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Unfair Trade in the Circular Economy? Price Dynamics in Chinese and European waste to biofuel industries

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Amid ongoing concerns about the alleged dumping of Chinese waste-based biodiesel, this paper investigates the price formation dynamics of Used Cooking Oil (UCO) and its derived biodiesel, Used Cooking Oil Methyl Ester (UCOME), between China and Europe. Using a Vector Error Correction Model (VECM) and Granger causality tests, we examine both long-run equilibrium relationships and short-run price interactions. Our results show that European biodiesel prices lead both UCO and UCOME prices across regions, confirming Europe's role as the primary price setter. However, we identify persistent periods during which Chinese biodiesel prices fall significantly below their long-run equilibrium, suggesting strategic pricing. An extended VECM reveals that during these episodes, price correction mechanisms break down, indicating a temporary decoupling of Chinese prices from European market signals. This pattern points to potential distortions linked to export strategies or state intervention. These findings have important policy implications. They provide robust empirical evidence of sustained price misalignments that may justify anti-dumping duties or other trade measures. More broadly, the study highlights the need to integrate strategic trade considerations into European biofuel policy to protect domestic industry and uphold the environmental integrity of the circular economy.

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KEYWORDS

Used cooking oil | Biofuels | Circular economy | Price integration

Executive summary

This study investigates the pricing dynamics of waste-based biodiesel and its feedstock (Used Cooking Oil, or UCO) between China and Europe. This trade has grown rapidly following EU decarbonization policies that introduced blending mandates. Using high-frequency price data and an econometric time-series, we examine to which extent biodiesel markets in both regions are integrated. Our goal is to assess the credibility of concerns about strategic pricing or trade distortions, which have triggered recent EU anti-dumping investigations and duties on Chinese biodiesel imports.

Key findings

- Strong long-run price links exist between UCO-based biodiesel and UCO prices in China and Europe, indicating that markets are economically integrated.
- Persistent price decoupling episodes, where Chinese biodiesel is significantly cheaper than its European counterpart.
- During these episodes, Chinese biodiesel prices stop reacting to European market signals, implying possible strategic pricing or policy interference.

Policy implications

1. Tighten sustainability verification: Existing voluntary certification schemes have proven vulnerable to fraud and poor traceability. Cross-border verification and digital traceability tools should be prioritized to ensure UCO origins are genuine and sustainable.
2. Strengthen domestic capacity: Europe’s reliance on imported biodiesel risks repeating past industrial policy failures (e.g., solar panels). Targeted support is needed to boost local UCO collection and UCOME production capacity.
3. Enhance trade oversight: Persistent price distortions justify anti-dumping actions, but a broader response is needed. This includes international dialogue and ongoing monitoring of Chinese pricing behavior to ensure fair competition and policy consistency.

1. Introduction

Biofuels represent a credible option to reduce carbon emissions in sectors such as heavy-duty transport, aviation, and shipping which rely on energy-dense liquid hydrocarbons (Bardon and Massol, 2025; Chiaramonti et al., 2021; Issa et al., 2022). As their cost remains higher than that of fossil fuels, the expansion of biofuel production and consumption depends on the implementation of dedicated support policies. Over the last two decades, numerous policy instruments, such as blending mandates, tax exemptions, investment incentives, and research funding, have been introduced to scale up biofuels use (Ebadian et al., 2020). In Europe, while the main driver of these policies is the ambition to lower carbon emissions, other underlying public policy goals are also invoked. At the feedstock level, these include support for domestic agriculture and the promotion of sustainable practices; at the processing stage, they include the development of a domestic biofuel industry (Cadillo-Benalcazar et al., 2021). Strategic trade considerations also play a role in justifying support for this infant industry, which is expected to generate future export opportunities in low-carbon fuels and processing technologies. Finally, energy security concerns are prominent in policy narratives, as a biofuel sector based on domestic feedstock is seen as a way to reduce reliance on imported fossil fuels (Lundberg et al., 2023).

Over the past decade, European policies have increasingly promoted the development of advanced (i.e., second-generation) biofuels, derived from feedstocks such as waste and agricultural residues (Cadillo-Benalcazar et al., 2021). This strategy supports the emergence of a circular bioeconomy by repurposing waste into valuable resources.[1] In particular, policy efforts have favored the conversion of used cooking oil (UCO) into UCOME (Used Cooking Oil Methyl Ester), a type of biodiesel. Although initially conceived as a domestic industry, the policy-driven appetite for UCOME in the European market has triggered a globalization of the supply chain. The impact was first felt in the UCO market, as the search for affordable feedstock led to rising imports of waste edible oil from densely populated Asian countries with a comparative advantage in UCO collection. More recently, this globalization has extended to the final product, with the rapid emergence of an export-oriented biodiesel industry in China, a country where UCOME is not consumed domestically. In Europe, the influx of Chinese biodiesel has undermined domestic producers,[2] disrupted the processing of locally

[1] These policies were conceived in response to concerns raised about first-generation biofuels (i.e., processed from food crops), particularly regarding food security (Hasegawa et al., 2018), and land-use changes (ILUC) and deforestation (Banse et al., 2008).

[2] Source: https://ebb-eu.org/news/eu-biodiesel-industry-may-not-survive-2024-if-left-unprotected-from-chinese-unfair-imports/

collected UCO, and prompted suspicions of dumping and fraud involving prohibited feedstocks. In response, the European Commission launched a formal investigation in December 2023.[3] This led to the imposition of provisional anti-dumping duties in August 2024, recently confirmed by EU Member States.[4] In parallel, the United Kingdom initiated its own anti-dumping investigation in June 2024, with a decision expected in the first half of 2025.

The purpose of this research note is to contribute to ongoing discussions surrounding the alleged dumping of Chinese biodiesel by examining the price formation dynamics of UCO-based biodiesel and its feedstock in Europe and China. To empirically investigate the spatial and vertical interlinkages among these prices, we adopt a time-series approach based on a Vector Error Correction Model (VECM), estimated using daily price data for UCOME and UCO across both regions. By construction, this method captures the dynamic interdependencies among the price series and is well suited to analyzing both long-run equilibrium relationships and short-run adjustments.

Our estimation results provide strong evidence of market integration, with biodiesel and feedstock prices co-moving across regions. However, we also observe persistent price deviations, which suggest potential distortions in the Chinese biodiesel market. Granger causality tests further reveal that during these periods, Chinese biodiesel prices become less responsive to European market signals—raising concerns about possible strategic pricing or policy intervention.

From a methodological perspective, this work builds on a well-established empirical literature examining price formation and spatial price integration in commodity markets (Goodwin and Schroeder, 1991; Amoutzias et al., 2017; Dukhanina and Massol, 2018). In the context of biofuels, this literature has explored the spatial and vertical linkages between the prices of first-generation biofuels and the food crops used to produce them (e.g., Peri and Baldi, 2013; Paris, 2018; Cheng, 2023; Declerck, 2023). To the best of our knowledge, however, such interactions have not yet been examined for advanced, waste-based biofuels.

This paper helps fill that gap by contributing to policy discussions on trade regulation, sustainability compliance, and the risk of price manipulation in global biofuel markets. A related strand of research has also focused on the design of national biofuel policies, specifically on the effects of blending mandates on biofuel consumption, production, emissions, and fuel prices (Ebadian et al., 2020; Lundberg et al., 2023).

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[3] *Source: https://policy.trade.ec.europa.eu/news/european-commission-examine-allegations-unfairly-traded-biodiesel-china-2023-12-20_en*

[4] *Source : https://policy.trade.ec.europa.eu/news/commission-protects-eu-biodiesel-industry-dumped-chinese-imports-2025-02-11_en*

The rest of the paper is structured as follows: Section 2 provides a concise overview of the European biofuel policy landscape and the emerging international trade patterns of both UCO-based biodiesel and UCO. Section 3 describes the data and the econometric methodology. Section 4 presents the empirical findings, and the final section offers concluding remarks and policy implications.

2. Background

2.1 Policy landscape for biofuels and advanced biofuels in Europe

First introduced in 2009 and subsequently revised and expanded, the European Renewable Energy Directive (RED) serves as the primary regulatory framework for supporting the scale-up of biofuels and ensuring their sustainability. Table 1 outlines the evolution of the EU regulations and corresponding targets over time.

