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Is ethanol production responsible for the increase in corn prices?

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ABSTRACT

This paper aims to investigate the effects of the production of ethanol, a renewable biofuel, oil prices, population, and exchange rate on corn prices in the US (1985:m1-2020:m7) using a nonlinear smooth transition model. According to the findings, (i) ethanol production ($\beta_1 = 0.072$, $p < 0.01$) has an increasing effect on corn prices. (ii) Oil prices ($\beta_2 = 0.064$, $p < 0.05$) and population ($\beta_3 = 0.851$, $p < 0.01$) put a pressure on corn prices. (iii) The increase in the real exchange rate ($\beta_4 = -2.142$, $p < 0.01$) has a decreasing effect on corn prices. The estimation results provide several critical policy implications for ethanol-food competition within the framework of sustainable development policies. First, ethanol production puts pressure on corn prices. Second, policy-oriented research on the biofuel-food competition can provide guidance to ensure sustainability. Finally, in the transformation process of the ethanol industry, technological innovations (use of second or third-generation biofuels) can moderate the food-fuel nexus.

1. Introduction

Biofuels are seen as a clean and alternative energy source that has a critical role in achieving sustainable development goals (SDGs). Especially, biofuels are directly related to three important policy objectives. First, biofuels stand out as an alternative fuel in reducing greenhouse gas emissions caused by fossil fuels [1]. In recent years, when global warming and climate change have become a more vital concern than ever, governments have made the use of biofuels a priority target, especially in reducing greenhouse gas emissions from the transportation sector [2,3]. Similarly, the International Energy Agency (IEA, 2018) recommends the 2 °C scenarios (2DS) to combat global warming. According to this scenario, an energy system consistent with the target emission level should be developed to limit the average global temperature rise to 2 °C. To 2DS, greenhouse gas emissions, especially carbon dioxide (CO_2), need to be reduced by 70% in 2060 compared to 2014 [4]. For this goal, the use of biofuels in the transportation sector is seen as a necessity [5]. Second, biofuels have great potential in ensuring energy security. The negatives environmental externalities and non-renewable nature of fossil resources increase the importance of biofuels in meeting the future energy demand [6]. Biofuels are a safe alternative solution for energy importing countries against energy supply and price shocks [7]. Finally, biofuels can promote rural development, increase employment, and support agricultural production. Therefore, the development of the biofuel industry in poor countries is vital to economic growth [8].

Due to all these advantages and high oil prices, it is seen that global biofuel production has increased sharply in recent years. Many countries, especially the USA and Brazil, have encouraged biofuel production by offering various subsidies and tax advantages [9]. Today, the biofuel market is dominated by ethanol, accounting for 74% of global biofuel production [10]. While global ethanol production was 13,123 million gallons in 2007, the production level reached 25,583 million gallons in 2016. Global ethanol production has doubled in the last decade [11]. On the other hand, biofuels such as ethanol and biodiesel are liquid fuels, and their raw materials are agricultural products. The dramatic increase in biofuel production results in the use of sugarcane, corn, sugar beet, cassava, soybean, rapeseed, wheat, palm oil, and other agricultural products for non-food consumption [12]. Therefore, some correlation is expected between biofuels and agricultural commodity prices [13]. More strikingly, global food prices exploded almost at a time when global biofuel production was at its peak [14]. In early 2008, the rate of rise in global food prices was unprecedented [15]. The prices of food doubled between 2005 and 2008 [16]. While there was a short-term decrease in food prices in 2009, prices started to rise again in 2010 [10]. Today's world is facing a global food crisis and high levels of food

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prices continue. In particular, the increasing economic policy uncertainties with the COVID-19 pandemic have an increasing effect on global commodity and food prices [17,18]. Also, the Ukraine-Russia war has further increased the risk of food security [19]. After all, the answer to the following question has a critical importance in the context of sustainable development. Do biofuels put pressure on food security/prices?

