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How Have Oilseed Relative Price Relationships Changed Over Time?

K. Aleks Schaefer
Department of Agricultural Economics, Oklahoma State University, Stillwater, Oklahoma, USA
Email: aleks.schaefer@okstate.edu

Robert J. Myers
Department of Agricultural, Food and Resource Economics, Michigan State University, East Lansing, Michigan, USA.

Stanley R. Johnson
National Center for Food and Agricultural Policy, Washington, D.C., USA.

Michael D. Helmar
National Center for Food and Agricultural Policy, Washington, D.C., USA.

Tony Radich
USDA Office of the Chief Economist, Office of Energy and Environmental Policy, Washington, D.C., USA.

This paper uses econometric modeling to assess how relative price relationships in the international oilseed system, including those for soy, canola, palm, and sunflower oil, have changed over time. We find that structural change in the international oilseed price system aligns strongly with the timing of mandates on the labeling of trans fats and international policy efforts to promote biodiesel production. Our results indicate that—following an initial adjustment period—price premiums for sunseed oil and canola oil increased by 28% and 4%, respectively, relative to soy oil. We also find that—prior to the boom in biodiesel production and trans-fat labeling requirements—no long-run co-integrating relationship existed between palm oil prices and those for other oilseeds. However, in the wake of these changes, palm oil prices are now strongly co-integrated with other oilseed prices.

Key words: oilseeds, relative prices, biodiesel policy, trans fat labeling
JEL Codes : Q42, Q48, Q11

1. INTRODUCTION

Regulations targeting downstream food and transportation markets can have substantial implications for the economic returns to upstream oilseed producers. Production subsidies and mandatory blending requirements for biodiesel and ethanol into transportation fuels have generated a substantial boost in the global demand for biofuel over the last twenty years. These programs originated under the 2001 EU Biofuels Directive and the 2005 U.S. Energy Policy Act. Oilseeds, including soy canola, palm, and sunflower oil, represent major feedstocks for biodiesel production. The U.S. biodiesel industry is dominated by soy, but sunflower oil and other feedstocks also play key roles. In the EU, canola oil is the major biodiesel feedstock but palm oil from Malaysia, soy, and sunflower have also been used. In 2019, the EU determined that palm oil is not environmentally sustainable and banned biodiesel made from palm oil to be counted towards the required uses. Going forward, this has effectively eliminated palm oil-based biodiesel from EU consumption, blending, and therefore, from production.

Alongside the expansion of biofuels, health concerns have led legislators across the world to regulate foods containing trans fats. This began in March 2003, when Denmark became the first country to ban packaged foods containing trans fats. In the U.S., the Food and Drug Administration (FDA) began requiring food manufacturers to provide information about trans fats on Nutrition Fact panels in 2006. These regulations have substantial implications for oilseed relative prices—soy and canola oil have high trans-fat content, whereas sunflower seed oil and palm oil do not contain any trans fats.

In this paper, we focus on an under-researched aspect of the potential effects of these regulatory changes—we seek to quantify their impact on relative price relationships among oilseed feedstocks. Understanding policy-induced changes in relative prices is critical because it is relative prices that drive the incentive to shift production between different crops, which has implications for land use and greenhouse gas emissions, not to mention the welfare of farmers and other market participants. This is of consequence because the oilseeds we study are grown on more than 200 million hectares of land worldwide.

Certain conditions must be satisfied for regulatory changes to affect international price relatives. First, there is existing evidence of unit root processes in international oilseed prices. Thus, analysis of policy effects on long-run relative prices requires co-integration among oilseed prices before and after global regulatory changes. Second, the regulation must have induced a permanent change in this co-integrating relationship. Here, we employ an empirical analysis to test for each of these conditions in turn.

Our analysis contributes to the economic research on the effects of biofuel growth on agricultural and food price relationships (Ciaian, 2011; Myers, Johnson, Helmar, & Baumes, 2014; Wetzstein & Wetzstein, 2011; Zhang, Lohr, Escalante, & Wetzstein, 2010; Zilberman, Hochman, Rajagopal, Sexton, & Timilsina, 2013). Most of this research finds evidence that the growth in biofuels has enhanced linkages between energy and agricultural prices, and that increased demand for biofuels increased the price of biofuel feedstocks, at least in the short run. Drabik, De Gorter, and Timilsina (2014) argue that the jointness between oil and meal in oilseed crushing diminishes the impact of biodiesel growth on oilseed feedstock prices, but that the prices of higher oil content feedstocks, such as canola and sunflower, should increase relative to soy, which has a lower oil content. Cui and Martin (2017) argue that biodiesel expansion will lead to substitution of palm oil for soy oil, thus increasing the relative price of palm oil. However, both papers use a stylized computational model calibrated to a few data points. Here we investigate whether an econometric approach supports or contradicts these conclusions. There is some existing econometric evidence on biodiesel feedstock price relationships (Hassouneh, Serra, Goodwin, & Gil, 2012; In & Inder, 1997), but these studies focus on cointegration and long-run price relationships rather than structural changes in relative feedstock prices.

Our analysis also relates to research on the impacts of mandatory nutrition labeling policies. Much of this research relates to the impacts of these labels on consumer behavior. For example, Teisl, Bockstael, and Levy (2001) use experimental methods to analyze the impacts of nutrition labeling claims on supermarket shelves. Kalaitzandonakes, Marks, and Vickner (2004) use scanner data to evaluate consumers' purchasing decisions in the context of mandatory labeling rules for genetically engineered (GE) foods. Perhaps most relevant in this line of literature for our purposes, Carter and Schaefer (2019) study the impacts of mandatory GE labeling on the relative prices of GE and non-GE sugar feedstocks. They find that the labeling policies induced a 13% price discount for GE sugar and a premium of about 1% for non-GE sugar. In our context, the GE to non-GE feedstock distinction is comparable to oilseeds containing trans fats versus oilseeds that do not contain trans fats.

