis but rather the spread in the case of a cross hedge. In this case, if λ is not statistically different from zero, then the second model has no more explanatory power than the first. Therefore, if $\lambda = 0$, the new contract does not provide a reduced basis or spread risk above the original contract. Following Granger and Newbold (2014), adding λy to each side of equation (4), simplifying, and substituting for $y - y_0$ and $y - y_1$ with the corresponding residual errors e_0 and e_1 from the ordinary least squares (OLS) regressions of equations (2) and (3) yields:

$$e_{0,t} = \Phi + \lambda[(e_{0,t} - e_{1,t})] + v_t. \quad (5)$$

Equation (5) is similar to Harvey, Leybourne, and Newbold's (1998) regression test for forecast encompassing. Here, λ is the weight to be placed on the new futures contract and $(1- \lambda)$ is the weight to be placed on the original contract. A two-tailed test of the null hypothesis that the incumbent encompasses the alternative (i.e., $\lambda = 0$) reveals the relative effectiveness of the proposed hedges in terms of residual basis risk.[3] Below are the alternative potential results in a hedging context.

$\lambda = 0$:	All hedging should be in the original, incumbent futures market.
$0 < \lambda < 1$:	A combination of hedging should be done in each market with λ as the weight assigned to the new futures contract.
$\lambda = 1$:	All hedging should be done in the alternative, competing futures market.

[3] Harvey, Leybourne, and Newbold (1998) suggest a one-tailed test in the context of a composite forecast. In a hedging context, the possibility of negative hedge ratios (Anderson and Danthine, 1981) makes a two-tailed test more appropriate.

As shown by Maddala (1992), the λ that best reduces error or risk can be illustrated as:

$$\lambda = \frac{\sigma^2 e_0 - \rho e_0 e_1}{\sigma^2 e_0 + \sigma^2 e_1 - 2\rho e_0 e_1 \sigma e_0 \sigma e_1}, \tag{6}$$

where, σ^2, σ, and ρ represent the variance, standard deviation, and correlation concerning basis risk for the original and new models. Maddala (1992) also shows:

$$\lambda \geq 0 \text{ iff } \frac{\sigma e_0}{\sigma e_1} \geq \rho e_0 e_1, \text{ and} \tag{7}$$

$$\lambda < 0 \text{ iff } \frac{\sigma e_0}{\sigma e_1} < \rho e_0 e_1. \tag{8}$$

The λ in equations (3b) and (3c) show the ability of the new futures contract to reduce the residual basis risk associated with the original futures contract.

Myers and Thompson (1989) argue that the appropriately specified hedging rule is conditioned on all available information (e.g., lagged or past prices). Sanders and Manfredo's (2004) approach is applicable to alternative specifications, including conditional hedging regressions. Accordingly, the appropriate hedging model is investigated including lag structure and whether paired price series are cointegrated such that a long-run equilibrium relationship exists and inclusion or an error correction term is appropriate. In the interest of space, general findings of this analysis are described below with further details available from the authors upon request.

As noted, ADF tests fail to reject the null hypothesis of a unit root for the data in levels (i.e., nonstationarity) but do reject it using first-differenced data (i.e., stationarity), meaning that long-run equilibrium relationships may be estimated. The well-known test for cointegration attributed to Engle and Granger (1987) applies the ADF test of stationarity to the error term from an OLS regression of two individual nonstationary price series. Finding a (non)stationary error term means the two series are (not) cointegrated. ADF test statistics exceed the five percent critical value (though just barely in some cases), indicating stationarity of the error term, and hence, cointegration of the series for most price pairs. As exceptions, ADF tests fail to reject the null hypothesis of non-cointegration (i.e., nonstationarity) at the five percent, but not the 10 percent, level when pairing heating oil/diesel futures with Gulf biodiesel prices and at all conventional levels when pairing it with the New York biodiesel price.

Multivariate tests of cointegration commonly employ the Johansen (1988) method, which utilizes trace tests to investigate the number of cointegrating vectors. The null hypothesis is that there are no more than *r* cointegrating vectors with the alternative hypothesis that there exist more than *r* cointegration vectors. Like the ADF tests of stationarity of residuals, the trace test results are somewhat more supportive of cointegration of biodiesel prices with soybean oil futures than with heating oil/diesel futures. Recent research has identified difficulties with testing for unit roots in the presence of cointegration (Mallory and Lence 2012; Reed and Smith 2017) that may apply to the results obtained here. Here, we follow a straightforward and conservative path. Allowing for the possibility of cointegration, we proceed below with results of error correction models with various lag structures chosen by minimizing SIC.