The literature directly associates the causes of high food prices with the energy sector. However, factors such as population, urbanization, economic growth, adverse weather conditions, drought, global trade, and exchange rates are other important causes of fluctuations in food prices [20–22]. Since the main theme of this paper is the relationship (if exists) between biofuels and food prices, we focus on the behaviour of the energy sector. Agricultural production costs are directly related to energy prices through transportation, fertilizer, pesticides, and food processing costs. Crude oil is therefore the basic factor for production, processing, and delivery of the product to market in the agriculture and food sector. There is an enormous literature on the relationship between oil prices and food price/production, and is within the scope of mainstream agricultural economics [23]. The role of biofuels in the oil prices-food relationship is due to the substitution effect. Biofuel production is promoted worldwide through renewable energy subsidies, loans, and tax incentives. As biofuel production increases, a substitution relationship emerges between biofuels and fossil fuels in the world energy market, and prices of fossil resources such as oil and gas decrease due to the substitution effect [24,25]. In this respect, biofuels may have a mitigating effect on food prices by causing a fall in oil prices. In addition, some researchers argue that global warming has a major negative impact on food security/prices, and reductions in global temperatures through the development of biofuels will increase food production efficiency. According to this approach, biofuels do not contradict the food safety target [12,13,20,26,27].

On the other hand, the focus of the literature is based on biofuel-food competition. Biofuel sources include cereal grains, agricultural products and residues, energy crops, food waste, animal manure, wood and forest residues, municipal solid waste, seaweeds, etc. takes place. It is obtained from biological sources of biological materials such as Therefore, bioethanol and biodiesel stand out as the two most promising fuels for transportation that can partially/completely replace conventional gasoline and diesel, respectively [28]. However, the concern that the explosion in biofuel production, especially due to the food crisis in recent years, suppresses food prices has become the main agenda item of economic and political discussions [29–31]. The pressure of biofuels on food prices is explained by the change in supply and demand mechanism. The demand side approach underlines that the increase in agricultural product demand is not only about nutrition but also about biofuel production [32]. Agricultural products such as corn, sugar, sugar cane, soybean and rapeseed, which were previously used for nutritional purposes, are used as raw materials for the production of biodiesel and ethanol, and an additional demand for these products occurs outside of nutrition [12]. Also, due to rapid population growth and industrialization, the global demand for ethanol is constantly increasing. Given the wide primary uses of traditional crops such as maize and sugarcane as food and feed, the global demand for bioethanol production is driving demand for agricultural products such as maize and sugarcane [33]. This additional demand causes pressure on food prices. The supply side approach states that the ethanol and biodiesel production boom is a shift towards growing energy crops on farmland that was previously used for food production [10,15]. The competition between biofuels and food is experienced in the use of water, fertilizers, pesticides, machinery equipment, and agricultural labour in addition to land use [26,34]. However, Shrestha, Staab, & Duffield [36] state that when they evaluate real-world data, there is no evidence that biofuel production suppresses food prices or changes agricultural land use. Their paper also highlights that oil prices and population are two important factors affecting the world food price index. Therefore, considering the discussions, it is seen that the relationship between biofuels and food prices is complex and there is no complete consensus on this relationship [11,30,37]. Discussions about biofuels-food competition cause confusion among researchers, economists, energy experts and politicians. Moreover, empirical evidence on this topic does not seem sufficient and there is a research gap in the literatures [38].

This paper considers the research gap in the literature and examines the effect of ethanol production, oil prices, population, and exchange rate on corn prices in the US using a non-linear smooth transition model. Our paper has novelties in the field and provides the following contributions.

Firstly, doubts have been recently raised about the benefits of promoting biofuels. It is argued that the support of governments for biofuels should be reconsidered [39]. The food versus fuel debate is one of the important agenda items of the sustainable development goals [40,41]. In particular, the rise in food prices has direct effects on poverty [42]. As the poor devote a significant part of their budget to food consumption, the rise in food prices deepens their poverty [13]. The increase in food prices is also closely effected by food security and hunger [43–45]. Therefore, biofuel production and food prices are directly and indirectly related to SDG-1 (No poverty), SDG-2 (Zero hunger), SDG-7 (Affordable and clean energy), SDG-12 (Responsible production and consumption) and SDG-13 (Climate action). After all, this initiative can guide the design of sustainable development policies by revealing the links between biofuels and food prices. Secondly, a significant portion of empirical research in the literature examines the relationships between biofuels and food using linear methods. However, Enders [46] denotes that most of the time series variables demonstrate non-linear behaviours. In addition, a smooth transition model can be more attractive and realistic than the abrupt changes between regimes, meaning the parameters can be slowly changed [47–49]. Hence, to reveal efficient and reliable empirical output, this paper relaxes the strong assumption of linearity and employs time series methods based on smooth transition models. Third, this paper focuses on the United States as an example country. This choice is rational. Since the 1970s, the US government has followed an incentive and tax policy focused on the ethanol industry. Thus, the US produces about 58% of global ethanol production [11]. On the other hand, USA is the major corn exporter country [50,51]. Although various raw materials are used in the production of ethanol, the most common raw material used in ethanol production in the US is corn. While the use of corn in ethanol production was 6% of the total domestic consumption in 1990, this rate increased to 37% in 2008 with the acceleration of ethanol industry [9]. As a result, examining the biofuel-food price relationship in the context of ethanol-corn price for the US may provide important political implications.

