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Short communication

Impact of carbon emission trading on the European Union biodiesel feedstock market

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ABSTRACT

The last decade has witnessed a significant growth in biodiesel production in order to mitigate the adverse impact of CO_2 emissions. Given that the EU biodiesel is mainly produced from rapeseed oil, higher carbon taxes are likely to raise the production of biodiesel which, in turn, increase the prices of this important edible oil. Nevertheless, the association between the EU emission trading scheme and the biodiesel market remains understudied. In this paper, we aim to fill this vacuum in the existing literature. Adopting a bivariate DCC-GARCH model, we show that risk significantly transmits from emission market to the EU rapeseed oil market suggesting that volatile carbon prices would cause uncertainties in the rapeseed oil price index. We also find that an increase in the emission prices tends to promote the biodiesel feedstock prices. Implications of the results are discussed as well.

1. Introduction

Biodiesel has emerged as the leading biofuel used in the European Union (EU) transport sector. A recent report, published by the European Commission, indicates that the biodiesel production capacity has increased to about 26.3 billion liters, with an annual production of about 10.5 billion liters (8.3 Mtoe) or 40% of the total capacity. Such significant growths in biodiesel could be due to the concerns about energy security, greenhouse gas (GHG) emissions and oil market uncertainty. Chiu et al. [1], for instance, argue that the usage of biofuels has increased with a view to reducing GHG emissions and moderating the negative effect of volatile energy prices. In other words, biofuels have received considerable attention as they emit less carbon than the traditional energy sources. Other studies [3,5,6] also claim that the CO_2 emission seems to be a major factor causing this upward trend in biofuel usage. Hence it is rational to assume that increased carbon taxes inspire the investors in financing further in biofuel sectors.

In the EU, biodiesel is mainly produced from rapeseed oil. At present, rapeseed oil accounts for about 80% of the biodiesel feedstock. Given that rapeseed oil is the main feedstock for producing biodiesel in the EU, it is likely that an upsurge in emission prices leads to an upward trend the prices of rapeseed oil. Crago and Khanna [2] also argue that as biofuel production competes for land with agricultural production, rising carbon taxes could promote land rents which would then increase feedstock prices. Nevertheless, investigating the connection between European Union Allowance (EUA) market and the rapeseed oil remains understudied in the existing literature. This study aims to fill this void. Understanding the biodiesel feedstock price trend is particularly important as proper knowledge of biofuel markets could be crucial when designing the EU bioenergy policies.

Considering the growing importance of renewable fuels, several empirical studies have explored the association amongst biofuel-related prices. Serra et al. [10], for instance, demonstrate that a growth in crude oil price levels results in an upsurge in ethanol prices, which in turn causes sugar price levels to increase. While analyzing the US data, Serra et al. [17] show that the biofuel prices are affected by both crude oil and corn prices. The findings also reveal a significant connection between corn and energy markets with biofuels connecting these markets occurring mainly through the ethanol market. Employing a nonparametric correction to time series estimations, Serra [16] finds that sugarcane prices have a long-term impact on the ethanol prices, but not the other way around. Moreover, the results of Trujillo-Barrera et al. [12] exhibit that there is a significant risk transmission from corn to ethanol market and not vice versa. Gardebroek & Hernandez [9] also document similar results when investigating the food-biofuel nexus for the US market.

A recent study by Kristoufek et al. [19] documents a long-term linkage amongst the price levels of ethanol and corn which remains positive, strong and stable across time. The results also confirm that feedstock prices lead the prices of ethanol and not vice versa. On the contrary, Chiu et al. [1] show that corn prices are driven by ethanol prices, but not the other way around. A recent study by Dutta [3] finds

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that the effect of sugar prices on the Brazilian ethanol market is positive implying that rising sugar prices leads to an increase in biofuel prices. The author further shows that variations in ethanol price do not impact sugar prices. Additionally, Dutta et al. [15] conclude that the US ethanol price changes react positively to the corn market volatility shocks after controlling for the effect of oil price uncertainty. The findings further reveal that the impact of corn price volatility on the US ethanol prices appears to be asymmetric.

Although the literature on food–biofuel nexus is growing, earlier studies have mainly focused on the Brazilian and US ethanol markets and less attention has been paid to EU biodiesel markets. Abdelradi and Serra [12], for example, investigate the volatility linkage between biodiesel and rapeseed oil prices. The study suggests that biodiesel price volatility is sensitive to edible oil price shocks indicating that the EU biodiesel prices are affected by the feedstock price volatility.