We find that the timing of structural change in the international oilseeds system aligns strongly with the timing of mandates on the labeling of trans fats and international policy efforts to promote biodiesel production. Our price impact results provide empirical support for the conclusions in Drabik et al. (2014) and are consistent with the upstream impacts of mandatory labeling discussed in Carter and Schaefer (2019). We find that—following an initial adjustment period—international biodiesel expansion and regulatory changes has induced a 28% increase in the price premium for sunseed oil and a 4% increase in the premium for canola oil relative to soy oil. Our findings also lend insights to the discussion in Cui and Martin (2017). We find that—prior to the boom in biodiesel production and trans-fat labeling requirements—no long-run co-integrating relationship existed between palm oil prices and those for other oilseeds. However, in the wake of these changes, palm oil prices are now strongly co-integrated with other oilseed prices.

2. BACKGROUND

This section details major policy efforts affecting the international oilseed price system. In Section 2.1, we provide a brief overview of the international biodiesel promotion. Section 2.2 discusses legislation regarding the mandatory labeling of trans fats. Figure 1 plots global production of oilseeds. Across the world, there are approximately 124.9 million hectares planted in soybeans (35.7 million hectares in the U.S.), 37.6 million hectares planted in canola (0.8 million hectares in the U.S.), 26.7 million hectares planted in sunflower (0.5 million in the U.S.) and 18.9 million hectares planted in palm.

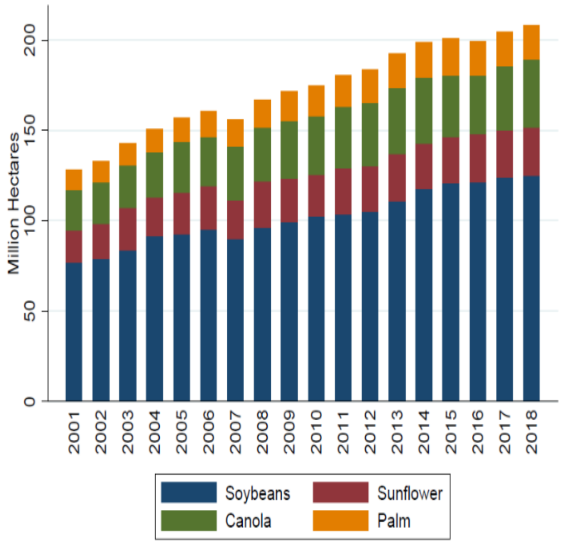


Figure 1: Global Oilseed Production
Source: Data obtained from FAOSTAT.

2.1. International Biodiesel Promotion

World production and use of biodiesel have risen dramatically in the last twenty-five years. Initial optimism about the environmental benefits of reducing fossil fuel use, reducing energy dependence on imports, and enhancing farmer incomes has given way to pessimism surrounding the diversion of valuable resources away from food production, increased food prices, and food price volatility, and a reassessment of whether biofuels can really provide environmental benefits and mitigate climate change (Carter, Rausser, & Smith, 2017; Cui, Lapan, Moschini, & Cooper, 2011; De Gorter & Just, 2009a, 2009b; Lade, Lin Lawell, & Smith, 2018; Runge & Senauer, 2007).

The two largest international producers are the United States and the European Union. In the U.S., the growth in biodiesel production began with the Energy Policy Act of 1992, which initiated biofuel subsidies and provided guidance for federal programs designed to encourage increased use. However, it was not until the Energy

Policy Act of 2005 that biofuels really took off. The 2005 Act increased subsidy levels and implemented the Renewable Fuel Standard, which required the blending of ethanol and biodiesel into transportation fuels, providing a huge boost to biofuel demand. Subsequent legislation has continued to encourage biodiesel production and use in the U.S., which has grown steadily (Figure 2). In 2019, the U.S. produced over 5.6 million metric tonnes of biodiesel (B100) from 91 biodiesel plants nationwide. Production occurs in 38 U.S. states, and is heavily concentrated in Iowa, Missouri, and Texas (EIA, 2020).

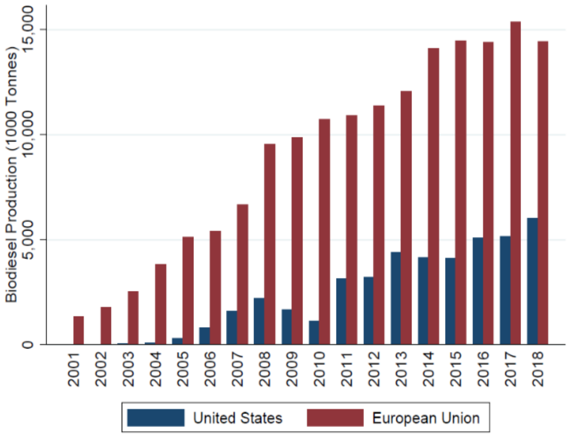


Figure 2: U.S. and EU Biodiesel Production

Source: U.S. biodiesel production data obtained from the U.S. Energy Information Administration "Monthly Biodiesel Production Report", converted from barrels to metric tons using a conversion factor of 0.1364. EU biodiesel production data obtained from EU Biofuels Annals (various years) GAIN Reports provided by the USDA Foreign Agricultural Service.

In the EU, growth in biodiesel was initially incentivized through the Biofuels Directive of 2001, which required 5.75% of all transport fuels to be replaced by biofuels by the end of 2010. The 2009 Renewable Energy Directive provided additional support by raising binding targets to 20% renewables for total energy use and 10% for transportation fuel by 2020. Combined with subsidies and import protection, these policies have led to rapid increases in EU biodiesel production and use. In 2019, the EU produced approximately 11 million metric tons of biodiesel in 120 biodiesel production plants, concentrated primarily in Germany, Italy, Austria, France, and Sweden.

Crushing margins differ among oilseed feedstocks (Table 1). Soybean feedstock produces approximately 19% oil content (versus 79% meal content). Crush margins for sunflower and canola are much higher. Canola oil content is about 42% (with meal content 58%), and sunflower oil content is approximately 42% (with 45% meal). Palm fruit oil content ranges as high as 56%. We note that biodiesel made from different vegetable oil feedstocks are not perfect substitutes because of different cold filter plugging points (CFPP).