2. Literature review

Food-energy competition is of great interest to academics and economists as it has critical political implications. With the oil crisis (the 1970s), the literature began to examine the impact of the energy sector and oil prices on economic growth, employment, production, inflation and food [52–54]. After Pindyck & Rotemberg [55]'s pioneering paper examining the co-movements between commodity prices, the literature started to grow rapidly [14,56]. It is seen that the papers in this field generally focused on the oil prices-commodity prices relationship until the end of the 2000s [57–61]. While the literature on the impact of oil/energy prices on commodity prices remains up-to-date [62–66], with the 2007/2008 Food Crisis, the literature has begun to discuss the impact of biofuels on food prices. Global food prices reached higher peaks in 2011 than in 2008. In the same period, oil prices were falling. Researchers focused on the biofuel production boom and debated the status of biofuels as a possible cause of the rise in food prices [67]. Later, empirical studies began to provide increasing evidence of biofuel-food competition.

When empirical papers are evaluated, it is seen that biofuel-food competition is investigated with various methods such as microeconomic-macroeconomic models, general equilibrium-partial equilibrium analysis, ARCH-GARCH models, statistical methods, time series analyses and panel data methods. While there is no consensus in the literature, the results vary according to the method followed, countries, regions, and time dimension. We analysed the literature review by dividing the papers into two groups. The first group involves the papers that support arguments that biofuels are putting pressure on food prices. The second group comprises the papers that support the arguments that biofuels have no or insignificant/minor impact on food prices.

Serra et al. [9] analyse the relationships between ethanol, gasoline, and corn prices in the USA for the period 1980–2008 with a vector error correction model. The analysis indicates co-movement and strong relationships between ethanol, gasoline and corn prices. Tokgoz, Zhang, Msangi, & Bhandary [68] investigate the relationship between biofuel production and food prices in OECD countries with the International Model for Policy Analysis of Agricultural Commodities and Trade. Research shows that increases in biofuels affect food prices upwards, posing a food security risk. Monteiro et al. [30] examine the effect of ethanol production on the global food price index in the US and Brazil for the period 1980–2007 using the least squares (OLS) method. The findings show that the growth in the ethanol industry in Brazil is pushing food prices upwards. Also, it is estimated that ethanol in the US does not have a significant impact on food prices. As a result, the impact of the ethanol sector on food prices differs in the US and Brazil. Bahel, Marrouch, & Gaudet [70] demonstrate the impact of biofuels and oil prices on food using a general equilibrium model. General equilibrium results show that biofuels are putting pressure on food prices. To & Grafton [71] test the impact of oil, GDP per capita and biofuels on food in the US with autoregressive models. According to their results, biofuels and oil prices have a significant impact on global food prices. Also, in the 2008 Global Food price boom, biofuels and crude oil prices affected the increase in food prices by 38% and 41%, respectively. Koizumi [34] evaluates the impact of oil and biofuels on food using the OLS method. Example countries are China, Thailand, Indonesia, Brazil, Malaysia, and the USA. OLS findings confirm that biofuel production negatively impacts food security. Dick & Wilson [72] search the impact of increased ethanol on land-use and food security in Nigeria over the period 1995–2010. The paper follows the partial equilibrium analysis. The analysis results indicate that the growth in ethanol production negatively affects food security and land use.