Results

Table 2 contains selected regression results derived from error correction models using a four week hedging horizon.[4] Recall that prior to regression analysis, soybean oil futures prices are converted from cents per pound to dollars per gallon, consistent with the pricing of heating oil futures and biodiesel. The estimated hedge ratio β is obtained from estimating the hedging regressions for the incumbent futures contract (i.e., heating oil/diesel) and alternative or competing futures contract (i.e., soybean oil futures) given in equations 2 and 3. Taking Iowa as an example (Table 2), the heating oil and soybean oil hedge ratios of 0.33 and 0.40 are the ratios of heating oil-to-biodiesel and soybean oil-to-biodiesel, respectively. That is, for separate hedges, 0.33 gal of heating oil or 3.02 lb (= 0.40 gal × 7.55 lb/gal) of soybean oil is required to hedge each gallon of biodiesel. These values are somewhat lower than the hedge ratios implied for other locations by error correction models. The Chicago and Gulf locations are somewhat more consistent with hedge ratios of 0.67 and 0.69 for heating oil futures and 0.52 and 0.46 for soybean oil futures (Table 2). The two locations have similar sample sizes (Table 1) and similar SIC minimizing lag structures. Greater differences in hedge ratio magnitudes for Iowa and New York partly reflect different lag structures and smaller sample size, respectively.

The estimated hedging weight λ for the alternative futures contract (i.e., soybean oil futures) is obtained from estimating the encompassing regression given in equation 5, with the remainder ($1-\lambda$) being the weight to be placed on the incumbent futures contract (i.e., heating oil futures). The results in Table 2 indicate that substantial hedging weight should be placed on the soybean oil futures contract with the highest weights for soybean oil found for Iowa (0.89) and the lowest for New York (0.43).

Table 3 displays the number of futures contracts to be used in a composite hedge of spot biodiesel price risk for various monthly amounts of biodiesel production. Using Iowa as an example, the number of heating oil contracts is determined by multiplying the biodiesel quantity hedged (say 100,000 gallons) by the heating oil hedge ratio (0.33) and by the hedging weight for heating oil (1 – 0.89) and then dividing by 42,000 gallons per heating oil futures contract. Similarly, the number of soybean oil futures contracts to use is determined by multiplying the biodiesel quantity hedged (100,000 gallons) by the corresponding hedge ratio (0.40) and hedging weight (0.89) and dividing by 7,815 gallons (or 60,000 pounds per soybean oil futures contract ÷ 7.6776 pounds/gallon of soybean oil). Reporting the number of both futures contracts to be used in a cross hedge is useful for industry stakeholders that desire to limit exposure to biodiesel spot price risk. However, when using these numbers to interpret the relative importance of each contract for hedging biodiesel price risk, the differences in contract size should be taken into

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[4] Qualitatively similar results are obtained for eight week and 24 week hedging horizons and for GARCH(1,1) models that are considered due to their robust nature (Hansen and Lunde 2005). Additionally, similar results are found by starting the analysis after the transition of heating oil futures to ultra low sulfur diesel fuel (ULSD) futures in May 2013. These results, while not reported here, are available from authors upon request.

account. The 42,000 gal heating oil futures contract is over five times the size of the 60,000 lb or equivalently 7,947 gal (= 60,000 lb ÷ 7.55 lb /gal) soybean oil futures contract. Across each location, the results suggest that notable weight should be placed on soybean oil futures contracts, and in some cases, more so than on the conventionally used heating oil futures contract. For Iowa, in particular, the hedging ratio and hedging weight are so small for heating oil that for smaller amounts of biodiesel it may be most practical to hedge with only soybean oil futures contracts.

Conclusions

We apply an encompassing framework to assess the viability of hedging spot biodiesel price risk for four U.S. markets with a conventionally used heating oil futures contract and a soybean oil futures contract based on the reasoning that supply shifts (i.e., price of soybean oil as an input) drives biodiesel price changes when binding Renewable Fuel Standard (RFS) blending mandates are in place. We find that soybean oil futures should in fact be included as part of a composite hedge, and that in some instances greater hedging weight should be placed on this futures contract than the conventionally used heating oil futures contract. Arguably, for the Iowa market if hedging small quantities of biodiesel, it may be more practical to hedge entirely in the soybean oil futures market.

Again, these are striking findings, given that heating oil futures are typically used to hedge biodiesel price risk. Conventional approaches consider only heating oil as biodiesel is clearly a substitute for heating oil in diesel blends. However, the RFS mandates create a unique situation where the price of soybean oil, as an input feedstock, is a primary driver of biodiesel price, despite linkages to other energy prices through diesel.