Table 1. Evolution of the European Renewable Energy Directive (RED)

RED-I (2009)	ILUC (2015)	RED-II (2018)	RED-III (2023)
20% of the EU's total energy consumption from renewables by 2020.	Amended RED-I: Limits conventional biofuels to <7% of transport energy in 2020.	Increased renewable energy target to 32% by 2030, with 14% of transport energy from renewables.	Strengthened sustainability requirements, including a 65% GHG emissions reduction for biodiesel from refineries established after 2021.
Promoted first-generation biofuels derived from food crops.	Encouraged the shift toward advanced biofuels from waste and residues.	Advanced biofuels (Annex IX Part A): >0.2% in 2022; >1% in 2025; >3.5% by 2030.	Crop-based biofuels capped at 2020 levels, max 7% blending rate in transport fuels.
Concerns over food security and sustainability led to policy shifts.	Harmonization of feedstocks for biofuels eligible for double counting (Annex IX).	Biofuels and biogas from UCO and animal fat (Annex IX Part B): <1.7% of transport fuels (cap).	Double-counting mechanism for biodiesel from waste and residues (Annex IX-B).
		High ILUC biofuels: 0% in 2030.	Increased reliance on biodiesel imports, raising concerns over traceability and fraudulent certification.

The first iteration of the Renewable Energy Directive (RED-I) established a binding target for renewable energy to account for 20% of the EU's total energy consumption by 2020. RED-I promoted the development of first-generation biofuels derived from food crops. However, mounting concerns regarding their implications for food security (Hasegawa et al., 2018) and environmental sustainability (Banse et al., 2008) prompted a gradual shift in EU policy priorities, reflected in the adoption of the Indirect Land Use Change (ILUC) directive in 2015, which aimed to support the deployment of advanced biofuels produced from waste and residual feedstocks such as animal fats and used cooking oil (Cadillo-Benalcazar et al., 2021).

Recognizing the need for stronger climate action, RED-II (2018) increased the renewable energy target to 32% by 2030, mandating that 14% of transport energy must be derived from renewables.

The latest revision, RED-III (2023),[5] further strengthens sustainability requirements. Biodiesel must now achieve a minimum 65% reduction in greenhouse gas (GHG) emissions compared to fossil fuels, a requirement applicable to all refineries established after 2021.[6] To prevent competition with food supply, crop-based biofuels remain capped at 2020 levels, with a maximum blending rate of 7% in transport fuels. Furthermore, biodiesel produced from waste and residues, as specified in Annex IX-B of RED III, benefits from a double-counting mechanism, meaning it is credited twice toward meeting renewable energy targets.

2.2 Certification as a cornerstone of the EU biofuel policy

To be classified as sustainable under EU regulations, waste-based biodiesel must comply with strict environmental standards. Notably, it must not originate from land that was deforested after 2007, in accordance with Direct Land Use Change and Indirect Land Use Change rules. Compliance is ensured through voluntary certification audits conducted by EU-endorsed organizations such as the International Sustainability & Carbon Certification (ISCC) and the Roundtable for Sustainable Biofuels (RSB). These certification bodies verify that biodiesel producers adhere to traceability, environmental sustainability, and quality assurance requirements (see Figure 1 for an example of a delivered certificate).

Figure 1. Example of a certification delivered to a biodiesel producer in the Netherlands, the raw material here is specified: UCO and animal fats (Source: ISCC Certificates Database)

✓	EU-ISCC-Cert-DE129-35382982	Sunoil Bio Fuels B.V., Emmen, Netherlands	PO, CP, BP, TRS	Used cooking oil (UCO) entirely of veg. origin, Animal fats from rendering (category 3), Animal by-products (category 3) ...		Biodiesel	2024-09-22	2025-09-21		TÜV NORD CERT GmbH, Essen, DE			

2.3 Turning waste edible oil and its derivatives into globalized commodities

The EU's voluntarists push for advanced biofuels, through increasingly stringent mandates, has significantly expanded the derived demand for UCO without securing corresponding domestic supply capacity (see Lundberg et al., 2023, for a detailed analysis of the impact of these blending mandates on biofuels development).

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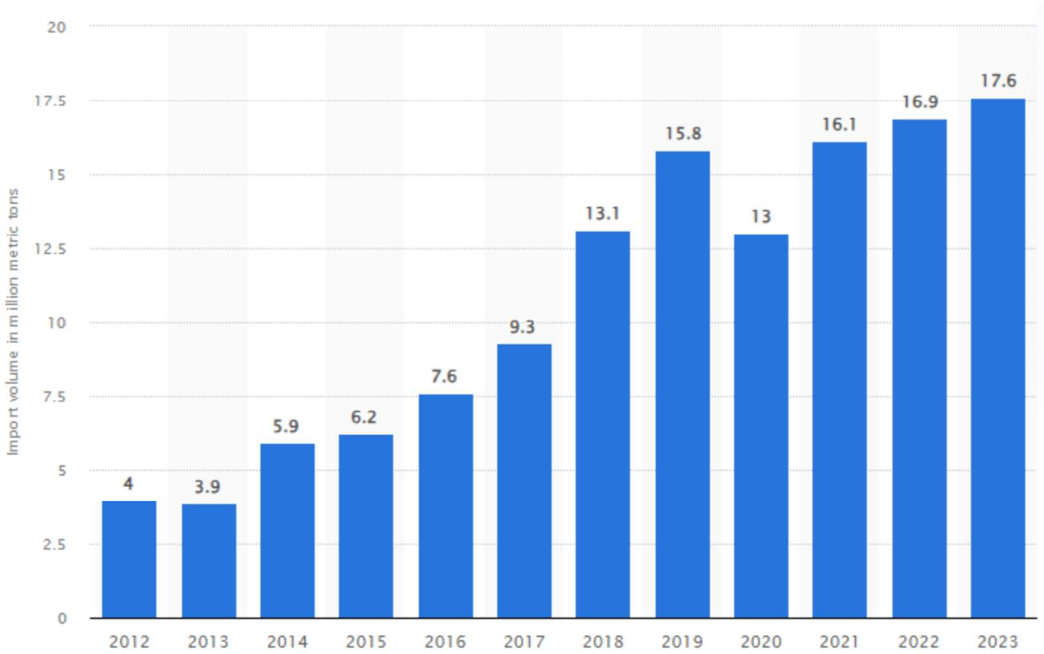
[5] *Renewable Energy Directive III; October 2023 : Renewable Energy Directive*

[6] *RED III Trilogue deal maintains role of sustainable biodiesel, April 2023 : European Biodiesel Board (EBB)*

Compared to Europe, Asian countries benefit from lower wages and higher population density which gives them a comparative advantage in collecting UCO. Over the years, UCO trade has flourished, and Europe has become increasingly reliant on Asian imports, particularly from China. In 2022, EU imports of UCO reached 1.65 million tons (source: Eurostat) of which 43% emanated from China (see Figure 2).

In an attempt to capture a larger proportion of that international value chain, the Chinese government has recently promoted the development of a waste-based biofuel processing sector involving large-scale, export-oriented plants. Following this development, China now favors the domestic processing of UCO and the export of UCO-based biofuels to Europe. These exports have soared, surpassing those of unprocessed feedstock. As an illustration, Chinese biodiesel exports have surged from less than 100 kilotons in the early 2010s to over 1.5 million tons in 2023.

Figure 2. Imports of Biodiesel in Europe since 2012 (Source: EuroStats/Statistica).



2.4 *Unfair and fraudulent conduct in the global trade of UCO-based biofuels?*

The scale of China's government-backed expansion, combined with the opaque nature of its waste collection and processing activities, raises concerns about possible trade distortions driven by neo-mercantilist industrial policies.

These concerns are further exacerbated by suspicions of non-compliance with EU sustainability standards. The lack of robust traceability is believed to enable fraudulent practices, especially in light of reports of fake certification[7] and the mislabeling of unauthorized feedstocks.[8] From a technical standpoint, it is extremely difficult to determine whether a biofuel has been produced from UCO or from unused virgin oil, due to their near-identical chemical and physical properties. Adulteration – such as blending with biofuels produced from unsustainable feedstocks such as palm oil or other non-compliant feedstocks mislabeled as UCO is similarly hard to detect.