Table 1: Oilseed Crush Margins and Trans Fat Content

Oil Type	Crush Margin		Trans Fat Content (g/tbsp)
	Oil	Meal	
Soy	0.19	0.79	0.1
Canola	0.42	0.58	0.2
Sunseed	0.42	0.45	0.0
Palm	0.56	0.40	0.0

2.2. Mandatory Trans Fat Labeling

In the late 1990s, academic research began into the adverse health effects of trans fatty acids (Ascherio, Katan, Zock, Stampfer, & Willett, 1999; Ascherio & Willett, 1997). According to the American Heart Association, trans fats raise negative cholesterol levels and increase risks for heart disease, stroke, and type-2 diabetes (American Heart Association, 2017). As a result, legislators across the world instituted mandatory labeling procedures for foods containing trans fats. In March 2003, Denmark became the first country to ban packaged foods containing trans fats (Smith, 2018). Similar legislation has since been adopted in many EU countries. Later in 2003, the U.S. passed a regulation requiring food manufacturers to provide information about trans fats on Nutrition Fact panels (21 CFR Part 101). This mandate took effect on January 1, 2006. The state of California later banned to use of trans fats in restaurants in July 2008.

These regulations have substantial implications for oilseed relative prices because the content of trans fatty acids differs across oilseeds (Table 1). Soy and canola oil have high trans-fat content at 0.1 and 0.2 grams per tablespoon, respectively (USDA, 2021). In contrast, sunflower seed oil and palm oil do not contain any trans fats. As a result of the regulatory shift away from trans fats, there was a significant reduction in demand for human consumption of soybean oil, as it became increasingly viewed as unhealthy and was avoided by food manufacturers. This has been estimated by the industry to be a 20% reduction in soybean oil market share by 2006 when the trans-fat labeling went into effect in the U.S. (Market View Insight, 2017). This directly shifted oil demand away for soybean oil and toward sunflower oils (and to a much lesser degree palm oil).

3. METHODOLOGY

We employ a three-step empirical analysis (outlined in Figure 3) to assess how relative price relationships in the international oilseed system have changed over time. First, we apply Bai-Perron structural break tests to univariate models of price differentials between several pairs of oilseed prices (Bai & Perron, 2003). The Bai-Perron approach allows simultaneous estimation of the number of endogenously determined structural breaks and identify the timing of breaks in a time series sample. The goal is to estimate empirically the number and location of structural breaks in relative oilseed prices. The structural breaks identified coincide well with the timing of major policy innovations, suggesting these policy changes have altered relative oilseed price relationships. Second, we conduct a series of bivariate cointegration analyses to identify—for each regime—the nature, existence, and stability of the underlying long-run equilibrium relationships. Finally, the structural break tests and cointegration results are combined to provide empirical estimates of the extent to which biofuel policy has shifted relative price differentials between key oilseed prices.

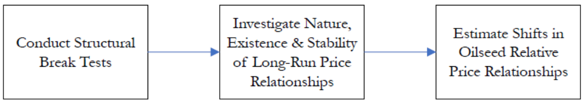
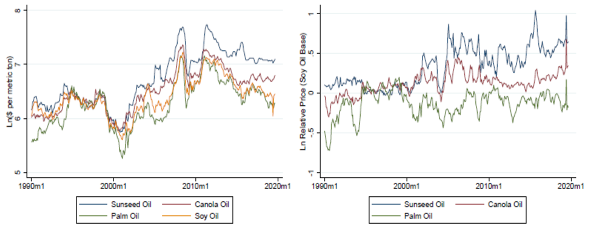


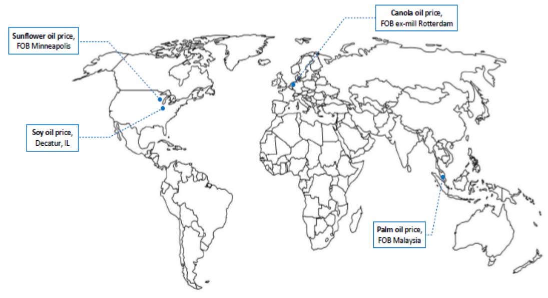
Figure 3: Three-Step Empirical Analysis

Our analysis uses international prices for four oilseeds: (1) sunflower oil, (2) canola oil, (3) palm oil, and (4) soy oil. Panel (a) of Figure 4 shows these prices in natural logarithmic form. The geographic locus of each price is shown in Panel (c) of Figure 4. Sunflower oil prices are FOB Minneapolis, canola oil prices are FOB ex-mill in Rotterdam, palm oil prices are FOB Malaysia, and soy oil prices are from Decatur and are an average wholesale tank price. All prices are in U.S. dollars per metric ton, converted at the appropriate exchange rate when necessary. Prices are monthly from January 1990 through November 2019 (357 total observations), and the source for all the price data is the Foreign Agricultural Service of the United States Department of Agriculture.



(a) Price Levels

(b) Price Relatives (Soy Oil Base)



(c) Geographic Locus of Oilseed Price Data

Figure 4: International Oilseed Prices, 1990–2019

Source: Price data are obtained from the USDA Foreign Agricultural Service.

For our main analysis, we specify price relatives as:

$$(y_t = \ln\left(P_{it} \backslash P_{jt}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where P_{it} is the price of oilseed i at time t. This relative price measure is the price premium (discount if less than one) that oilseed i has relative to oilseed j in each period. This measure of relative price was chosen because it is a natural and intuitive measure of the way in which policy treatments have altered price relatives among oilseed prices and is consistent with previous work on the impacts of policy changes on relative price relationships (Carter & Smith, 2007; McKendree, Saitone, & Schaefer, 2021). Other measures of price relatives could also be used. For example, one could take the simple difference in prices ($P_{it} - P_{jt}$) or the price ratio without natural logarithmic transformation. We explore alternative constructions of the price relative in Appendix A, and results are consistent with those from the log price relatives.