Evaluating more recent research over the past few years, Martínez-Jaramillo, Arango-Aramburo, & Giraldo-Ramírez [73] consider the impact of biofuels on land-use change and food security for Colombia. The research makes predictions with the system dynamics model for the period 2016–2030. Estimates indicate that biofuel production reduces the supply of land dedicated to food production and increases food prices. Lima et al. [62] investigate the relationship between sugar and biofuels in Brazil using detrended partial cross correlation. Correlation findings indicate a strong positive correlation between ethanol and sugar price and volatility. Maitah et al. [29] evaluate the effect of the growth in ethanol production in Brazil on sugar, wheat, corn, and barley prices with unit root and cointegration analyses. Empirical findings confirm that the increase in ethanol production affects the prices of sugar, wheat, corn, and barley. Gilbert & Mugera [27] examine the links between ethanol production and corn prices in the US. In the research, a structural break regression method is followed. According to the estimation results, ethanol production has a positive effect on corn prices.

When we examine the second group of studies supporting the arguments in favour of biofuel in the literature, Ajanovic [20]'s paper has noteworthy outputs. The paper considers the relations between biofuels, production cost, land, crude oil and food prices in the US and Europe. As a method, a comparative analysis is followed by considering various statistics. According to the findings, biofuel production may have an additional price effect on agricultural raw material prices by triggering raw material demand. However, the dominant effect on agricultural raw material prices is oil prices and speculation. In other words, the impact of biofuels on food prices is slight and minor. Gilbert [26] investigates the relationships between food, crude oil, biofuels, exchange rate and speculation using the Granger causality test method. The findings reveal that the main reason for the changes in agricultural commodity prices is the explosion of demand, monetary and financial developments. The paper notes that there is no substantial evidence about the impact of biofuels on commodity prices. Zilberman et al. [31] evaluate the impact of biofuels on food prices through simulations and other theory-based calculations. The findings show that the biofuels market does not have a significant impact on food prices. The paper further argues that biofuels are not one of the dominant causes of food inflation and that different biofuels have different effects. Tyner [13] evaluates the causes for the increase in commodity prices and the relationship between biofuel production and food prices in the US, Brazil and Europe. The research reveals that biofuels are not a key driver of the raise in global food prices. It is implied that global supply and demand trends, regional or commodity-specific supply disruptions, economic problems such as exchange rate volatility, recession, financial crisis, and trade policy changes have an impact on prices. Bentivoglio et al. [10] investigate the relationship between gasoline prices, ethanol and food prices in Brazil using VECM, Granger causality, impulse-response functions and variance decomposition method. The results confirm that there is no strong evidence that changes in the ethanol market have an impact on food prices. Dutta [11] investigates the relations between oil prices, biofuels and sugar prices in Brazil employing an augmented autoregressive distributed lag bounds testing (ARDL) and causality methods. The findings show that sugar prices are not affected by ethanol price fluctuations, while ethanol prices are affected by sugar prices.

When examining more recent papers that present evidence in favour of biofuels, we first focus on Taghizadeh-Hesary, Rasoulinezhad, & Yoshino [75]'s empirical paper on the energy-food security relationship in eight Asian countries for the period 2000–2016. The paper follows the panel-Vector Autoregression model (VAR) method. The research shows that 65% of the rise in food prices is explained by oil. It also confirms that the effect of biofuel prices on food prices is statistically significant, but the explanation rate is low (2%). Shrestha et al. [35] examine the impact of biofuel production on food price index and land-use change over the period 1991–2016 using Matlab®'s Statistical and Machine Learning Toolbox method. The research provides some important implications. (i) Crude oil and population are the two important drivers affecting the global food prices. (ii) There is no evidence that biofuels were the cause of the rise in food prices before and after the 2000 biofuel boom. (iii) Despite increasing biofuels in the US, corn and soybean exports are not falling. (iv) Finally, it confirms that there are no significant co-movements in food prices due to paper biofuel production. Also, biofuels do not cause agricultural land use change. Subramaniam et al. [12] investigate the relationship between biofuel production, environment, and food insecurity in fifty one countries using the generalized method of moments (GMM). According to the findings, biofuels have no significant effect on food prices. More importantly, biofuels increase food security by improving environmental quality (lowering global temperatures). Bilgili et al. [14] examine the effect of biofuel production on food prices in the US between 1981 and 2008 with the wavelet analysis method, using population and oil prices as control variables. The paper shows that biofuels had strong reducing effects on food prices in the period 2011–2017.

