Drop-in Ready Jet Biofuel from Carinata: A Real Options Analysis of Processing Plant Investments

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Selected Paper prepared for presentation at the 2020 Agricultural & Applied Economics Association Annual Meeting

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Fossil Fuels, CO2, and the Aviation Industry

- **Economic Impact:** The aviation industry is a significant component of the global economic system with a total annual impact of $2.7 trillion (3.6% of global GDP).
- **Fuel Efficiency:** Fuel efficiency has significantly improved by 70% since 1960. As a result, CO2 emissions per seat kilometer have dropped by 50% since 1990.
- **CO2 Emissions:** In 2017, the fossil fuel dependent aviation industry contributed about 2% (859 million tons) of total human-produced CO2 emissions globally (aviation accounted for 12% of transport-related CO2 emissions).
- **Aviation Growth:** Air traffic volume is expected to rapidly grow, doubling by 2032.

Carinata – A Feedstock for Aviation Biofuel

- **Brassica Carinata**: A non-GMO, non-food, low-input oilseed crop currently grown globally for alternative biofuels and seed meal. Carinata prefers cooler weather and has demonstrated success growing during the winter months in the Southeastern U.S. as a cash cover crop on land typically fallowed.
- **Carinata Oil for Aviation Fuel:** Contains high levels of erucic acid and other long carbon chain fatty acids, making carinata oil highly efficient for conversion into aviation fuels.
- **Industrial Scale Fuel Production:** As with other agricultural biofuels, developing the supply chain and processing infrastructure requires significant financial investments and faces structural challenges from incumbent fuel supply sources and uncertain market price conditions.

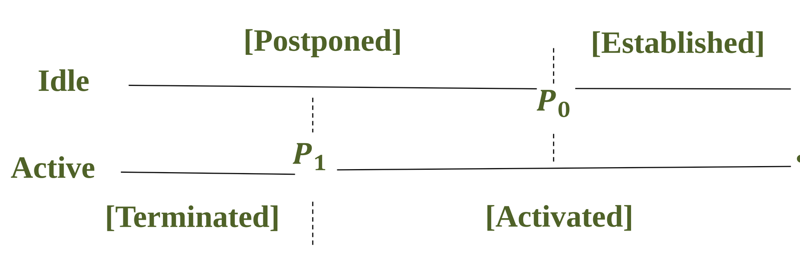
- **Oil Processing Plant Feasibility:** Previous studies (e.g., Chu et al., 2017; McGarvey and Tyner, 2018) estimate, depending on multiple factors such as production capacity and production methods, significant investment costs ($33.5-$104 million) and annual operating costs ($12.8-$109 million) for an industrial scale carinata oil processing facility.

Research Questions

1. What is the impact of aviation fuel price volatility on the optimal market conditions for investing in an industrial scale carinata biorefinery?
2. How sensitive are the optimal investment thresholds to conventional aviation fuel price volatility under net present value (NPV) vs. real options analysis (ROA)?

Real Options Analysis (ROA)

- Models an investment opportunity as a financial call option where prices are stochastic.
- ROA, in contrast to NPV, accounts for managerial flexibility, investment cost irreversibility, and project value uncertainty.



- **P_0 - Threshold aviation fuel price for an idle firm to construct and operate a carinata biorefinery.**
- **P_1 - Threshold aviation fuel price for an active firm to exit the industry.**

Methodology

ROA Model Overview

- Assume aviation fuel prices follow a geometric Brownian motion, $dP = \alpha P dt + \sigma P dz$, where α is the drift rate, σ is the instantaneous volatility of price, dz is an incremental Wiener process and dt is a time interval.
- The Bellman equation for $V_0(P)$, the value of an idle firm, is $rV_0 dt = E(dV_0)$, where r is the discount rate of returns. Expanding dV using Ito's Lemma for geometric Brownian motions, $E(dV_0) = V_0'(P)(\alpha P dt + \sigma P dz) + ½V_0''(P)(\sigma^2 P^2 dt + 2\alpha\sigma P^2 dt dz + \alpha^2 P^2 dt^2)$.
- The Bellman equation for $V_1(P)$, the value of an active firm, is denoted by $rV_1 dt = E(dV_1) + \pi(P)dt$, which upon expansion yields $\frac{1}{2}\sigma^2 P^2 V_1'' + \alpha P V_1' - rV_1 + (P - C) = 0$.
- Following Dixit and Pindyck (1994), substituting the value functions into the value matching and smooth pasting conditions yields four equations solvable using numerical methods:

$$-A_1 P_0^{\beta_1} + B_2 P_0^{\beta_2} + \frac{P_0}{r-\alpha} - \frac{C}{r} - K = 0, \qquad -\beta_1 A_1 P_o^{\beta_1 - 1} + \beta_2 B_2 P_0^{\beta_2 - 1} + \frac{1}{r-\alpha} = 0,$$

$$-A_1 P_1^{\beta_1} + B_2 P_1^{\beta_2} + \frac{P_1}{r-\alpha} - \frac{C}{r} + E = 0, \qquad -\beta_1 A_1 P_1^{\beta_1 - 1} + \beta_2 B_2 P_1^{\beta_2 - 1} + \frac{1}{r-\alpha} = 0,$$

where A_1 and A_2 are constants to be determined, β_1 and β_2 are known constants, E is the lump sum cost of abandonment, P_0 is the threshold aviation fuel price for entry (i.e. plant construction) and P_1 is the threshold aviation fuel price for industry exit.

NPV vs. ROA

- The present value of the return flow over an infinite time horizon is

$$\sum_{i=1}^{\infty} \frac{\pi_i}{(1+\mu)^i} = \frac{P(1+\alpha)}{\delta} - \frac{C}{\mu}.$$

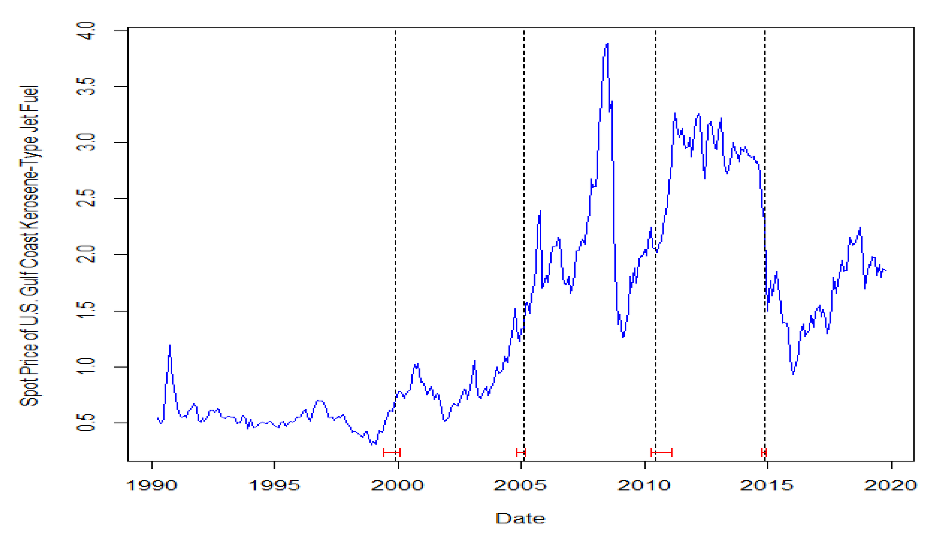
where μ represents the risk adjusted discount rate and $\delta = \mu - \alpha$. Comparing with the lump sunk cost of exercising the option to enter, a positive net return flow, $\frac{P(1+\alpha)}{\mu-\alpha} - \frac{C}{\mu} - K > 0$ results in carrying out an investment. Conversely, a negative net return flow, derived by $\frac{P(1+\alpha)}{\mu-\alpha} - \frac{C}{\mu} < -E$ yields a project termination. The NPV price thresholds are

$$P^{ENTRY} = \left(\frac{\mu-\alpha}{1+\alpha}\right)\left(K + \frac{C}{\mu}\right), \; P^{EXIT} = \left(\frac{\mu-\alpha}{1+\alpha}\right)\left(\frac{C}{\mu} - E\right).$$