Our study extends the work of Abdelradi and Serra [12] by examining the impact of carbon emission price risk on the rapeseed oil market. As mentioned earlier, such investigations are important given that biofuels have been brought into the energy market as a substitute in order to moderate the amount of carbon emissions released into the atmosphere and promote the usage of low-carbon technologies [1]. Higher carbon taxes, therefore, tend to raise the production of biofuels, which could, in turn, cause a substantial growth in the price levels of edible oils, used as the main feedstock in the EU biodiesel sector.

Methodologically, the DCC-GARCH process has been employed to examine the price and volatility spillovers between carbon emission and rapeseed oil markets. Our findings indicate that risk significantly transmits from carbon emission to rapeseed oil prices implying that volatile carbon prices would cause uncertainties in the rapeseed oil price index. Moreover, we also find a significant price linkage running from emission to rapeseed oil market. Such effect appears to be positive indicating that a growth in the EUA prices tends to promote the biodiesel feedstock prices, confirming our hypothesis.

The rest of the article is structured as follows. The next section discusses the data and methods considered in this empirical research. The empirical findings are discussed in Section 3. The last section concludes our study.

2. Data and methodology

2.1. Data

This paper uses daily spot prices of the EUA allowance and rapeseed oil spanning from 1 July 2009 to 31 December 2017. The sample consists of 2218 data points. The data have been retrieved from Thomson Reuters DataStream.

For the EU emission market, the data for three different periods are available. Phase I covers the period from January 2005 to December 2007, while phase II goes from January 2008 to December 2012. At present, the EU-ETS is completing the third phase. The data for phase I are not included as the allowance prices are close to zero towards the end of phase I as a consequence of interphase EUA banking restrictions [7].

Table 1 reports the descriptive statistics for EUA and rapeseed oil price indexes. These numbers suggest that emission market is more volatile than the food market as evidenced by the corresponding standard deviations. In addition, both indexes are negatively skewed and kurtosis is found to be higher than 3 for each series implying that the data follow leptokurtic distributions. The Jarque-Bera test also confirms that the data are not normally distributed. Moreover, Fig. 1 exhibits the price indexes for these two markets.

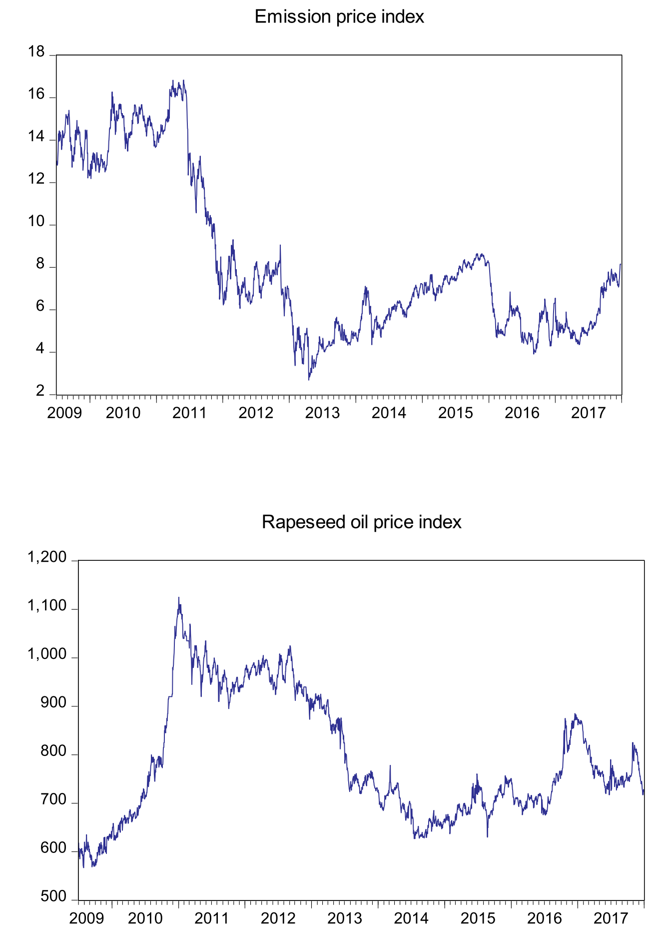

Fig. 1. Emission and rapeseed oil price indexes.

Table 2 displays the unit root test results for the indexes used. The results of two different tests (ADF and PP) indicate that although the price series follow a non-stationary process at levels, the stationary condition is satisfied when log returns are considered.