On the other hand, energy is an important production factor that directly affects different sectors such as transportation, agriculture, industry, and households. In the food-energy nexus, many papers confirm that oil prices are a major driver in the agriculture sector [75]. However, the biofuels-food nexus is relatively new and controversial. There is no consensus in the literature and new evidence is needed [14]. The main motivation for this paper is to provide more robust and new evidence on the relationship between ethanol production and corn prices. Therefore, we employ a non-linear smooth transition model using the control variables of exchange rate, population, and crude oil to explain the effect of ethanol on corn prices.

3. Model and data

This paper launches a model (Eq. (1)) as follows to examine the effect of ethanol on corn prices. In Eq. (1), corn prices are the dependent variable and ethanol production is the explanatory variable, while population and exchange rate are the control variables. θ represents the error term. $\beta_0, \beta_1, \ldots, \beta_4$ are the estimation parameters showing the effect of the explanatory and control variables on the dependent variable. The series are used with their natural logarithmic form. The data covers the period 1980–2020 and consists of monthly observations. Table 1 shows summary information about the data.

$$Corn\_P_t = \beta_0 + \beta_1\, Ethanol\_P_t + \beta_2\, Oil\_P_t + \beta_3\, Population_t + \beta_4\, Exchange\_R_t + \theta_t \tag{1}$$

The expected results about the estimation parameters are as follows. (i) If $\beta_1 > 0$ and significant, ethanol production has an increasing impact on corn prices. (ii) If $\beta_1 < 0$ and significant, ethanol production has a reducing effect on corn prices. (iii) If the coefficient of β_1 is not significant, ethanol production has no effect on corn prices. (iv) Crude oil prices are expected to have an increasing impact on corn prices ($\beta_2 > 0$ and significant). (v) The expected sign is positive as the population is an indicator that triggers food demand ($\beta_3 > 0$ and significant). (vi) An increase in the real exchange rate (or an increase in the value of the US dollar) means a decrease in foreign demand for corn and a decrease in corn prices. Therefore, the parameter of β_4 is expected to be negative and significant.

In Table 2, descriptive statistics and correlation matrix are presented to reveal initial information about the variables. According to Table 2, the statistical values of the variables are close to each other. The mean, median, maximum, and minimum values of the population variable are larger than the other variables. According to the Jarque-Bera test results, the series of the variables do not have a normal distribution. There is a positive correlation between Ethanol_P, Oil_P, Population and Corn_P. There is a negative correlation between Exchange_R and Corn_P. There is no high-order correlation between independent variables. The multicollinearity problem is excluded. These results indicate that the data are economically/statistically fit with the analysis.

Fig. 1 shows the trend of variables overtime to provide preliminary information about the co-movement of corn prices and ethanol production. Fig. 1 provides information on trends and co-movements between ethanol production and corn prices. The variable Ethanol_P is predicted by the polynomial equation of $y = 7E\text{-}09x^2 - 0.0002x + 0.6184$ and the variable Corn_P is described by $y = 3E\text{-}09x^2 - 0.0002x + 3.1864$. R^2 values are 0.938 and 0.843, respectively. Finally, the trends show an increasing co-movement between ethanol production and corn prices after 1996.

Table 1
Data definition and sources.

Data	Definition (unit)	Variable type	Source
Corn_P	Corn Prices Received (U.S. Dollars per bushel)	Dependent	United States Department of Agriculture National Agricultural Statistics Service (USDA NASS)
Ethanol_P	Fuel ethanol production (trillion BTU)	Explanatory	U.S. Energy Information Administration (EIA)
Oil_P	Crude Oil Prices (U.S. Dollars per Barrel)	Control	EIA
Population	Total Population (Million)	Control	U.S. Bureau of Economic Analysis
Exchange_R	Real monthly commodity trade weighted exchange rate (Indexes)	Control	USDA NASS

Table 2
Descriptive statistics and correlation matrix.