These challenges are further intensified by broader issues surrounding China's domestic cooking oil market. A recent investigation reported instances where cooking oil was transported in containers previously used for fuels, without proper cleaning.[9] The controversy, which implicated a major state-owned enterprise, underscores the risks associated with weak oversight and lax quality control in Chinese supply chains, raising doubts about the traceability and compliance of Chinese UCO and UCOME exports.

Taken together, these elements highlight the limitations of the EU's current voluntary certification schemes. The market-driven, paper-based nature of these systems is criticized for encouraging a race to the bottom, marked by weak auditing of upstream suppliers and insufficient traceability across complex supply chains (T&E, 2024).

In the EU, the European Biodiesel Board (EBB) has raised concerns about the authenticity of UCO used in biodiesel production,[10] calling for stricter verification mechanisms and anti-dumping measures to protect European producers from unfair competition. In response, the European Commission launched an investigation in 2024 into whether low-priced biodiesel imports from China have led to market disruptions, potentially justifying trade restrictions or countervailing duties.[11] Subsequently, in July 2024, the Commission imposed a provisional tariffs on Chinese biofuel imports,[12] which were made definitive following approval by EU member states in January 2025.[13] However, these tariffs do not yet apply to the entire sector, as Sustainable Aviation Fuels (SAFs) remain exempt for now.

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[7] *Enquête sur des millions d'euros de fraude au biodiesel, July 2023 : L'Echo*

[8] *Producers braced for glut of palm oil after Indonesia curbs exports, February 2025 : Financial Times*

[9] *Fury erupts in China over a food-safety scandal, July 2024 : The Economist*

[10] *EU To investigate Chinese Biodiesel dumping allegations, December 2023 : MarketScreener*

[11] *EU Begins probe into biodiesel imports from China, January 2024; Biofuels International Magazine*

[12] *Are tariffs enough to save Europe's biofuels sector?, August 2024; Financial Times*

[13] *Commission protects EU biodiesel industry from dumped Chinese imports, February 2025; European Commission*

3. Data and Methodology

3.1 Data

Our dataset consists of 581 daily price observations (weekdays) for UCO and UCOME delivered in Europe and China, obtained from Argus, a widely used price-reporting service (Argus, 2021). Prices are denominated in US dollars per ton, covering the period from April 1, 2022, to June 21, 2024. The sample start date corresponds to the lifting of COVID-19 restrictions in Austria, Benelux, Germany, France, and Italy in March 2022, which significantly impacted waste edible oil collection and biodiesel production. The end date precedes the results of the European anti-dumping enquiry.

While our primary focus is on biodiesel produced from waste and its feedstock, the analysis must also account for external shocks affecting the broader European diesel market. Since fluctuations in biodiesel prices may be influenced by fossil-based diesel prices, we include Diesel FOB NEW (Northwest Europe) as an exogenous variable to account for these market effects.

To ensure consistency in the time domain, missing values are interpolated using a cubic spline on log-transformed price series. Table A.1 in Appendix A summarizes the statistical properties of the data, highlighting that biodiesel is systematically more expensive than fossil-based diesel and that Chinese UCO and UCOME prices tend to be lower than their European counterparts. Figure 1 presents time series plots of the raw price data, suggesting a close relationship between biodiesel and feedstock prices and potential non-stationarity in price levels.

To analyze price dynamics, we work with log-transformed prices and compute log-returns, which approximate daily percentage changes. As reported in Table A.1, the distribution of log-returns exhibits excess kurtosis, characteristic of fat-tailed (leptokurtic) distributions often observed in energy markets. Moreover, correlation analysis (Table A.2, Appendix A) confirms that log-returns of biodiesel prices are significantly correlated with both contemporary and lagged movements in diesel prices. To control for potential omitted variable bias, our model systematically includes contemporary and 1-day lagged log-returns of diesel prices as exogenous variables. This assumption is justified given the relatively small size of the UCOME market compared to the broader European diesel market (see Declerck et al, 2022, on the dynamics of biofuels prices with oil prices).

Figures 3 and 4 display the raw price series and their corresponding log-returns, visually indicating that price levels exhibit signs of non-stationarity, while log-returns appear stationary.

Figure 3. Data plots of the raw price series in USD per ton (Source: Argus).

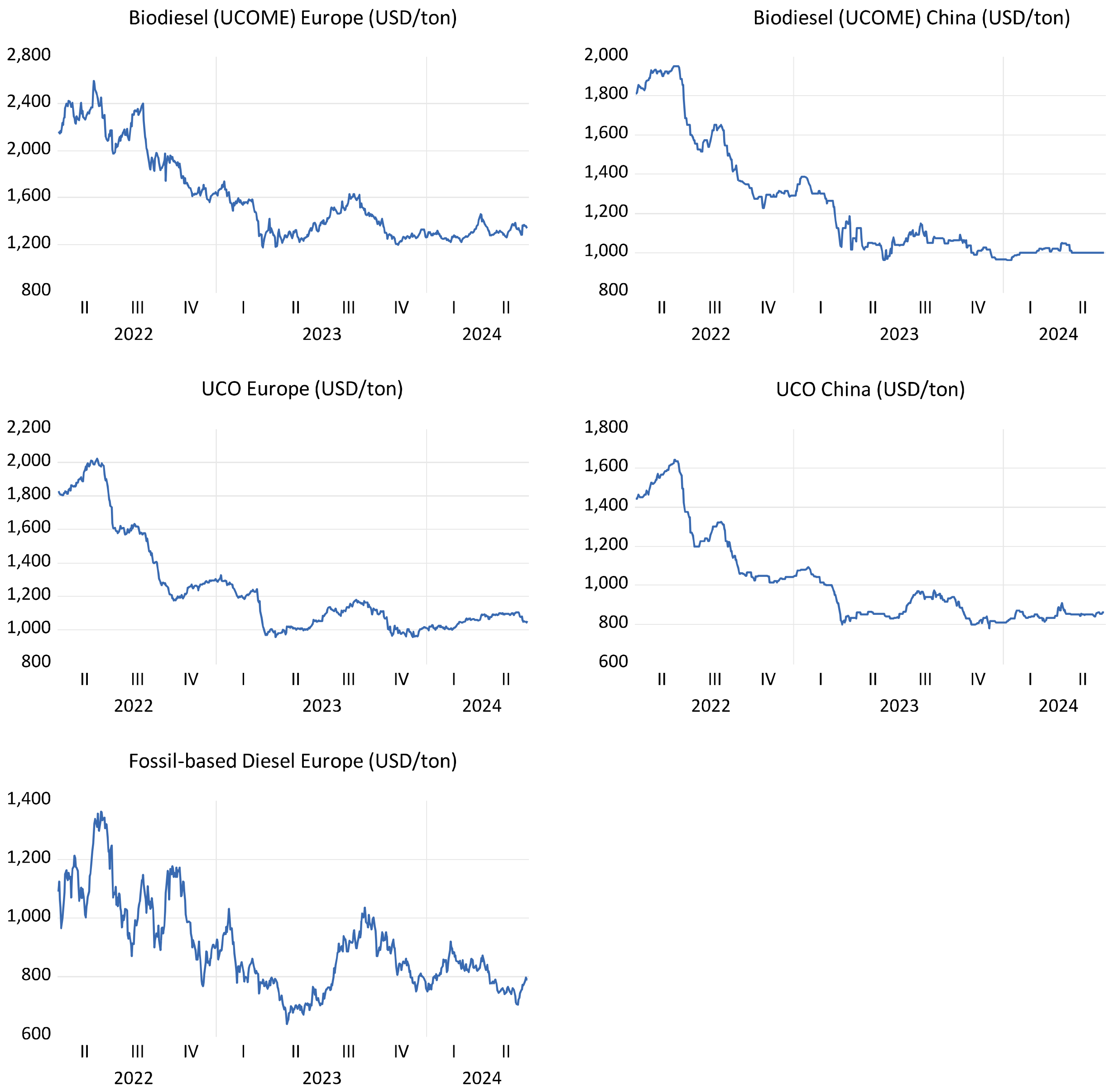
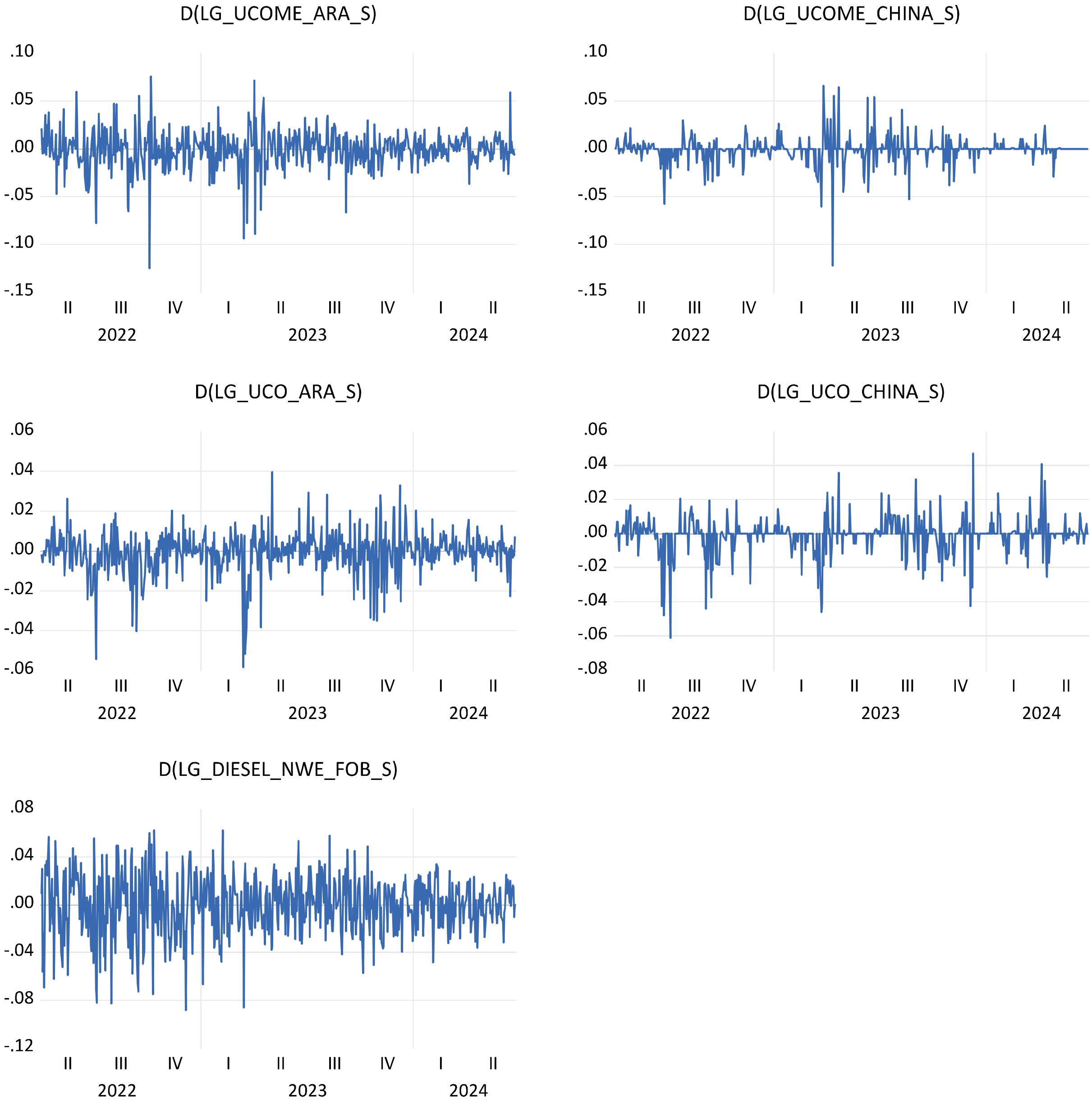