2.2. DCC-GARCH model

This study employs the multivariate DCC-GARCH process of Engle [4] to understand the association between emission and biodiesel feedstock prices. A number of studies have considered the application of multivariate GARCH models to explore the price and volatility dynamics of biofuel-related markets. Important contributions include Serra et al. [10], Trujillo-Barrera et al. [11], Gardebroek, and Hernandez [9], Wu and Li [8], Abdelradi and Serra [12] and others. These studies argue that multivariate GARCH models are appropriate to examine the price and volatility linkages amongst biofuel-related markets. Gardebroek, and Hernandez [9], for instance, demonstrate that DCC-

Table 1
Summary statistics.

Index	Mean	Standard Deviation	Skewness	Kurtosis	Jarque-Bera Test
EUA	−0.0093	1.3522	−1.1425	26.25	50429.29 (0.00)***
Rapeseed oil	0.0031	0.4836	−0.0594	7.95	2269.06 (0.00)***

Notes: This table reports the main descriptive statistics for two different return series under study. *** indicates statistical significance at 1% level.

Table 2
Results of unit root tests.

Index	ADF Tests		PP Tests	
	Level	1st Difference	Level	1st Difference
EUA	−1.60 (.48)	−34.93 (.00)***	−1.59 (.49)	−46.03 (.00)***
Rapeseed oil	−1.81 (.37)	−50.63 (.00)***	−1.72 (.42)	−50.64 (.00)***

Notes: This table shows the results for the ADF and PP tests. The values in parentheses denote the *p*-values. *** indicates statistical significance at 1% level.

GARCH model allows us to investigate whether the interdependence between biofuel, food and relevant sectors changes across time.

It is worth mentioning that numerous studies [1,3,13] employ other methods such as cointegration techniques and multivariate regressions to analyze the price dynamics of biofuel-related sectors. However, these studied have not focused on the volatility (risk) transmission relationships amongst the biofuel and food markets. Studying the volatility dynamics of biofuel-related prices is important given that what matter for both market participants as well as policy makers are not the market price variations per se, but their unpredictability and the resultant risks for producers, traders, consumers and government agents. Unpredictable high price volatility can cause additional management costs throughout the supply chain and investment-based processes can be interrupted. Therefore, price volatility is an important concern both at macro level for the government and at the micro level for consumers, producers, and investors [14].

Now, our DCC-GARCH process consists of two equations: mean and volatility. The mean equation of the bivariate GARCH approach is given by

$$R_t = L + \tau R_{t-1} + \varepsilon_t \tag{1}$$

$$\varepsilon_t = H_t^{1/2} \eta_t \tag{2}$$

where R_t is a return matrix for the EUA and rapeseed oil prices, L designates a matrix of fixed parameters, τ is a matrix of coefficients gauging the influence of own-lagged and cross mean transmission, ε_t indicates the noise term, η_t is a matrix of *iid* innovations. Moreover, $H_t^{1/2}$ refers to the matrix of conditional volatilities of emission and edible oil prices which is further decomposed as:

$$H_t = D_t R_t D_t \tag{3}$$

$$D_t = diag(\sqrt{h_t^o}, \sqrt{h_t^c}) \tag{4}$$

$$R_t = diag(Q_t)^{-1/2} Q_t \, diag(Q_t)^{-1/2} \tag{5}$$

$$Q_t = (1 - \theta_1 - \theta_2)\overline{Q} + \theta_1 \xi_{t-1}\xi'_{t-1} + \theta_2 Q_{t-1} \tag{6}$$

In equation (4), h_t^o and h_t^c appear to be the conditional volatilities of vegetable oil and carbon emission prices, respectively.

$$h_t^o = d_o^2 + b_{11}^2 h_{t-1}^o + b_{21}^2 h_{t-1}^c + a_{11}^2 \varepsilon_{o,t-1}^2 + a_{21}^2 \varepsilon_{c,t-1}^2 \tag{7}$$

$$h_t^c = d_c^2 + b_{12}^2 h_{t-1}^o + b_{22}^2 h_{t-1}^c + a_{12}^2 \varepsilon_{o,t-1}^2 + a_{22}^2 \varepsilon_{c,t-1}^2 \tag{8}$$

Additionally, in equation (6), Q_t is the time-varying conditional correlation of residuals, θ_1 and θ_2 are non-negative scalar parameters such that $\theta_1 + \theta_2 < 1$ for the model to be stationary and Q_0 refers to the matrix of unconditional correlations for the standardized noise ξ_t.