	Corn_P	Ethanol_P	Oil_P	Population	Exchange_R
Mean	1.040	3.115	3.425	12.560	4.714
Median	0.955	2.739	3.265	12.572	4.707
Maximum	2.032	4.787	4.852	12.706	4.854
Minimum	0.336	1.368	2.083	12.378	4.533
Std. Dev.	0.372	0.192	0.624	0.100	0.077
Jarque-Bera	28.684[a]	48.555[a]	32.703[a]	31.058[a]	13.858[a]
Observation	425	425	425	425	425
Correlation matrix					
Corn_P	1				
Ethanol_P	0.382	1			
Oil_P	0.462	0.547	1		
Population	0.402	0.799	0.567	1	
Exchange_R	−0.366	−0.106	−0.308	−0.095	1

[a] indicates 1% statistical significance.

The descriptive statistics, correlation matrix, and trend plot of the series provide some preliminary information about the impact of ethanol production on corn prices. However, for more robust findings, we use unit root, cointegration and parameter estimators. Before going into the analysis, the critical question is which of the linear or nonlinear methods should be used. This paper performs the Broock, Scheinkman, Dechert, & LeBaron [77] and Luukkonen, Saikkonen, & TerÄsvirta [78] tests to check for non-linearity. As is seen in Table 3, both tests' results indicate the rejection of the null hypothesis of linearity. In other words, the relationship between ethanol production, crude oil, population, exchange rate and corn prices in the US exhibits a non-linear trend process. Therefore, we follow nonlinear methods in the econometric analysis.

4. Methodology

Over the last decades, linearity has been considered as a very strong assumption for a time series analysis and researchers have paid attention to nonlinear time series models. The initial models, such as threshold autoregressive models and Markov regime switching models, have focused on abrupt changes between regimes. However, a smooth transition between regimes which lets the slope parameters slowly change is more realistic compared to the abrupt changes between regimes indicated by the initial models [47–49]. Therefore, the present paper performs time series techniques based on smooth transition models.

4.1. Non-linear unit root test

Kapetanios, Shin, & Snell [79] suggest a unit root test for examining unit root properties of a time series variable. While the null hypothesis of the test implies there exists a unit root, the alternative hypothesis means there is a non-linear exponential smooth transition autoregressive (ESTAR) process which means stationarity. Kapetanios et al. [79] utilize the ESTAR model defined as

$$y_t = \beta y_{t-1} + \gamma y_{t-1}\left[1 - exp\left(-\theta y_{t-d}^2\right)\right] + \varepsilon_t \tag{2}$$

Equation (1) could be restated as below:

$$\Delta y_t = \varphi y_{t-1} + \gamma y_{t-1}\left[1 - exp\left(-\theta y_{t-d}^2\right)\right] + \varepsilon_t,\ \varphi = \beta - 1 \tag{3}$$

Afterwards, they reveal the ESTAR model described below by respectively assuming φ and d as 0 and 1:

$$\Delta y_t = \gamma y_{t-1}\left\{1 - exp\left(-\theta y_{t-1}^2\right)\right\} + \varepsilon_t \tag{4}$$

They present the following equation by utilizing a first-order Taylor series approach for this model:

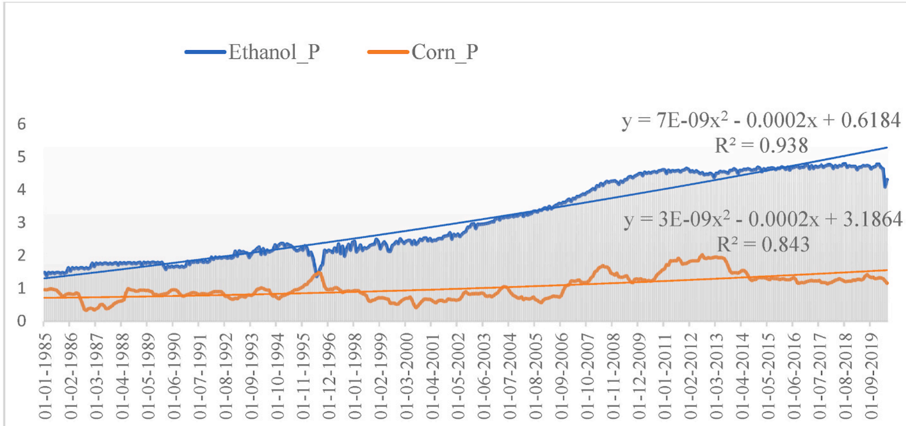

Fig. 1. The trends of Ethanol_P and Corn_P, 1985:01–2020:07.
Source: EIA (2021), USDA NASS (2021).

Table 3
Results of non-linearity estimate.