Panel (b) of Figure 4 depicts the price relatives computed using equation (1) using soy oil as the denominator. Soy oil is chosen as the denominator because it is the most important biodiesel feedstock in the U.S. and is used extensively in the EU as well. Sunflower-soy oil price relatives have the distinct appearance of two separate regimes, with a break somewhere around the beginning of 2005. In the earlier regime, the sunflower premium appears smaller while in the later regime it appears to undergo a substantial jump, with sunflower oil prices rising relative to soy oil. Potential breaks in the canola-soy and palm-soy oil price relatives are less obvious from visual inspection of the figure.

4. STRUCTURAL BREAK TESTS

Using the price relatives depicted in Figure 4(b), we first ask whether policy-induced thresholds in the growth in biodiesel use and trans-fat labeling mandates coincide with the existence and timing of long-run changes in international oilseed relative price relationships. An inherent issue, of course, is that it is not clear when policy treatments occur. Obvious candidates are the date of major policy changes, such as the U.S. Energy Policy Act of 2005 and the imposition of trans fat labeling mandates on January 1, 2006. However, it is logical that some of the impacts of major legislative actions were anticipated prior to implementation and therefore may have at least some of their impact prior to enactment. It is also likely that some adjustment to legislative changes may be delayed due to adjustment costs and rigidities, so that there is a dynamic response to some of the policy changes that have occurred. Particularly early on, implementation can lag because of the time required to build out processing and blending capacity.

We account for these timing issues in two ways. First, we include lagged price differentials as explanatory variables in our structural break regressions to allow for a dynamic response (slow adjustment) to shifts in the policy treatment variables. Second, we undertake tests for multiple structural breaks at unknown break points to allow the data to identify whether and when key shifts in the relative price relationships have occurred (Bai & Perron, 2003). We compare the identified break points with legislative evidence on biofuels policy to determine whether they can be interpreted as policy treatments.

The structural break analyses are based on estimating econometric models that take the general form:

$$y_t = \alpha + \mathbf{X}_t\beta + \epsilon_t \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where y_t is the relative price differential and $\boldsymbol{X}_t$ is the vector of lagged price differentials? The optimal lag order is determined according to the Hannan-Quinn Information Criterion (HQIC) (Hannan & Quinn, 1979).

Table 2 reports results of the structural break tests. The tests identify two structural breaks in the sunseed-soy price relative—the earlier occurring in August 1994 and the latter in May 2004. The timing of both breaks aligns well with events affecting international oilseed markets. The earlier break follows shortly after the signing of the Uruguay Round Agreement in April 1994 in which some 120 countries agreed to significant changes in agricultural trade policies, including domestic support, tariffs and import quotas. While oilseeds had generally lower policy impacts from grains, commodities like sunflower seed and rapeseed are grown in areas that also are major grain (wheat and barley, primarily) producing areas in the EU and Canada. Cereal's policies and agencies were affected to a significant extent by these GATT negotiations. The trade liberalization coming from this agreement was phased in over several years following signing. The WTO came out of these agreements on January 1, 1995.

The second break occurs a few months after the FDA passed rules requiring food manufacturers to list trans-fat on the Nutrition Facts panels. This is also a few months before the promulgation of the 2005 Energy Policy Act in the United States. The canola-soy price relative also identifies two structural breaks—in October 1990 and June 2000. As with the sunseed-soy price relative, the earlier break in the canola-soy relative price occurs prior to the establishment of the WTO. The latter break aligns strongly with the inception of the 2001 Biofuels Directive in the EU. This is intuitive given that canola is the primary feedstock used for biodiesel production in the EU.

The model does not identify a structural break in the palm-soy price relative. There are two potential explanations for this. The finding could indicate there has not been a permanent change in the relationship between palm and soy oil prices over the period of observation. Alternatively, it could suggest that—even if the relationship has changed—the relationship was sufficiently noisy over one period that the model is not able to separate that regime for others. The co-integration analysis in the next section sheds light on this result.

Table 2: Tests for Structural Break in Relative Prices (Soy Base)

Price Series	Lag Specification	Break Number	Break Date	Statistic	p-value
Sunseed-Soy	2				
		(1)	2004m5***	20.45	0.00
		(2)	1994m8***	13.72	0.01
		(3)	2014m7	6.13	0.23
Canola-Soy	1				
		(1)	2000m6**	10.55	0.03
		(2)	1990m10***	16.24	0.00
		(3)	2006m10	7.29	0.14
Palm-Soy	1				
		(1)	1994m4	5.846	0.25

***p<0.01, **p<0.05, *p<0.1

Focusing on the structural breaks for the sunseed-soy and canola-soy price relatives (and excluding periods prior to the establishment of the WTO), our structural break analysis identifies three main regimes for oilseed price relatives. The first regime runs from January 1995 to June 2000. This regime runs prior to trans-fat labeling requirements and the large-scale expansion in global biodiesel production. The second regime runs from July 2000 to May 2004. In this period, trans fat labeling was being considered in many countries and biodiesel production was in its early stages. The third regime runs from June 2004 to the end of the sample period. We find it telling that no structural breaks occur in oilseed price relatives from 2005 onwards—the primary era of biofuels expansion, and after trans-fat labeling requirements had entered U.S. law. If the cointegration analysis in the next section suggests oilseed prices moved together in long-run equilibrium during this period, we believe it appropriate to coin this period the "modern regulatory era" for the purposes of the impact analysis.

5. COINTEGRATION ANALYSIS

Having identified three regimes in oilseed price relatives, which align with international regulatory changes affecting oilseeds, we now evaluate the stationarity and co-integration properties of feedstock prices in each of the three regimes. Successful identification of the policy impacts requires the existence of a mean-stable relationship in oilseed price relationships prior to and after trans-fat labeling mandates and international biodiesel expansion (Carter & Smith, 2007). Two log price series are co-integrated with a co-integrating vector (1,-1) if y_t is stationary. We use the augmented Dickey-Fuller (ADF) test (Dickey & Fuller, 1979) to determine if unit roots are present in our oilseed price relatives under the three regimes. As above, lag length for each unit root test is determined according to the HQIC.