It is worth noting that the parameters of the DCC-GARCH model are estimated using the quasi-maximum likelihood estimation technique.

3. Results and discussions

The findings of the bivariate DCC-GARCH process are presented in Table 3, where r_{t-1}^o indicates the return for the rapeseed oil market at

Table 3
Results of DCC-GARCH analyses.

Independent Variable	Rapeseed oil	EUA
r_{t-1}^o	−0.0882 (.00)***	−0.0430 (.24)
r_{t-1}^c	0.0059 (.00)***	0.0018 (.93)
$\varepsilon_{o,t-1}^2$	0.1702 (.00)***	−0.0057 (.71)
$\varepsilon_{c,t-1}^2$	−0.0001 (.00)***	0.1180 (.00)***
h_{t-1}^o	0.6956 (.00)***	−0.0201 (.42)
h_{t-1}^c	0.0006 (.00)***	0.8874 (.00)***
DCC		
θ_1	0.0090 (.13)	
θ_2	0.9035 (.00)***	

time *t*-1 and r_{t-1}^c denotes the same for the emission market. h_{t-1}^o is the conditional volatility of edible oil prices at time *t*-1, while h_{t-1}^c is the conditional volatility of carbon emission prices at time *t*-1. In addition, $\varepsilon_{o,t-1}^2$ and $\varepsilon_{c,t-1}^2$ capture the news impact in rapeseed oil and emission price indexes, respectively.

The results, displayed in Table 3, suggest the presence of strong ARCH and GARCH effects in both rapeseed oil and emission markets. The sum of the ARCH and GARCH parameters also confirm that these markets are characterized by time-varying volatility. Therefore, large and small price changes are observed in each of the markets under study. In other words, periods of high prices tend to be followed by periods of high prices and periods of low prices tend to be followed by periods of low prices. Our findings are consistent with those reported by Gardebroek, and Hernandez [9] and Abdelradi and Serra [12]. These studies also find that biofuel feedstock markets (corn and rapeseed oil) are highly volatile and extreme price movements are often detected in corn/rapeseed oil markets.

Moreover, for the rapeseed oil price index, past returns appear to be impacting the current returns implying that present feedstock prices can be predicted by the lagged prices. It is also worth mentioning that there is a significant price transmission from carbon allowance market to the vegetable oil sector. Such finding is expected given that rising carbon prices inspire investors for financing in biofuel industry which, in turn, raises the biodiesel production and hence the feedstock prices. This finding is important for the policymakers arguing that as the ultimate goal of the European emissions trading system is to offer incentives for innovation and investment in clean energies, increased carbon price could play a pivotal role in serving such purpose.

Turning to the variance equations, we observe a significant volatility cross-effect between the EUA allowance and the biodiesel feedstock prices. More specifically, we find that volatility runs from emission market to edible oil market. Therefore, risk (measured by the volatility) in carbon prices transmits to the rapeseed oil prices. This finding could carry important information when predicting the biofuel market uncertainty. Further, the connection between emission and food prices should receive considerable attention while making the EU agricultural policies. Besides, these findings could be useful for investors in making proper investment decisions.

Next, Table 4 exhibits the descriptive statistics of time-varying correlations between the markets under investigation. Note that the unconditional correlations cannot capture the dynamics of the aforementioned linkage as they ignore the time-varying fluctuations of the

Table 4
Descriptive statistics of time-varying correlations.

Mean	Standard Deviation	Maximum	Minimum
0.0273	0.1577	0.5954	−0.5844

Notes: This table reports the main descriptive statistics for the time-varying correlations between carbon emission and rapeseed oil prices.

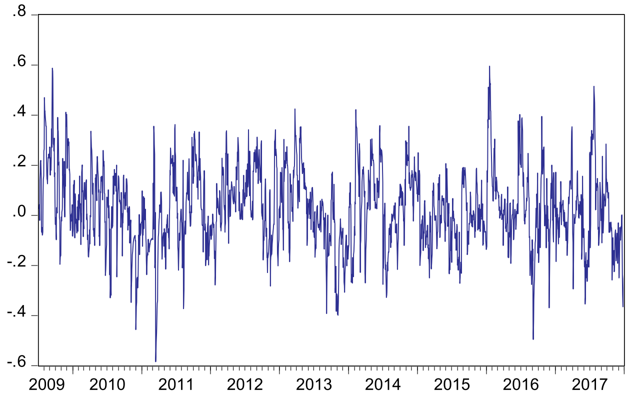

Fig. 2. Time-varying correlations between emission and rapeseed oil price indexes.

correlation structure. Exploring the connection between these markets in a time-varying environment would help us to observe how the said association evolves over time. Looking at the numbers presented in Table 4, we notice that the mean correlation is positive suggesting that emission and biodiesel prices move in the same direction. That is, an upsurge in emission prices results in increased feedstock prices, confirming our previous result.