Figure 4. Data plots of the log-returns.



Given that the data consists of price series, we expect potential unit root behavior (non-stationarity), as suggested by Samuelson (1965). Visual inspection of Figures 3 and 4 supports this assumption, with price levels showing non-stationary patterns, whereas log-returns appear stationary. To formally test for stationarity, we apply the Augmented Dickey-Fuller (ADF) and Phillips-Perron (PP) unit root tests. As reported in Table A.2, both tests fail to reject the null hypothesis of a unit root for price levels but strongly reject it for log-returns, confirming that the first-differenced log price series are stationary (I(1)). Since regressions using non-stationary data can lead to spurious results, all modeling is conducted using first differences of logged prices (log-returns). However, despite the individual series being nonstationary, Figure 3 strongly suggests the presence of cointegration between the series. This allows us to determine whether long-run equilibrium relationships exist among UCO and UCOME prices in Europe and China.

To test for cointegration, we first determine the optimal lag length using the Akaike Information Criterion (AIC), which recommends a VAR model with six lags, corresponding to a VECM specification with five lags. We then conduct the Johansen trace test for cointegration, considering specifications with and without deterministic terms.

Table 2 presents the Johansen test results, revealing evidence of long-run price comovements. The results suggest three cointegrating relationships when no deterministic terms are included and two relationships at the 10% significance level when intercepts are added. To resolve this discrepancy, we select the no-deterministic-term specification with three cointegration equations based on the lowest AIC value.

These findings indicate that UCO and UCOME prices in Europe and China share long-term equilibrium relationships, likely driven by traders' spatial arbitrage and biodiesel processors' preference for the least-cost feedstock. The existence of cointegration supports the hypothesis that regional biodiesel and UCO markets are interconnected over the long run.

Table 2. Johansen ML results for multiple cointegrating vectors - biodiesel UCOME prices (Europe, and China) and UCO prices.

Hypothesized No. of CE(s)		**Trace Statistic**	**(P-value)**	**0.05 Critical Value**	**Akaike Information Criterion**
H_0	**H_1**				
No deterministic term					
r=0	r≥1	57.941***	(0.000)	40.175	-24.175
r≤1	r≥2	31.177***	(0.006)	24.276	-24.207
r≤2	r≥3	13.927**	(0.027)	12.321	-24.223
r≤3	r≥4	2.316	(0.151)	4.130	-24.230
Intercept included					
r=0	r≥1	61.829***	(0.009)	54.079	-24.175
r≤1	r≥2	34.899*	(0.054)	35.193	-24.204
r≤2	r≥3	17.609	(0.111)	20.262	-24.217
r≤3	r≥4	5.978	(0.192)	9.165	-24.220

Note: r is the cointegration rank. Asterisks *, **, and *** denote rejection of the hypothesis at the 0.1, 0.05, and 0.01 levels, respectively. The test statistics is computed using lag length indicated by the Akaike Information Criterion and two exogenous variables: the contemporary and 1-day lagged log-returns of the Diesel price series.

3.2 Methodology

Given the evidence of cointegration among the price series, it is necessary to adopt an error correction approach to model both the long-run equilibrium relationships and short-run price dynamics. We employ a Vector Error Correction Model (VECM), which accounts for deviations from long-run equilibrium while allowing for short-run adjustments among the price variables.

Let P_t denote a vector of m (where m=4) nonstationary price series $P_{i,t}$ at time t. Given the integration properties of the variables, the data-generating process of P_t can be expressed as a VECM with $k-1$ lags, derived from a Vector Autoregression (VAR) model with k lags:

$$\Delta P_t = \Pi P_{t-1} + \sum_{j=1}^{k-1} \Gamma_j \Delta P_{t-j} + \mathrm{A} Y_t + \varepsilon_t \qquad (1)$$

where Δ is the difference operator ($\Delta P_t = P_t - P_{t-1}$), and Γ_j is a $(m \times m)$ matrix of coefficients that capture the impact of lagged price changes on current price movements, describing the short-run dynamics of the system.

Matrix Π, decomposed as $\Pi = \alpha\beta'$, is a $(m \times m)$ matrix of coefficients relating lagged levels of prices to current changes in prices.[14] The matrix Π can be decomposed into β which is the $(m \times r)$ cointegrating vector that determines the r long-term relationship(s) between the m series, and α which is the loading matrix that determines how the endogenous variables respond to disequilibrium in the long-run relationships. Y_t is a vector of n exogeneous stationary variables (here, n=2, the contemporary and 1-day lagged log-returns of diesel prices) and A is the associated $(m \times n)$ loading matrix. Finally, ε_t is a $(m \times 1)$ vector of filtered residuals with a conditional variance-covariance matrix H_t such that $E(\varepsilon_t) = 0$ and $cov(\varepsilon_t, \varepsilon_s) = 0$ for $t \neq s$. These residuals represent unmodeled innovations, reflecting the arrival of new information affecting each price series.