Results for each of these tests are reported in Table 3. In Regime 1, we reject a unit root in the relative price for sunseed-soy at the 5% level. We conclude log sunseed and soy oil prices experienced a mean-stable relationship—and are therefore co-integrated with cointegrating vector (1,-1)—between January 1995 and June 2000. Similarly, the ADF test also rejects non-stationarity in the canola-soy price relative at the 10% level. In contrast, the ADF test suggests the palm-soy price relative was non-stationary (i.e., non-mean-stable) in this period.

Table 3: Multi-Regime Price Relative Co-Integration Tests

	Regime 1	Regime 2	Regime 3
Price Relative	**(Jan-95–Jun-00)**	**(Jul-00–May-04)**	**(Jun-04–End)**
Sunseed-Soy	-2.88**	-2.12	-4.27***
	(-2.60)	(-2.60)	(-2.57)
Canola-Soy	-2.67*	-1.80	-3.53***
	(-2.60)	(-2.60)	(-2.57)
Palm-Soy	-2.07	-1.93	-3.61***
	(-2.60)	(2.02)	(-2.57)

***p<0.01, **p<0.05, *p<0.1

10% Critical value in parentheses.

Lag specification determined according to HQIC.

Co-integration tests for Regime 2 (July 2000–May 2004) in Table 3 fail to reject unit root processes for all price relative relationships. In other words, we observe no mean-stable relationships in oilseed prices in this period. This is likely the result of a combination of two factors. First, in the early stages of trans fat labeling changes and biodiesel production, oilseed price relationships were likely undergoing a long-run adjustment process that would not occur instantly (illustrated in Figure 5). Additionally, the test is likely of low statistical power because Regimes 2 includes less than four years of data.

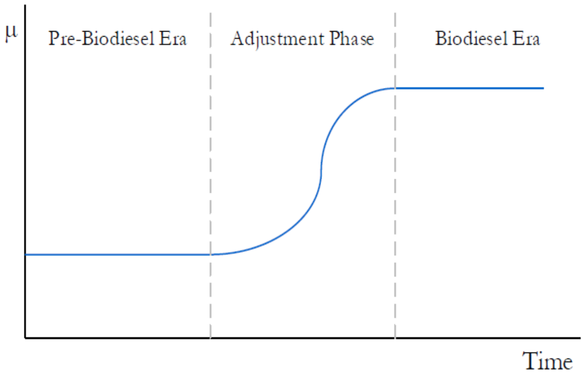


Figure 5: Illustration of Cointegration Regimes

Results for Regime 3 in Table 3 tell a very different story from that for Regime 2. ADF tests suggest at the 1% level that the sunseed-soy, canola-soy, and palm-soy price relatives are mean-stable from June 2004 to the end of the sample period (November 2019). These findings suggest that any short-term adjustments experienced during Regime 2 were resolved by June 2004, and prices had reached a new long-run co-integrating relationship and therefore a shift in the mean price differentials.

The co-integration results for Regimes 1 through 3 are used to conduct the price impact analysis in Section 6. We use the cointegration results to define the set of prices to include in the price impact analysis and the "benchmark" and "impact" periods with which to estimate the price impact. Because our results indicate that palm oil was not integrated with other international oilseed prices until Regime 3, we exclude it from the price impact analysis. For the purposes of the impact analysis, we define Regime 1 as the "pre-policy" period against which to measure the impacts of trans fat labeling mandates and biodiesel expansion. To be conservative, we interpret Regime 2 in which we reject a mean-stable relationship for all price relatives as an "adjustment" period as producers and industries adapted to trans-fat labeling and biofuel production. Thus, we do not rely on price relationships in this period for the purposes of the impact analysis. Because we believe price relationships in Regime 3 likely represent an accurate and stable representation of the long-run co-integrating processes in the modern regulatory era, we measure the impacts of trans fat labeling and biodiesel expansion on relative oilseed prices by comparing actual prices in this period with those predicted by the historical relationship measured under Regime 1.

6. PRICE IMPACT ANALYSIS

In this section, we estimate the structural change in sunseed-soy and canola-soy price relatives associated with trans-fat labeling mandates and the expansion in biodiesel production. For each price relative, we estimate the following model:

$$y_t = \alpha_1 + \alpha_2 \mathrm{R2}_t + \alpha_3 \mathrm{R3}_t + \mathbf{X}_t\beta + \epsilon_t \ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where y_t is the price relative for either sunseed or canola oil, expressed as in equation 1, $\boldsymbol{X}_t\beta$ is a covariates model, and treatment variables $R2_t$ and $R3_t$ are indicators that take values one during Regimes 2 and 3, respectively, and are otherwise equal to zero. As suggested by the HQIC, we include in $\boldsymbol{X}_t$ two lags of the dependent variable for the sunseed-soy model and one lag of the dependent variable in the canola-soy model.

Table 4 reports the results of estimating Equation (3). Referring first to Column (1), we see that the Regime 3 treatment effect is positive and statistically significant at 1%, indicating a short-run effect of trans fat labeling and biodiesel expansion was to increase the sunseed-soy price relative by 6.8%

1 Similarly, referring to Column (2), we see that the Regime 3 treatment effect is also positive and statistically significant at 1%, indicating a 2.1% short-run increase in the canola-soy price relative.

We note that the treatment effects on $R3$ in Table 4 are short-run estimates that under-estimate the long-run

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[1] This effect is short-run because it does not take account of the dynamic adjustment (lagged dependent variables).