These results are obtained utilizing the full sample of data to generate the hedging rule, as opposed to saving a later period to test hedging effectiveness out-of-sample, which future research may consider. These results, while specific to four U.S. markets studied here, seem generally consistent enough across locations that it is likely that the main finding of improved hedging effectiveness with inclusion of soybean oil futures likely holds for other U.S. biodiesel markets. In markets outside of the U.S. where other inputs to biodiesel production are more common other hedging instruments may prove beneficial, and this too is an avenue for future research.

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Table 1. Summary Statistics

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Prices on Fridays					
CP^{IA}	681	3.63	0.83	2.33	5.85
FP^{HO}	681	2.25	0.64	0.93	4.11
FP^{ZL}	681	39.39	9.86	26.05	68.15
Prices on Thursdays					
$CP^{Chicago}$	681	3.59	0.84	2.43	5.88
$CP^{New\ York}$	383	3.34	0.64	2.39	5.45
CP^{Gulf}	677	3.62	0.90	2.34	6.00
FP^{HO}	681	2.25	0.64	0.90	4.11
FP^{ZL}	681	39.40	9.86	26.63	67.53

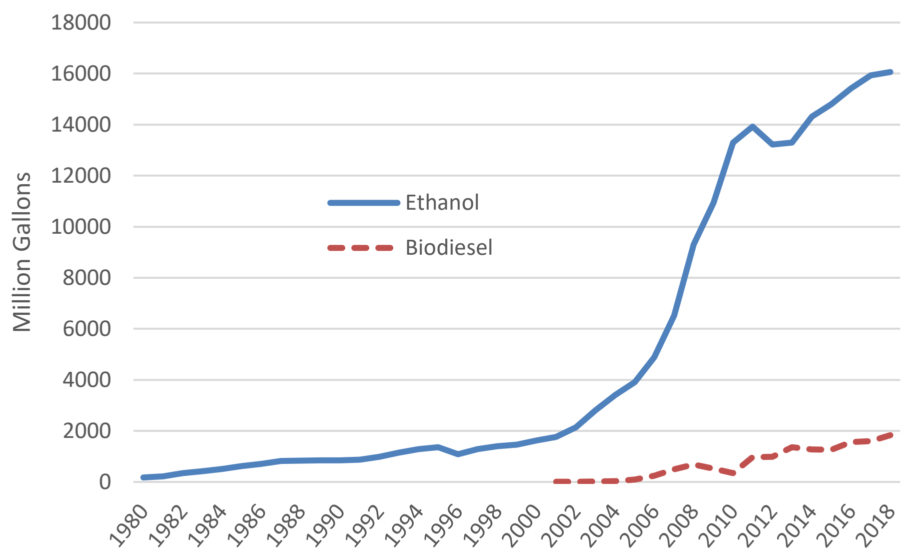
Table 2. Hedging Results, Four-Week Horizon

	Iowa		Chicago		New York		Gulf of Mexico	
Hedging Regressions	Heating Oil	Soybean Oil	Heating Oil	Soybean Oil	Heating Oil	Soybean Oil	Heating Oil	Soybean Oil
Estimated Hedge Ratio (β)	0.33	0.40	0.67	0.52	0.86	0.52	0.69	0.46
(Standard Error)	(0.05)	(0.03)	(0.05)	(0.04)	(0.08)	(0.08)	(0.04)	(0.04)
N	675	675	675	676	378	378	672	672
F(6, 640)	212.54	3576.61	259.01	323.76	135.64	74.05	421.70	305.87
Prob > F	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
R^2	0.6562	0.8404	0.7300	0.7469	0.5926	0.5688	0.7166	0.7244
Standard Deviation (e_t)	0.13	0.11	0.12	0.12	0.13	0.14	0.13	0.13
Correlations ($\rho e_0 e_1$)	0.80		0.75		0.80		0.79	
Encompassing Regression								
Estimated Hedging Weight (λ)		0.89		0.56		0.43		0.53
(Standard Error)		(0.06)		(0.06)		(0.10)		(0.07)
N		675		675		378		672
R^2		0.2834		0.1565		0.0744		0.1185

Note: Results from error correction models with chosen structure based on minimum SIC. The optimal model for both Iowa regressions includes 2 lags of price changes and a lagged residual; for Chicago-Heating Oil includes 1 lag of price changes and no lagged residual and for Chicago-Soybean Oil includes 1 lag of price changes and a lagged residual; and for all other pairings includes 1 lag of price changes and a lagged residual. Robust standard errors are reported in cases where evidence of heteroskedasticity is found.