4. Empirical Findings

4.1 Cointegrating equations

Table 3 – Panel A details the estimated cointegrating vectors.[15] We assumed that the cointegrating relation described the long-run value of the biodiesel in China, UCO in Europe and China in terms of the price of biodiesel in Europe. The estimated coefficients for the latter variable are highly statistically significant, which confirms that the prices at hand are particularly related. Equation EC_1

[14] Actually, Π may be of order m×(m+1) depending on whether the constant is inside or outside of the cointegration space.

[15] The estimated VECM was subjected to several time series diagnostic tests (see Appendix B). The test results indicate that the model is properly specified. In particular, we find no indication of serial correlation in the residuals. These diagnostics also show no evidence of parameter instability over the estimation period. These findings thus confirm the validity of our estimates.

describes the long-run equilibrium between the regional biodiesel prices (UCOME) in China and Europe. Consistent with the remark raised on the descriptive statistics, the coefficient for European biodiesel is lower than one, which indicates that the long-run equilibrium price of biodiesel (UCOME) in China is smaller than that observed in Europe. Similarly, equation EC_2 (respectively EC_3) describes the long-run equilibrium between the prices of biodiesel in Europe and that of the UCO feedstock in Europe (respectively China).

Table 3. Estimated VECM specification.

Panel A: co-integrating (long-run) coefficients β

	Biodiesel_China	UCO_Europe	UCO_China	Biodiesel_Europe
EC_1	1.000	0.000	0.000	-0.9641*** *[-399.480]*
EC_2		1.000	0.000	-0.9662*** *[-466.994]*
EC_3			1.000	-0.9381*** *[-526.463]*

Panel B: Speed of adjustment (error correction) coefficients α

Model I: Unrestricted model (Log Likelihood: 7050.674)				
Equation	ΔBiodiesel_China	ΔUCO_Europe	ΔUCO_China	ΔBiodiesel_Europe
EC_1	-0.043*** [-3.138]	-0.008 [-0.718]	0.019* [1.835]	0.017 [0.877]
EC_2	0.010 [0.692]	-0.035*** [-2.820]	0.025** [2.214]	0.047** [2.173]
EC_3	0.024 [1.030]	0.039** [2.022]	-0.067*** [-3.872]	-0.031 [-0.928]

Note: These cointegrating relations consider the four endogenous price series in natural logarithms as well as two exogenous variables: the contemporary and 1-day lagged log-returns of the Diesel price series. The lag structure has six lags in VAR, as suggested by the Akaike Information Criterion, and five lags in VECM. The t-statistics are in [ ]. Asterisks indicate rejection of the null hypothesis of a zero coefficient at the 0.1*, 0.05**, and 0.01*** significance levels, respectively.

Table 3—Panel B presents estimates of the loading matrix. These error correction adjustment coefficients govern the price response to deviations in the three estimated cointegrating relationships. Three lines of remarks suggest that these statistically significant loading coefficients are consistent with *a-priori* views on the economics of the biofuel industry.

First, the negative and very significant value for the coefficient of the cointegration equation EC_1 (respectively EC_2 and EC_3) in the ΔBiodiesel_China (respectively ΔUCO_Europe and ΔUCO_China) equation implies that adjustments of regional biodiesel prices (respectively feedstock and European biodiesel prices) produce subsequent price movements that restore the cointegrating relationships. This finding indicates that the estimated system is stable.

Second, we observe positive and significant loading coefficients for EC_2 in the equations governing the price changes of Chinese UCO and European biodiesel. Whenever the price of European UCO is higher than the equilibrium level in EC_2, the inflated price of that feedstock is transferred to the price of European biodiesel. That disequilibrium also yields an increase in the price of Chinese UCO as European biofuel producers react by importing more feedstock from China.

Third, in the equation governing the European UCO's price movements, the positive loading coefficient for EC_3 indicates that whenever the price of Chinese UCO is higher than the equilibrium level in EC_3, that disequilibrium yields a subsequent increase in the price of European UCO. This finding is consistent with the rational behavior of European biofuel producers, who, having observed the inflated price of Chinese UCO, reorient their feedstock procurement decisions from Asian imports to domestically collected UCO.

4.2 Short-run dynamics

For concision, the estimated values of the short-run dynamic response coefficients are detailed and discussed in Appendix C. We simply comment below the results gained from a series of Granger causality tests conducted with the estimated specification (see Table 4).

Table 4. Granger causality Wald tests.

		χ_f^2	Degree of freedom (f)	p-value
ΔBiodiesel_China	Endogenous variables			
	ΔUCO_Europe → ΔBiodiesel_China	5.461	5	(0.362)
	ΔUCO_China → ΔBiodiesel_China	4.960	5	(0.421)
	ΔBiodiesel_Europe → ΔBiodiesel_China	19.934***	5	(0.001)
	Joint → ΔBiodiesel_China	39.577***	15	(0.001)
	Exogenous variable			
	ΔDiesel → ΔBiodiesel_China	2.974	2	(0.226)
ΔUCO_Europe				
	ΔBiodiesel_China → ΔUCO_Europe	7.234	5	(0.204)
	ΔUCO_China → ΔUCO_Europe	3.747	5	(0.586)
	ΔBiodiesel_Europe → ΔUCO_Europe	15.839***	5	(0.007)
	Joint → ΔUCO_Europe	30.765***	15	(0.009)
	Exogenous variable			
	ΔDiesel → ΔUCO_Europe	0.949	2	(0.622)
ΔUCO_China				
	ΔBiodiesel_China → ΔUCO_China	6.786	5	(0.237)
	ΔUCO_Europe → ΔUCO_China	24.534***	5	(0.000)
	ΔBiodiesel_Europe → ΔUCO_China	13.279**	5	(0.021)
	Joint → ΔUCO_China	51.969***	15	(0.000)
	Exogenous variable			
	ΔDiesel → ΔUCO_China	10.352***	2	(0.006)
ΔBiodiesel_Europe	Endogenous variables			
	ΔBiodiesel_China → ΔBiodiesel_Europe	5.908	5	(0.315)
	ΔUCO_Europe → ΔBiodiesel_Europe	9.714*	5	(0.084)
	ΔUCO_China → ΔBiodiesel_Europe	4.405	5	(0.493)
	Joint → ΔBiodiesel_Europe	19.342	15	(0.199)
	Exogenous variable			
	ΔDiesel → ΔUCO_Europe	111.100***	2	(0.000)

Note: Asterisks indicate rejection of the null hypothesis of no Granger causality at the 0.1*, 0.05**, and 0.01*** significance levels, respectively.

From these test results, we cannot reject the null hypothesis that past price movements of Chinese biodiesel or Chinese UCO do not affect the contemporary price movements of both UCO and biodiesel in Europe. Unsurprisingly, previous movements in the price of European biodiesel directly impact the observed variations in the price of domestic UCO, whereas the reciprocal impact is weaker as the *p*-value of no impact is only 0.084. In contrast, changes in the price of European biodiesel do Granger cause variations in the prices of biodiesel and UCO in China.

We find that the price of European biofuel is rather exogenous in the short run (the hypothesis of no joint impact is not rejected at the 10% level). Overall, these findings suggest that price formation in European markets is more driven by local biofuel demand considerations and the price changes of conventional fossil diesel than by the substitution of Chinese biodiesel or supply-side issues pertaining to the price of the feedstock used to process biofuel.