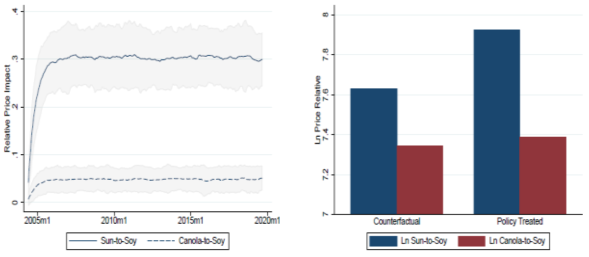
effect generated by the dynamic adjustment that occurs over time. To estimate these long-run effects, we compute the unconditional means of the relative price with and without the policy treatment effects. Panel (a) of Figure 6 shows the dynamic adjustment in relative prices to the $R3$ treatment. Note that we derive confidence intervals for this dynamic adjustment using a Bayesian bootstrapping procedure, where we make random draws from the posterior distribution of the $R3$ short-term treatment effect reported in Table 4. Panel (b) of Figure 6 reports the unconditional means of relative prices with and without the policy treatment effects. These results suggest that the modern regulatory regime has generated a 27.86% long-term increase in the sunseed price premium over soy. Similarly, the policy treatment has generated a 4.2% long-term increase in the canola price premium over soy. In Appendices A and B, we assess the sensitivity of these results to alternative specifications of the relative price and to expansion of the price impact model to multi-variate analysis. These analyses generally support the main results; however, we note that the statistical significance of the canola-soy price impact is sensitive to specification.[2]

Table 3: Multi-Regime Price Relative Co-Integration Tests

Variables	(1) Sunseed-Soy	(2) Canola-Soy
Dep Var (L1)	1.014***	0.862***
	(0.113)	(0.064)
Dep Var (L2)	-0.149	
	(0.097)	
Regime 2	0.027***	0.014
	(0.010)	(0.009)
Regime 3	0.068***	0.021***
	(0.015)	(0.007)
Constant	0.006	0.008
	(0.004)	(0.006)
Observations	294	295
R-Squared	0.94	0.80

Robust standard errors in parentheses

***p<0.01, **p<0.05, *p<0.1



(a) Dynamic Relative Price Adjustment (b) Relative Price Comparisons

Figure 6: Policy Impact Summary

7. CONCLUSION

This paper uses econometric modeling to assess how relative price relationships in the international oilseed system, including those for soy, canola, palm, and sunflower oil, have changed over time. We find that structural change in the international oilseed price system aligns strongly with the timing of mandates on the labeling of trans fats and international policy efforts to promote biodiesel production. Our results indicate that—following an initial adjustment period—price premiums for sunseed oil increased by 28% relative to soy oil. This is consistent with the demand for sunflower oil shifting upwards more rapidly than the demand for soy oil, primarily due to the substitution away from soy oil for human consumption due to the presence of trans fats. This result was found to be quite robust to alternative model specifications.

We also estimate a 4% increase in the premium for canola oil relative to soy oil. This suggests that the demand for canola oil increased relatively faster than the demand for soy, putting upward pressure on the price premium. However, the multi-variate analysis in Appendix B suggests this result is sensitive to model specification and requires further analysis. Finally, we find that—prior to the boom in biodiesel production and trans-fat labeling requirements—no long-run co-integrating relationship existed between palm oil prices and those for other oilseeds. However, in the wake of these changes, palm oil prices are now strongly co-integrated with other oilseed prices. This suggests that palm oil is now a more competitive product and viewed more directly as a substitute for sunflower, canola, and soy oil. A question for future research is whether this co-integrating relationship will persist going forward considering the 2019 prohibition of palm oil in EU blending requirements.

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[2] One potential explanation of this is the use of Rotterdam canola prices, as opposed to, say, Canadian canola prices. It is possible that transportation prices for overseas passage increases the noise in this relationship.

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APPENDIX A: ALTERNATIVE RELATIVE PRICE SPECIFICATIONS

In this Appendix, we explore whether the results presented in the main body of this manuscript are robust to alternative specifications of the price relatives. As specified in equation (1), the construction of relative prices used for the baseline analyses is the natural log of the price ratio, where the numerator price is alternatively specified as sunseed oil, canola oil, or palm oil, and the denominator price is soy oil. Here, we consider two alternative constructions of relative prices: (1) we re-do the analysis using the difference in price levels: $P_{i,t} - P_{soy,t}$, for $i \in \{\text{sunseed}, \text{canola}, \text{palm}\}$, and (2) we consider simple price ratios (without natural logarithmic transformation).

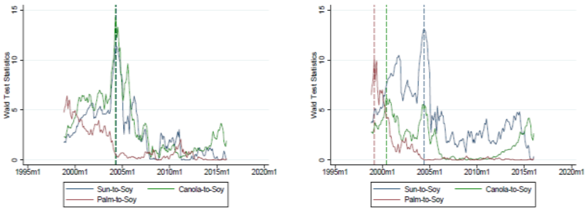
Figure A1 reports the supremum Wald statistics generated by re-running the structural break analysis in equation (2). Note for simplicity, we re-run this analysis including a single lagged dependent variable for each price series and search for a single break in the period Jan-1995–Nov-2019. Results of this analysis are qualitatively like the structural break results reported in Table 2 in the main body of the manuscript.

Panel (a) of Figure A1 reports supermum Wald statistics for candidate breakpoints under the price difference specification. According to this analysis, the sunseed-soy price difference indicates a structural break at June-20004 (statistically significant at the 5% level). This is identical to the first break identified in the sunseed-soy price relative in Table 2. Similarly, the canola-soy price difference indicates a structural break just one month earlier, in May-2004 (statistically significant at 1% level). As with the baseline analysis, we do not identify a statistically significant break in the palm-soy price difference over the sample period.

Structural break results under the price ratio specification in panel (b) of Figure A1 are also generally consistent with the baseline model. The sunseed-soy analysis indicates a break at July-2004 (statistically significant at the 1% level), just one month after the first sunseed-soy break in the baseline analysis. The canola-soy analysis indicates a break at July-2000 (statistically significant at the 10% level), which is identical to the first break found in the canola-soy price relative in the baseline analysis.

Interestingly, this specification also yields a break for the palm-soy equation in April-1999 (statistically significant at the 5% level). However, as discussed below, because we fail to identify a co-integrating relationship between palm and soy oil, we exclude it from the price impact analysis.

Figure A1: Structural Break Results—Model Robustness



(a) Price Differences (b) Price Ratios

Table A1 reports the p-value results for the multi-regime cointegration tests for the alternative relative price specifications. We evaluate cointegration over the three regimes identified in the main body of the manuscript (Jan-95–Jun-00; Jul-00–May-04; and Jun-04–End), using a single-lag specification. Findings are like those for our primary model in Table 3.