- Letting $\mu = r + s\rho\sigma$, where s represents the market price of risk, ρ is the coefficient of correlation between the price P and the entire market portfolio and σ is the instantaneous volatility rate of the GBM process for price P. Assuming no uncertainty, $\mu = r$.
- The inequalities between the ROA and NPV, i.e. $P_0 > P^{Entry}$ always holds for any GBM process with a positive drift rate, whereas in the exit scenario, $P_1 < P^{Exit}$ must hold for any process with a non-positive drift rate.
- For the GBM processes with a positive drift rate, there is an expected ambiguous relationship between the exit thresholds under the two approaches. Conversely, there exists an ambiguous relationship between the entry thresholds for a GBM process with a negative drift rate.
- A numerical analysis is employed to resolve the ambiguities and provide insights on the relative responsiveness of the optimal timing to parameter variation.

Data

U.S. Gulf Coast Kerosene-type Jet Fuel Spot Price FOB ($ per Gallon) (Source: EIA)



Note: The dotted vertical lines indicate the estimated break dates in the past three decades and the corresponding time intervals bounded by the red bars are the suggested respective 95 percent confidence intervals.

Model Parameter Assumptions

Brownian Motion Parameters in 2019 Dollars (Dec. 2015 – Oct. 2019)

	Baseline Estimate	Simulation Range
Drift (α)	0.045	0.02 – 0.09
Volatility (σ)	0.118	0.05 – 0.55

Model Parameter Assumptions

Construction, Operating, and Model Parameter Assumptions

	Baseline (2019 Dollars/gal)	Optimistic Scenario (-33% Unit Costs)	Pessimistic Scenario (+33% Unit Costs)
Unit Investment Cost (K)	$0.24	$0.16	$0.32
Unit Operating Cost (C)	$1.85	$1.24	$2.45
Unit Exit Cost (E)	$0.02	$0.03	$0.03
Discount Rate (r)	10%	10%	10%

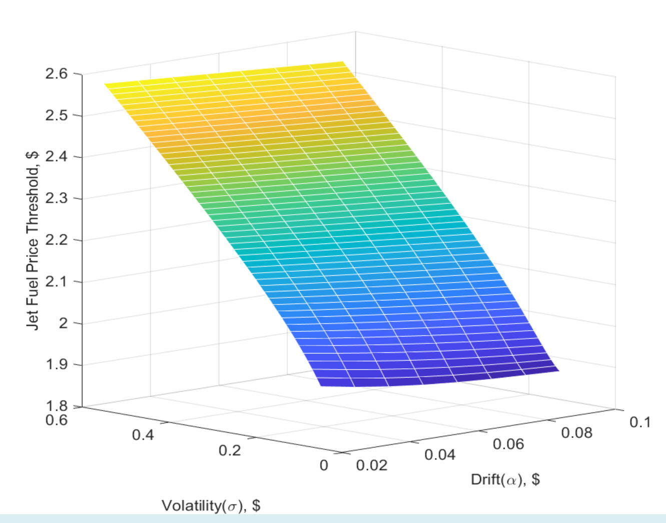
Sensitivity of Price Thresholds

ROA vs. NPV: Jet Fuel Price Thresholds for Entry and Exit

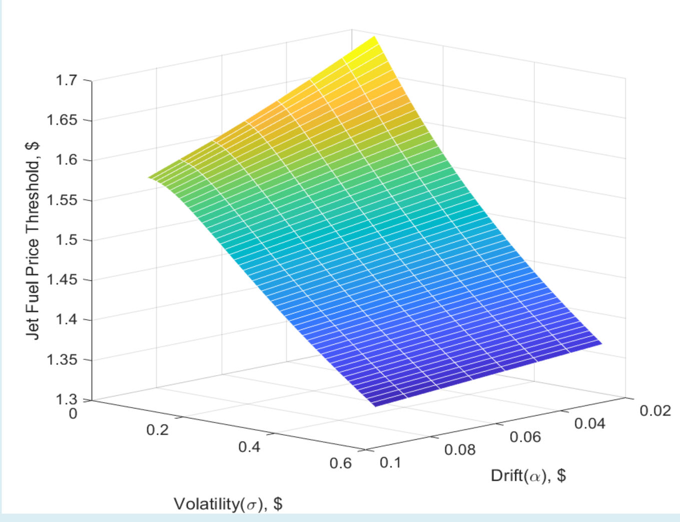
	Baseline (2019 Dollars/gal)	Optimistic Scenario (-33% Unit Costs)	Pessimistic Scenario (+33% Unit Costs)
ROA Entry Threshold (P_0)	$2.04	$1.37	$2.71
ROA Exit Threshold (P_1)	$1.61	$1.08	$2.14
NPV Entry Threshold	$0.99	$0.67	$1.32
NPV Exit Threshold	$0.98	$0.66	$1.30