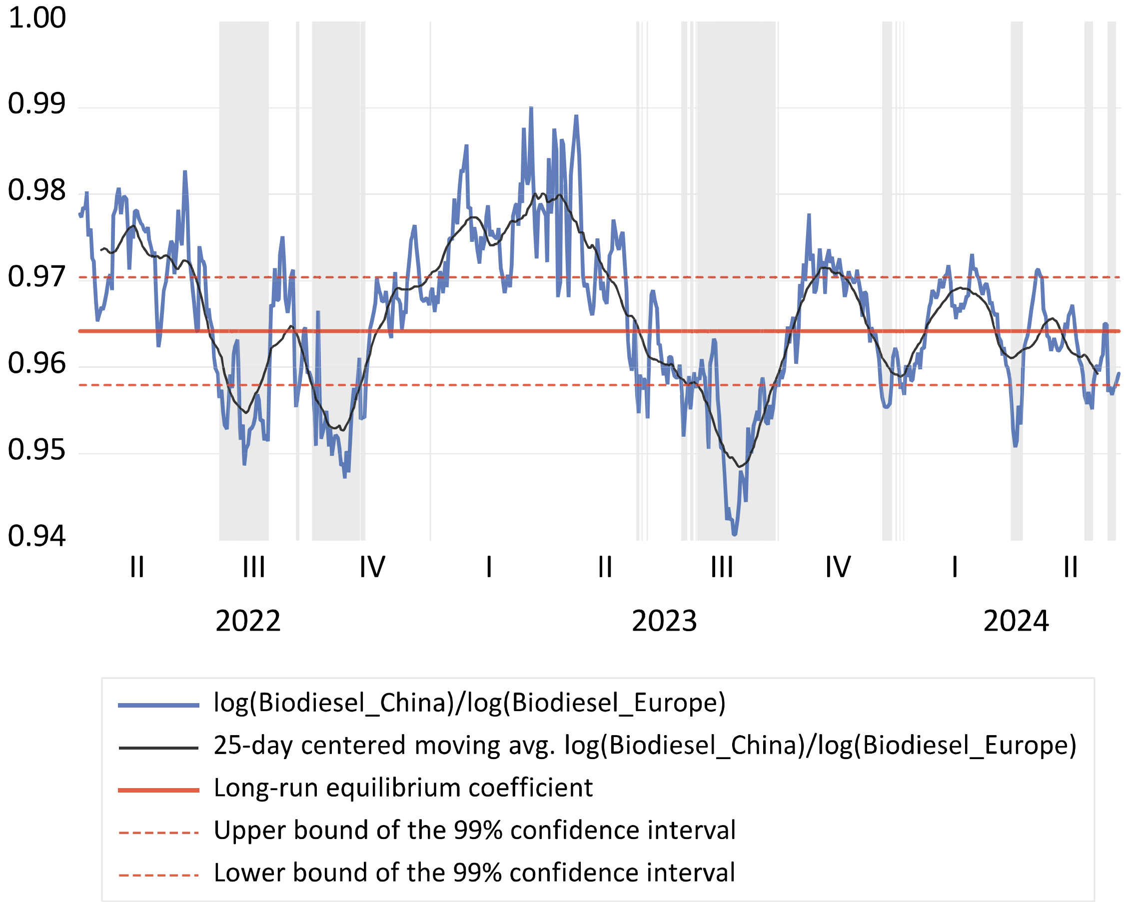
5. Conclusion and Policy Implications

The estimated VECM can be used to inform the ongoing European policy debate on the possible exertion of dumping by China.

5.1 Persistent departures from the long-run price equilibrium between European and Chinese biodiesel

Figure 5 is a graphical representation of the equilibrium condition associated with the first cointegrating equation EC_1 in Table 3 – Panel A. It provides plots of the relative logged prices of biodiesel in China and Europe, the estimated long-run coefficient in EC_1, and the associated 99% confidence interval. Whenever the observed ratio is below the lower bound of that confidence interval, the relative price of biodiesel in China is markedly cheaper than its long-run equilibrium level. In our sample, 124 observations verify this condition and are represented using shaded areas in Figure 5. In the sequel, we let D_t denote the dummy variable that takes the value one for these observations and zero otherwise.

Figure 5. Data plots of the observed relative logged prices of Chinese and European biodiesel, the cointegrating equation linking them, and the associated 99% confidence interval.



Given the policy discussions about the alleged dumping case, these observations deserve special attention. Arguably, the presence of a temporary disequilibrium is not *per se* a source of concern as it may reflect sporadic events such as e.g., the effects of a temporary bottleneck in the supply chain used to ship Chinese biodiesel to Europe. To discard such events, Figure 5 also plots the 25-day centered moving average of the observed ratio of the log-transformed prices.[16] From a visual examination, we observe three periods of persistent disequilibrium: Period #1 in August 2022; Period #2 in October and early November 2022; and Period #3 spans August and September 2023.

The presence of such persistent disequilibrium is puzzling. Recall that the estimated VECM above exhibits a negative and statistically significant loading coefficient for EC_1 in the equation governing the price variations of Chinese biodiesel that should bring back the system into equilibrium. This finding

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[16] As our analysis involves weekday data, that window spans five consecutive weeks, a duration sufficient to filter out sporadic episodes and detect more structural episodes of disequilibrium.

calls for further investigations aimed at clarifying the fundamentals of price formation when the relative price of Chinese biodiesel is markedly lower than its equilibrium level.

5.2 Objective signs of a changing dynamics in China

Recall that in our VECM above, the price changes of Chinese biodiesel are mainly driven by the loading coefficient correcting for possible disequilibrium in EC_1 and the lagged price changes of European biodiesel. To investigate the time invariant nature of the price formation of Chinese biodiesel, we now consider an extended version of the error-correction equation ΔBiodiesel_China whereby these six coefficients are allowed to change whenever a disequilibrium is observed (i.e., D_t=1).

From the estimation results reported in Table 5, the original restricted model with unchanged coefficient is firmly rejected by the data (the log-likelihood ratio test statistics of the null hypothesis of identical coefficients is χ_6^2=15.764 with a *p*-value of 0.015). Whenever a marked disequilibrium is observed, the estimated loading coefficient associated with EC_1 is much smaller and not significant. This finding explains why marked departures from the equilibrium in EC_1 can persist over time. Furthermore, we observe that, under these observations, the lagged price changes of European biodiesel are no longer statistically different from zero. From the Wald test result, we cannot reject the null hypothesis of no Granger causality from European biodiesel to Chinese biodiesel whenever D_t=1. Overall, under exceptional disequilibrium episodes, the pricing fundamentals of Chinese biodiesel are markedly different from the ones prevailing under normal circumstances. Our results show that the disequilibrium goes hand in hand with a decoupling of the price of Chinese biodiesel that becomes exogenous and is no longer governed by European (and thus demand side) considerations.

Table 5. Extended short-run model allowing shifts in the estimated coefficients.

	ΔBiodiesel_China	
	Coef.	t-stat.
$(1 - D_t) \times EC_1$	-0.050***	[-3.568]
$D_t \times EC_1$	-0.006	[-0.318]
$(1 - D_t) \times$ ΔBiodiesel_Europe		
t-1	0.124***	[3.604]
t-2	0.074**	[2.249]
t-3	0.037	[1.147]
t-4	0.036	[1.113]
t-5	0.067**	[2.117]
$D_t \times$ ΔBiodiesel_Europe		
t-1	-0.003	[-0.055]
t-2	0.046	[0.864]
t-3	0.015	[0.274]
t-4	0.065	[1.188]
t-5	0.027	[0.502]
Log Likelihood	1751.961	
Wald test: $D_t \times$ ΔBiodiesel_Europe → ΔBiodiesel_China	χ^2_5=2.040	(*p*-value: 0.844)

Note: The t-statistics are in [ ]. Asterisks indicate rejection of the null hypothesis of a zero coefficient at the 0.1*, 0.05** and 0.01*** significance levels, respectively. For concision, that table solely reports the estimates of the loading coefficient associated with EC_1 and the lagged price changes of European biodiesel. For concision, we do not report the estimated values of the other coefficients as they do not substantially differ from the ones presented in Appendix C. These estimated values are available from the authors upon request.

5.3 Implications for policymaking

Our findings have direct policy implications for European biofuel trade regulations and market oversight mechanisms. The identification of persistent price distortions in the Chinese biodiesel market raises concerns over potential strategic pricing or falsely labeled UCOME, which could justify trade defense measures. The European Commission's recent imposition of anti-dumping tariffs on Chinese UCOME is a first step, but challenges remain in ensuring compliance and addressing possible loopholes.