Now, Fig. 2, which depicts the time-varying correlations, demonstrates that these correlations tend to vary over time and, hence, they are not constant. Moreover, such time-varying correlations are observed in both positive and negative regions indicating a time-dependent association between emission and rapeseed oil prices. To sum up, these findings suggest that clean energy stock price risks can be diversified if investors include both renewable energy assets and commodity volatility indices in their portfolios.

4. Conclusion and policy implications

The last decade has witnessed a significant growth in biodiesel production in order to mitigate the adverse impact of CO_2 emissions. Given that the EU biodiesel is mainly produced from rapeseed oil, higher carbon taxes are likely to raise the production of biodiesel which, in turn, increase the prices of this important edible oil. Nevertheless, the association between the EU emission trading scheme and the biodiesel market remains understudied. In this paper, we aim to fill this vacuum in the existing literature. Adopting a bivariate DCC-GARCH model, we show that an increase in the emission prices tends to promote the biodiesel feedstock prices.

Our findings could be important for policymakers when formulating appropriate hedging strategies to avoid the contagious risk emanating from the EU emission trading scheme. In addition, the information on the EUA prices could be useful in predicting the price variations of the rapeseed oil as we find a significant association amongst these sectors.

Given that risk in carbon prices causes uncertainties in the rapeseed oil price index, it is essential to adopt effective measures to manage the price volatility on rapeseed oil market. One such strategy could be promoting better market monitoring systems by introducing futures market for edible oils. A developed and improved futures market could then limit the feedstock market risk more efficiently and further make the allied markets (such as biofuel markets) more stable. In addition, governments should also take appropriate steps in order to stabilize the feedstock prices. For instance, increasing the levels of biodiesel feedstock reserves could result in lower edible oil prices. Otherwise, future price volatilities of feedstock markets could be influenced by supply shortages due to the increasing demand for renewable fuels. Additionally, the high subsidies granted from public institutions should be considered as well, because such aids could minimize the feedstock price volatility if the increased demand cannot be met by the supply [14]. Thus, to deal with such risks, the importance of optimal storage along with the long-term feedstock supply contracts will likely increase for alternative energy sectors. Abdelradi and Serra [12] also conclude that biodiesel price volatility can be managed by increasing the rapeseed oil stock levels.

Moreover, although the main goal of introducing carbon taxes is to encourage investors, producers and consumers to shift from conventional fossil fuels to clean low-carbon technologies, rising carbon taxes could result in higher food as well as biofuel prices as our results evidence a positive relationship between emission and edible oil markets implying that higher carbon taxes lead to an upsurge in rapeseed oil prices which would further cause a growth in biodiesel price index. Therefore, while designing environmental policies, governments should take into account the impact of such strategies on the biofuel-related price indexes.

Finally, due to the significant association between feedstock and first-generation biofuels, the cost of biodiesel production heavily depends on the rapeseed oil prices which, in turn, have risen as a consequence of the worldwide increasing demand for alternative fuels [12]. Hence, it is important to develop second-generation biofuels. Natanelov et al. [18], for instance, argue that biofuels derived from cellulosic plant material could provide a possible means to tackle the limitations of first-generation biofuels. Gardebroek and Hernandez [9] also contend that a shift towards second-generation biofuels, if technically and economically feasible, could reduce the price volatility of renewable fuels. To sum up, the second-generation biofuels could be a solution to the food versus biofuel debate.

Notes: The table exhibits the findings of the DCC-GARCH analyses. r^o_{t-1}indicates the return for the rapeseed oil market at time t-1 and r^c_{t-1} denotes the same for the emission market. h^o_{t-1} is the conditional volatility of edible oil prices at time t-1, while h^c_{t-1} is the conditional volatility of carbon emission prices at time t-1. In addition, $\varepsilon^2_{o,t-1}$ and $\varepsilon^2_{c,t-1}$ capture the news impact in rapeseed oil and emission price indexes, respectively. *** indicates statistical significance at 1% level. Values in parentheses denote the p-values.

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