GBM parameters	ROA Entry	ROA Exit	NPV Entry	NPV Exit
α				
Overestimated	↓	↓	↓	↓
Underestimated	↑	↑	↑	↑
σ				
Overestimated	↑	↑	–	–
Underestimated	↓	↓	–	–

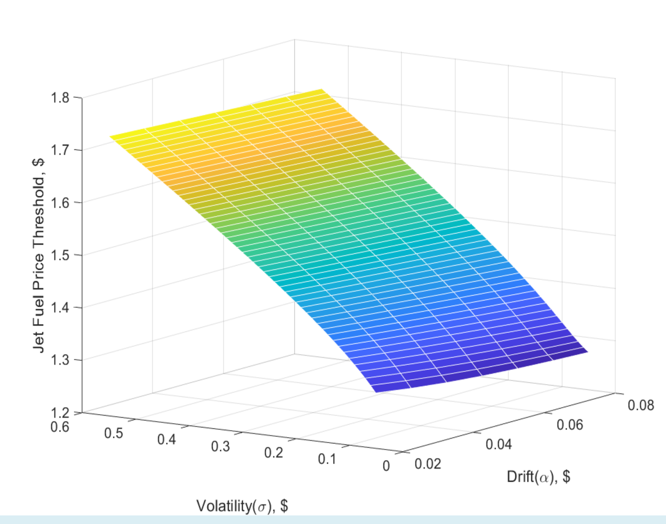
Baseline Scenario – Impact of Jet Fuel Price Volatility on ROA Entry Threshold (P_0)



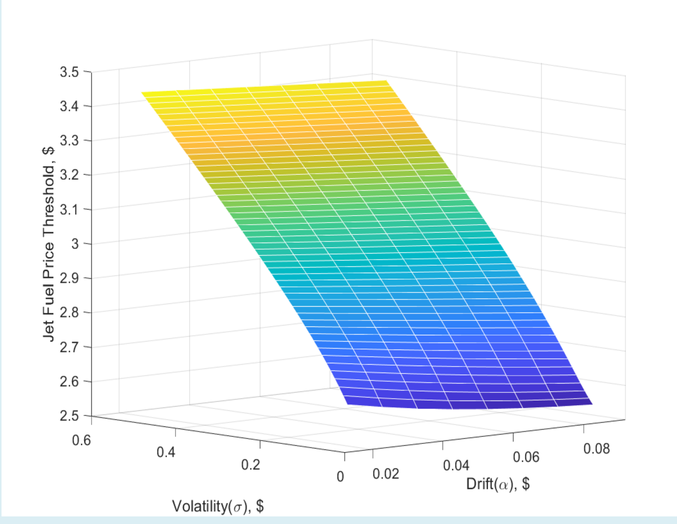
Baseline Scenario – Impact of Jet Fuel Price Volatility on ROA Exit Threshold (P_1)



Optimistic Scenario – Impact of Jet Fuel Price Volatility on ROA Entry Threshold (P_0)



Pessimistic Scenario – Impact of Jet Fuel Price Volatility on ROA Entry Threshold (P_0)



Conclusions

Results of the study indicate that:

1. There are significant divergences between ROA and NPV estimates of the necessary optimal market conditions for investing in a carinata processing plant (biorefinery).
2. Under ROA, entry and exit price thresholds are sensitive to jet fuel price volatility. Greater levels of volatility increase the required jet fuel price threshold for an idle firm to enter the industry.
3. Compared to the NPV exit thresholds, the ROA counterpart may suggest less hesitance toward exiting the market. It could be due to the relative responsiveness of NPV to the benchmark value of discount rate.
4. Comparing optimistic vs. pessimistic scenarios indicates entry conditions are highly sensitive to plant construction and operation unit costs.

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