First, enhanced sustainability verification is essential. While the EU's Union Database for biofuels, launched in 2024, aims to improve transparency, concerns persist over the authenticity of UCO origins.

Recent reports indicate that certification schemes alone may be insufficient to prevent fraud[17], suggesting the need for more stringent cross-border verification protocols.

Second, the EU's reliance on biodiesel imports reflects a strategic imbalance. Blending mandates have stimulated demand, but without parallel efforts to expand domestic UCO collection and refining capacity, Europe risks replicating past vulnerabilities seen in the solar panel industry where the rapid adoption of solar generation failed to spur the emergence of a domestic solar panel manufacturing sector.[18] Policy incentives should encourage investment in local biofuel production, reducing dependence on external suppliers with weaker sustainability controls.

Finally, market monitoring and trade policy coordination must be reinforced. The decoupling of Chinese biodiesel prices from European price signals raises concerns about strategic pricing behavior or state intervention. While anti-dumping duties are a necessary response, closer international cooperation—including WTO engagement on biofuel trade fairness—is needed to prevent future distortions.

5.4 Concluding remarks

The rapid expansion of UCO-based biodiesel trade between China and Europe has reshaped global biofuel markets, but it has also raised pressing concerns over sustainability compliance and market distortions. Our analysis confirms that European biodiesel prices remain the primary driver of global price formation, yet periods of persistent price decoupling in China suggest potential strategic pricing, state intervention or fraudulent biodiesel.

These findings underscore the need for stronger regulatory oversight, particularly in ensuring that biofuels marketed as "sustainable" truly adhere to environmental and trade standards. The European Commission's recent anti-dumping measures mark an important step, but further policy coordination will be required to balance climate goals, energy security, and fair market competition.

Future research could investigate the role of state subsidies and production incentives in Chinese biodiesel markets, as well as explore the effectiveness of emerging policy tools such as digital traceability systems for biofuels. The growing strategic importance of second-generation biofuels in decarbonization policies means that trade dynamics in this sector will remain a key policy challenge in the years to come.

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[17] *EBB proposals on how to improve the EU system for the verification of sustainable biofuels, January 2025; European Biodiesel Board*

[18] *We refer to Haley and Schuller (2011) and Yu et al. (2014) for discussions on that issue.*

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Appendix A – Preliminary analyses

Table A.1. Summary statistics.

Variable	Mean	Median	Max	Min	Std. Dev.	Skew.	Kurt.
Raw price series							
Biodiesel_Europe	1599.06	1464.52	2591.02	1176.00	372.62	0.96	2.62
Biodiesel_China	1241.78	1085.00	1950.00	960.00	292.32	1.15	3.15
UCO_Europe	1241.83	1120.15	2024.05	955.21	288.79	1.37	3.70
UCO_China	1013.93	932.50	1640.00	780.00	225.97	1.32	3.70
Diesel_NWE	901.37	862.00	1361.75	640.00	152.61	0.88	3.26
Log-returns							
Biodiesel_Europe	-0.0008	-0.0004	0.0751	-0.1254	0.0196	-0.83	8.52
Biodiesel_China	-0.0010	0.0000	0.0658	-0.1224	0.0132	-1.33	20.68
UCO_Europe	-0.0010	-0.0003	0.0395	-0.0584	0.0107	-1.01	7.57
UCO_China	-0.0009	0.0000	0.0470	-0.0611	0.0103	-1.01	9.77
Diesel_NWE	-0.0005	0.0003	0.0621	-0.0884	0.0252	-0.39	3.51

Note: Biodiesel_Europe (respectively Biodiesel_China) refers to UCOME biodiesel in the Amsterdam–Rotterdam–Antwerp area (respectively China) under fob incoterm. UCO_Europe (respectively UCO_China) refers to Used Cooking Oil in the Amsterdam–Rotterdam–Antwerp area (respectively China) under fob incoterm. Diesel_NWE refers to Diesel price series in Germany. Std.Dev. stands for Standard Deviation, Skew. for Skewness, and Kurt. for Kurtosis. The number of observations is 581.

Table A.2. Correlation between log-returns of biodiesel/UCO and diesel.

	Correlation coefficients with Diesel_NWE log-returns	
	Contemporary	**1-day lagged**
Log-returns		
Biodiesel_Europe	0.367***	-0.120***
Biodiesel_China	0.087**	0.082**
UCO_Europe	0.057	0.048
UCO_China	0.139***	0.067

Note: Asterisks indicate rejection of the null hypothesis of a zero correlation coefficient at the 0.1*, 0.05** and 0.01*** significance levels, respectively.

Table A.3. Unit root tests.

		Specification (a)	ADF (b)		PP (c)	
UCOME_ARA	Log-levels		-0.992	(0.29)	-0.985	(0.29)
	First difference (log-returns)		-24.181***	(0.00)	-24.183***	(0.00)
UCOME_China	Log-levels	C	-1.761	(0.40)	-1.726	(0.42)
	First difference (log-returns)		-20.187***	(0.00)	-21.715***	(0.00)
UCO_ARA	Log-levels	C	-1.908	(0.33)	-1.858	(0.35)
	First difference (log-returns)		-8.928***	(0.00)	-23.179***	(0.00)
UCO_China	Log-levels	C	-1.761	(0.40)	-1.726	(0.42)
	First difference (log-returns)		-20.187***	(0.00)	-21.715***	(0.00)
Diesel	Log-levels	C	-2.005	(0.28)	-2.076	(0.25)
	First difference (log-returns)		-21.977***	(0.00)	-21.894***	(0.00)

Note: Asterisks indicate rejection of the null hypothesis at the 0.1*, 0.05** and 0.01*** significance levels, respectively. (a) C and T are constant and trend, respectively. (b) ADF is the Augmented Dickey–Fuller test with a number of lags suggested by the Schwarz Information Criterion. (c) PP is the Phillips and Perron test based on the Bartlett kernel with bandwidth selected from the Newey–West method.

Appendix B – Diagnostic tests

The models were subjected to several diagnostic tests to examine the distributional properties of the residuals and detect the possible presence of heteroscedasticity and unmodeled serial correlation. The test results are detailed in Table B.1.

Table B.1. Diagnostic tests.

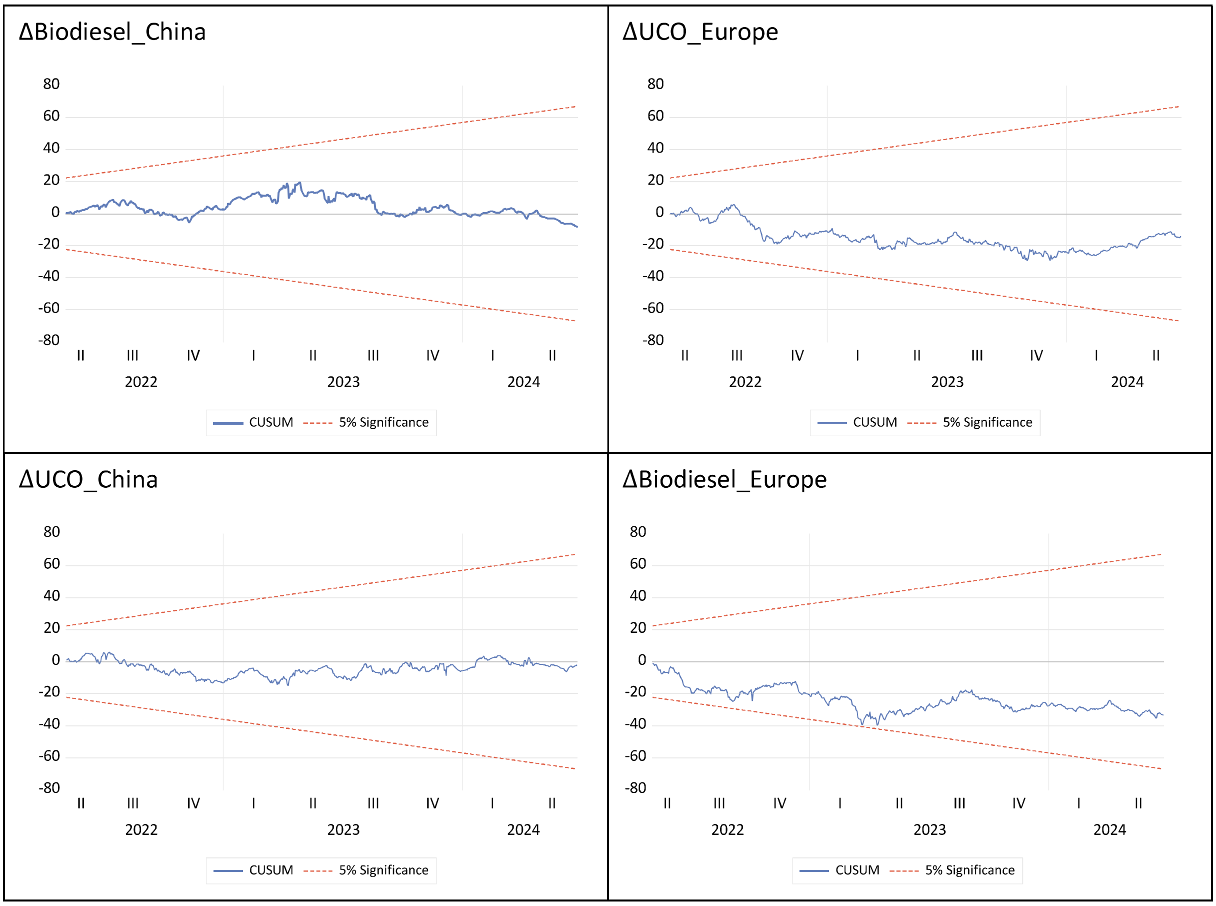
	JB χ_2^2	P-value	LB(10) χ_{10}^2	P-value	ARCH(2) χ_2^2	P-value
ΔBiodiesel_China	3748.39	(0.000)	8.625	(0.568)	16.151	(0.000)
ΔUCO_Europe	254.623	(0.000)	4.488	(0.923)	8.245	(0.016)
ΔUCO_China	711.783	(0.000)	10.657	(0.385)	28.222	(0.000)
ΔBiodiesel_Europe	1628.786	(0.000)	10.046	(0.436)	53.101	(0.000)