Table A1: Multi-Regime Co-Integration Tests—Model Robustness

Specification	Series	Regime 1	Regime 2	Regime 3
		p values		
Differences				
	Sunseed-Soy	0.02	0.44	0.00
	Canola-Soy	0.07	0.18	0.00
	Palm-Soy	0.35	0.89	0.00
Ratios				
	Sunseed-Soy	0.05	0.36	0.00
	Canola-Soy	0.17	0.13	0.01
	Palm-Soy	0.44	0.28	0.01

We turn first to the co-integration results in the price difference specification in Table A1. Results are effectively unchanged from the primary specification. In Regime 1, we reject non-stationarity for the sunseed-soy price difference (at the 5% level) and the canola-soy price difference (at the 10% level); however, we fail to reject non-stationarity for the palm-soy price. In Regime 2, we fail to reject unit root processes for all price differences, indicating a period of adjustment or a low power due to sample size limits. In Regime 3, all prices are co-integrated at the 1% level.

We repeat the price impact estimation analysis for the sunseed-soy and canola-soy price relatives under the price differences and price ratios constructions as in equation (3), using a single-lag structure for all models. Table A2 reports price impact results. As shown in the Table, the coefficient on $R3$ is positive and statistically significant in all specifications, indicating that biodiesel expansion increased sunseed-soy and canola-soy relative prices.

Table A2: Relative Price Impact Model—Robustness

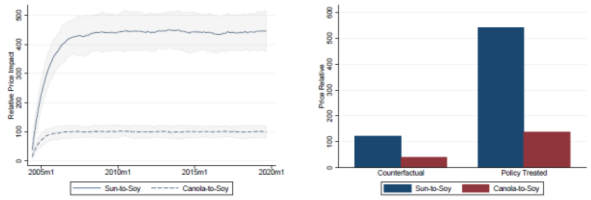
Variables	(1) Sunseed-Soy Diff.	(2) Canola-Soy Diff.	(3) Sunseed-Soy Ratio	(4) Canola-Soy Ratio
Dep Var (L1)	0.916***	0.854***	0.864***	0.831***
	(0.026)	(0.0529)	(0.0518)	(0.0935)
Regime 2	9.301*	4.921	0.0339**	00.018
	(5.143)	(3.916)	(0.0169)	(0.0117)
Regime 3	46.66***	19.64***	0.0959***	0.0281**
	(13.16)	(5.743)	(0.0304)	(0.0114)
Constant	1.666	4.826*	0.142***	0.180*
	(2.049)	(2.621)	(0.0542)	(0.101)
Observations	296	296	296	296
R-squared	0.956	0.858	0.905	0.757

Robust standard errors in parentheses.
***p<0.01, **p<0.05, *p<0.1

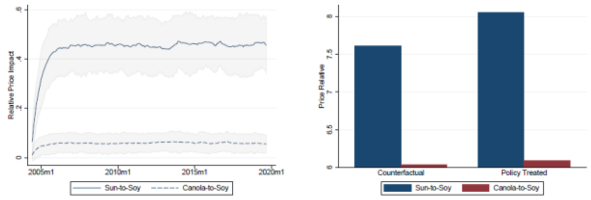
Using the coefficients in Table A2, we generate long-run price impact estimates (and corresponding confidence intervals) as in our primary specification in Section 6. The results—reported in Figure A2—are consistent with those generated by our primary model. Referring to the price difference results in panels (a) and (b) of Figure A2, we see that the modern regulatory era has increased the difference in prices by approximately $430 per metric ton. The long-run impact for the canola-soy price difference is approximately $95 per metric ton. According to the price ratio specifications, shown in panels (c) and (d) of Figure A2, each metric ton of sunseed oil trades for an additional 0.45 metric tons of soy oil. Similarly, each metric ton of canola oil trades for an additional 0.06 metric tons of soy oil.

APPENDIX B: MULTIVARIATE PRICE IMPACT ANALYSIS

In this Appendix, we construct a multivariate price impact model comprising the co-integrated oilseed system to assess the sensitivity of our univariate results. Strictly interpreted, the cointegration results in Table 3 imply two long-run co-integrating relationships among sunseed, canola, and soy oil prices of order CI(1,0,-1) and CI(0,1,-1), respectively. We construct a vector error correction (VEC) model for the set of co-integrated oilseed prices to estimate the pre-policy system equilibrium relationship. We then compare actual prices in the wake of trans fat labeling and biofuels legislation with the counterfactual prices implied by projecting the pre-policy co-integrating relationship to assess the impact of regulatory reform on oilseed price relatives.



(a) Dynamic Price Adjustment (Differences) (b) Price Comparisons (Differences)



(c) Dynamic Price Adjustment (Ratios) (d) Price Comparisons (Ratios)

Figure A2: Policy Impact Summary—Model Robustness

Lag length for the VEC model is specified prescribed by the Hannan-Quinn Information Criterion. Thus, we estimate the following VEC model over the pre-policy period from January 1995 to June 2000 (Engle and Granger, 1987):

$$(4)\quad \Delta P_t^{sun} = \alpha^{sun} v_{t-1} + b^{sun} z_{t-1} + e_t^{sun}$$