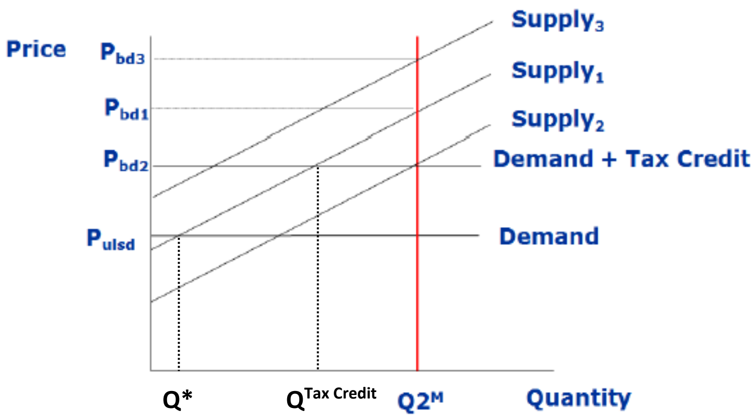
Table 3. Number of Futures Contracts and Gallon Equivalent to Hedge Biodiesel Production

		Monthly Biodiesel Production (Gallons)						
Location	Futures Contract	100,000	200,000	400,000	600,000	800,000	1,000,000	10,000,000
Number of Futures Contracts								
Iowa	Heating Oil	0.1	0.2	0.3	0.5	0.7	0.9	8.6
	Soybean Oil	4.5	9.0	17.9	26.9	35.8	44.8	448.0
Chicago	Heating Oil	0.4	0.8	1.6	2.4	3.2	4.0	39.9
	Soybean Oil	4.9	9.8	19.6	29.4	39.3	49.1	490.8
New York	Heating Oil	1.2	2.3	4.7	7.0	9.3	11.7	116.7
	Soybean Oil	2.8	5.6	11.3	16.9	22.5	28.1	281.4
Gulf	Heating Oil	0.8	1.5	3.1	4.6	6.2	7.7	77.2
	Soybean Oil	3.1	6.1	12.3	18.4	24.5	30.7	306.8
Number of Gallons								
Iowa	Heating Oil	3,630	7,260	14,520	21,780	29,040	36,300	363,000
	Soybean Oil	35,600	71,200	142,400	213,600	284,800	356,000	3,560,000
Chicago	Heating Oil	16,750	33,500	67,000	100,500	134,000	167,500	1,675,000
	Soybean Oil	39,000	78,000	156,000	234,000	312,000	390,000	3,900,000
New York	Heating Oil	49,020	98,040	196,080	294,120	392,160	490,200	4,902,000
	Soybean Oil	22,360	44,720	89,440	134,160	178,880	223,600	2,236,000
Gulf	Heating Oil	32,430	64,860	129,720	194,580	259,440	324,300	3,243,000
	Soybean Oil	24,380	48,760	97,520	146,280	195,040	243,800	2,438,000



Sources: Renewable Fuels Association (http://ethanolrfa.org) and Energy Information Administration (https://afdc.energy.gov)

Figure 1. U.S. annual ethanol and biodiesel production



Source: Adapted from Irwin (2015).

Figure 2. Biodiesel market with a volume mandate, blender tax credit, and supply shifts

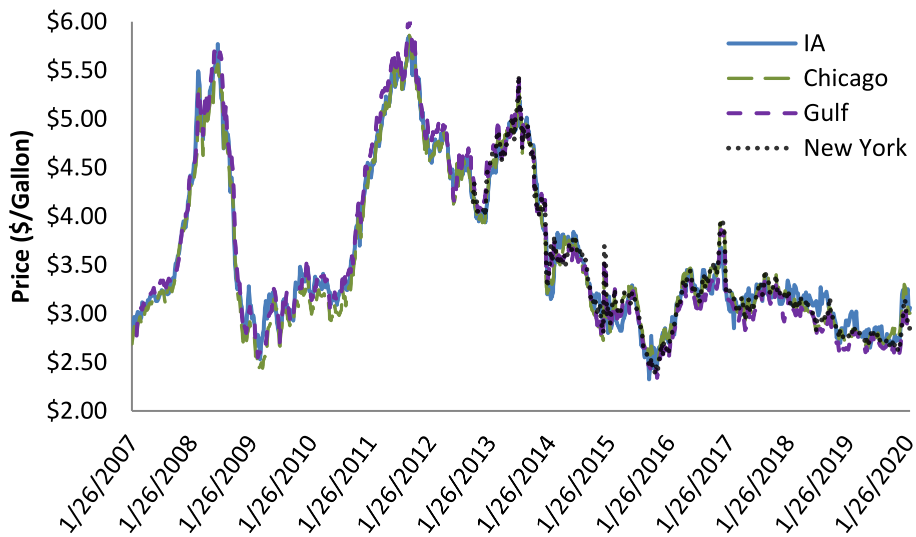


Figure 3. Biodiesel cash prices, January 26, 2007 through February 7, 2020