Note: JB is Jarque-Bera test for normality, LB(10) is the Ljung–Box Q-statistics for no autocorrelation up to the 10th order. ARCH(2) is the usual Engle's LM test with 2 lags for the null hypothesis that a series exhibits no ARCH effects.

The estimated models' autoregressive structures are statistically adequate since there is no evidence of residual autocorrelation (see the Ljung-Box statistic for up to the tenth order). From the Jarque Bera and ARCH test statistics, the residuals are non-normal and exhibit signs of conditional heteroscedasticity. These findings are not surprising in the context of commodity markets that usually exhibit fat-tailed distributions. That said, the presence of non-normal errors little affects the performance of the maximum likelihood estimator of the cointegrating vectors (Gonzalo, 1994). As indicated in Lütkepohl and Krätzig (2004, p 157-158), the presence of ARCH effects in the residuals of a VECM estimated using financial time series is not a signal of inadequate modeling.

To examine the temporal stability of our model, we report below the cumulative sum of recursive residuals (CUSUM) test statistics of the four individual equations in our preferred specification (see Figure B.1). In all cases, the test statistics are well within the 5% critical bounds, indicating no evidence of parameter instability in any of the error-correction equations over the estimation period.

Figure B.1. CUSUM tests for the error-correction equations.



Appendix C – Estimated VECM

Table C.1. Short-run Dynamic Responses in the estimated VECM.

	Endogenous Variable							
	ΔBiodiesel_China		ΔUCO_Europe		ΔUCO_China		ΔBiodiesel_Europe	
	Coef.	t-stat.	Coef.	t-stat.	Coef.	t-stat.	Coef.	t-stat.
ΔBiodiesel_China								
t-1	0.106**	[2.468]	0.035	[0.981]	0.054*	[1.667]	0.000	[-0.003]
t-2	-0.170***	[-3.941]	0.069*	[1.919]	0.021	[0.653]	0.025	[0.404]
t-3	-0.020	[-0.447]	0.039	[1.082]	-0.033	[-1.003]	-0.023	[-0.358]
t-4	-0.033	[-0.787]	0.053	[1.501]	0.051	[1.591]	-0.029	[-0.464]
t-5	0.081*	[1.907]	-0.002	[-0.063]	-0.009	[-0.278]	-0.138**	[-2.242]
ΔUCO_Europe								
t-1	0.022	[0.430]	0.030	[0.705]	0.123***	[3.170]	0.162**	[2.164]
t-2	0.063	[1.217]	-0.019	[-0.438]	0.042	[1.075]	0.064	[0.845]
t-3	0.050	[0.972]	0.100**	[2.316]	0.142***	[3.670]	-0.118	[-1.577]
t-4	-0.051	[-0.987]	0.110**	[2.542]	-0.016	[-0.400]	-0.095	[-1.256]
t-5	-0.074	[-1.411]	0.068	[1.565]	0.045	[1.143]	-0.049	[-0.651]
ΔUCO_China								
t-1	0.001	[0.018]	-0.034	[-0.708]	0.041	[0.947]	0.081	[0.962]
t-2	0.088	[1.530]	-0.012	[-0.254]	-0.023	[-0.543]	-0.099	[-1.186]
t-3	0.087	[1.535]	-0.011	[-0.227]	0.013	[0.309]	-0.009	[-0.108]
t-4	0.041	[0.726]	-0.049	[-1.057]	0.064	[1.518]	0.068	[0.833]
t-5	0.012	[0.216]	0.068	[1.475]	0.035	[0.849]	0.079	[0.996]
ΔBiodiesel_Europe								
t-1	0.091***	[3.093]	0.059**	[2.396]	0.057***	[2.581]	0.045	[1.049]
t-2	0.077***	[2.747]	0.054**	[2.325]	0.036*	[1.711]	0.009	[0.222]
t-3	0.039	[1.406]	0.018	[0.763]	0.021	[0.990]	-0.017	[-0.425]
t-4	0.049*	[1.781]	0.040*	[1.721]	0.049**	[2.342]	0.015	[0.369]
t-5	0.053*	[1.924]	0.055**	[2.367]	0.002	[0.095]	0.075*	[1.878]
Exogeneous variable ΔDiesel								
t	0.035*	[1.704]	0.015	[0.888]	0.050***	[3.198]	0.299***	[10.006]
t-1	-0.009	[-0.391]	-0.009	[-0.465]	-0.010	[-0.588]	-0.131***	[-4.034]
Log Likelihood	1744.079		1848.743		1909.194		1526.973	
Durbin-Watson Stat.	2.005		2.020		2.015		2.023	
Log Likelihood: 7050.674								

Note: The t-statistics are in [ ]. Asterisks indicate rejection of the null hypothesis of a zero coefficient at the 0.1*, 0.05** and 0.01*** significance levels, respectively.

These estimates convey a series of findings. First, an examination of the own autoregressive structures shows that the prices of Chinese biodiesel and European UCO respond to lagged own-price changes, though that effect occurs with a longer delay for UCO. In contrast, the price changes of biodiesel in Europe and UCO in China are not affected by their own past variations.

Second, short-run changes in the price of conventional diesel significantly impact the price variations of European biodiesel. A contemporary one percent change in the price of that exogenous variable directly causes a nearly 0.3 percent increase in the price of biodiesel (though that price increase will then be attenuated because of the negative coefficient associated with lagged variation in the price of fossil diesel). The contemporary movements of fossil diesel also affect the price changes of UCO collected in Europe.

Third, the price variations of Chinese biodiesel are not affected by lagged price changes of UCO collected in Europe. This finding is consistent with the fact that Chinese producers only process domestic UCO and do not import UCO from Europe.

Fourth, we observe a positive and significant relationship between the 1-day lagged price movements of European UCO and those of both the final good derived from the processing of that feedstock (i.e., European biodiesel) and the substitute (UCO in China). Regarding the latter, one can note that the coefficients describing the impacts of European UCO on the Chinese equivalent have a larger magnitude than other impacts. This finding confirms that European considerations and the arbitrages in feedstock exerted by European processing firms have major impacts on the price formation of UCO in China. Confirmation is given by the very strong rejection of the null hypothesis of zero impact in the Granger causality test results detailed in Table 4.

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