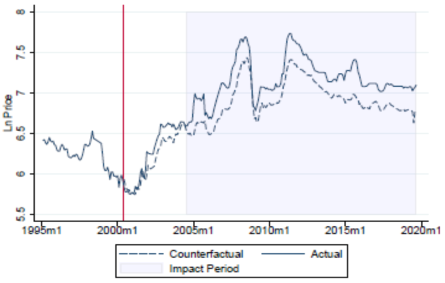
$$(5)\quad \Delta P_t^{can} = \alpha^{can} v_{t-1} + b^{can} z_{t-1} + e_t^{can}$$

$$(6)\quad \Delta P_t^{soy} = \alpha^{soy} v_{t-1} + b^{soy} z_{t-1} + e_t^{soy}$$

where $\Delta P_t^k;\ k \in \{sun, can, soy\}$ is the difference between the de-seasonalized price at time t and t-1 for sunseed, canola, and soy oil, respectively? Function $v_{t-1} = P_{t-1}^{sun} + \lambda_v P_{t-1}^{can} - P_{t-1}^{soy}$ and $z_{t-1} = \lambda_z P_{t-1}^{sun} + P_{t-1}^{can} - P_{t-1}^{soy}$ are the error correction terms. To match the co-integrating relationships implied by the cointegration tests, we constrain the coefficients on P_{t-1}^{sun} and P_{t-1}^{soy} to be 1 and -1 in term v_{t-1} and the coefficients on P_{t-1}^{can} and P_{t-1}^{soy} to be 1 and -1 in term z_{t-1}. We then conduct post-estimation tests to confirm that coefficients λ_v and λ_z are zero. Interpreted in words, our VEC specification allows oilseed prices to move together according to a long-run equilibrium. However, in each week, each price experiences an exogenous shock.

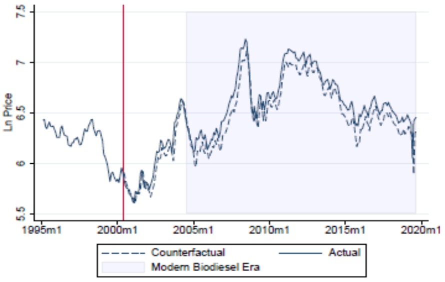
After estimating the VEC model, we fail to reject the constraints on error correction terms v_{t-1} and z_{t-1}. We also fail to reject that coefficient λ_v and λ_z in the error correction equations are zero. Coefficient estimates describing the historical long-run equilibrium relationships among international oilseed prices are reported in Table B1. Referring first to estimates for sunseed prices in Column (1) of Table B1, we see that the error correction term α is negative and statistically significant at the 1% level. This suggests that monthly sunseed oil prices adjust downward to correct short-run deviations from the long-run equilibrium. The estimated value of the error correction parameter $\alpha = -0.468$ indicates that (on average) the monthly sunseed oil price adjusted to correct 46.8% of any deviation from the long-run sunseed-soy price equilibrium. Estimated error correction parameters for canola and soy (Columns 2 and 3 of Table B1) are smaller in magnitude: 0.197 for canola and 0.170 for soy and are statistically insignificant at conventional levels. Taken together, these results indicate that it is primarily sunseed prices that adjust to correct deviations from long-run equilibrium.

Figure B1: Actual and Counterfactual Oilseed Prices



(a) Sunseed Prices

(b) Canola Prices



(c) Soy Oil Prices

Table B1: Pre-Break Error-Correction Mechanism Estimates

Variables	**(1)** ΔSun_t	**(2)** ΔSoy_t	**(3)** ΔCan_t
μ_t	0.042		0.070
	(0.006)		(0.019)
α_t	0.468	0.197	0.170
	(0.149)	(0.136)	(0.143)
b_t	-0.129	-0.081	0.073
	(0.114)	(0.132)	(0.138)
Constant	0.002	-0.005	-0.001
	(0.009)	(0.008)	(0.009)
RMSE	0.049	0.046	0.048
Log Likelihood		379.52	0.905
Autocorrelation		7.585	
(p-value)		(0.576)	

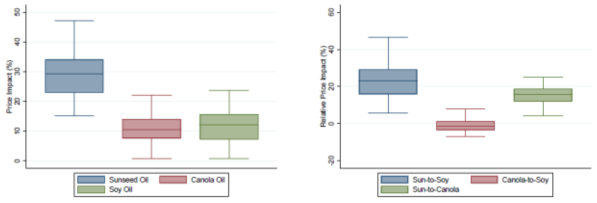
Note: Sample period is Jan-1995 to June-2000.
Standard errors are in parentheses.
Autocorrelation test is Lagrange-multiplier test for first-order serial correlation.

We use the predicted dynamic equilibrium relationships in Table B1 to generate counterfactual price series for sunseed, canola, and soy oil from July 2000 through the end of the sample had regulatory reform not occurred. Figure B1 plots actual versus counterfactual oilseed prices specified in natural logarithmic form. Panel (a) of Figure B1 shows results for sunseed oil prices. Panels (b) and (c), respectively, show results for canola and soy oil prices.

In each panel of Figure B1, the shaded region represents the modern regulatory era by which time oilseed price relationships had achieved stability following a period of adjustment from July 2000 to May 2004. We estimate impacts by comparing actual versus counterfactual prices and corresponding price relatives during this period. Comparing these price relationships in each panel of Figure B1, trans-fat labeling and biodiesel expansion increased absolute prices for all oilseeds. The impact appears to be largest for sunseed oil, and the impacts for canola and soy appear to be like one another.

Figure B2 summarizes the price impact estimates, expressed as a percent increase relative to the counterfactual price. Panel (a) of Figure B2 reports absolute price impact results. Panel (b) reports implicit results for price relatives. In each panel, the horizontal line within a given box represents the median estimated policy impact. The upper and lower limits of the box, respectively, represent the 75th and 25th percentile. The outer whiskers represent the 95th and 5th percentiles.

As shown in Panel (a) of Figure B2, the multi-variate analysis suggests that trans-fat labeling and biodiesel expansion has increased absolute prices for sunseed oil by approximately 25%, relative to a world in which these policies did not exist. Absolute prices for canola oil have increased by approximately 9\% and soy oil prices have increased by approximately 10% considering biofuels expansion. These absolute price impacts imply the relative price impacts shown in Panel (b) of Figure B2. The multivariate analysis suggests trans-fat labeling and biofuels promotion has increased the sunseed-soy and the sunseed-canola price relative by approximately 15%. On the other hand, the multivariate analysis yields no statistically significant impact of these policies on the canola-soy relative price.



(a) Price Levels

(b) Price Relatives

Figure B2: Price Impact Summary (Multivariate Model)

Note: In each panel, the horizontal line within the box represents the median estimated policy impact. The upper and lower limits of the box, respectively, represent the 75th and 25th percentile. The outer whiskers represent the 95th and 5th percentiles.