Panel $_A$: BDS test					
Variable	Dimensions				
	2	3	4	5	6
Corn_P	0.179[a]	0.299[a]	0.383[a]	0.434[a]	0.471[a]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Ethanol_P	0.197[a]	0.338[a]	0.437[a]	0.505[a]	0.553[a]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Oil_P	0.187[a]	0.315[a]	0.403[a]	0.462[a]	0.501[a]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Population	0.209[a]	0.355[a]	0.458[a]	0.531[a]	0.582[a]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Exchange_R	0.178[a]	0.299[a]	0.381[a]	0.435[a]	0.471[a]
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Panel $_B$: Luukkonen et al. (1988) test					
Test statistic			Prob. value		
25.376[a]			0.000		

[a] indicates 1% statistical significance. Values in parentheses indicate probability.

$$\Delta y_t = \delta y_{t-1}^3 + \varepsilon_t \tag{5}$$

They acquire the t_{NL} statistic for δ = 0 against δ < 0 as below:

$$t_{NL} = \widehat{\delta} / s.e.(\widehat{\delta}) \tag{6}$$

In Eq. (6), $\widehat{\delta}$ and $s.e.(\widehat{\delta})$ stand for the OLS estimation for δ and the standard error for $\widehat{\delta}$, respectively. If the calculated t_{NL} statistic is higher than critical values produced by Kapetanios et al. [79], the null hypothesis is rejected, which means the series under consideration is stationary.

4.2. Non-linear cointegration test

Kapetanios, Shin, & Snell [80] propound a cointegration test using non-linear exponential smooth transition (ESTR) error correction models. The null hypothesis of the test is that there is no cointegration in the model, while the alternative hypothesis implies ESTR cointegration. Their test not only considers the possible non-linearity in the model, but also has better small-sample performance compared to the linear Engle & Granger [81] and Johansen [82] cointegration estimations. They utilize several statistical regressions and present the ESTR error correction model defined as below:

$$\Delta y_t = \varphi u_{t-1} + \gamma u_{t-1}\left(1 - e^{-\theta(u_{t-1} - c)^2}\right) + \omega' \Delta x_t + \sum_{i=1}^{p} \psi_i' \Delta z_{t-i} + e_t \tag{7}$$

$$\Delta x_t = \sum_{i=1}^{p} \Gamma_{xi} \Delta z_{t-i} + \varepsilon_{xt} \tag{8}$$

$$\widehat{u}_t = y_t - \widehat{\beta}_x' x_t \tag{9}$$

In Eq. (9), $\widehat{\beta}_x$ denotes the OLS estimation of β_x. They produce four test statistics, namely F_{NEC}, F_{NEC}^*, t_{NEC}, and t_{NEG}, to test for cointegration in the empirical model. The F_{NEC} and t_{NEC} tests respectively indicate the F-type and t-type statistics that are directly obtained from the nonlinear ESTR error correction regression, while the t_{NEG} test corresponds to the nonlinear analogue of the Engle & Granger [81] cointegration statistic. They estimate the following regression to obtain the F_{NEC} statistic:

$$\Delta y_t = \delta_1 \widehat{u}_{t-1} + \delta_2 \widehat{u}_{t-2}^2 + \delta_3 \widehat{u}_{t-3}^3 + \omega' \Delta x_t + \sum_{i=1}^{p} \psi_i' \Delta z_{t-i} + \varepsilon_t \tag{10}$$

The null hypothesis of the absence of cointegration for this test is described as H_0: $\delta_1 = \delta_2 = \delta_3 = 0$. Kapetanios, Shin, & Snell [75] estimate the restricted version of the regression in Eq. (10) to calculate the F_{NEC}^* statistic. This regression model is described as follows:

$$\Delta y_t = \delta_1 \widehat{u}_{t-1} + \delta_2 \widehat{u}_{t-3}^3 + \omega' \Delta x_t + \sum_{i=1}^{p} \psi_i' \Delta z_{t-i} + \varepsilon_t \tag{11}$$

The null hypothesis of no cointegration for this test is described as H_0: $\delta_1 = \delta_2 = 0$. The t_{NEC} statistic that is obtained with the estimation of the following model:

$$\Delta y_t = \delta \widehat{u}_{t-1}^3 + \omega' \Delta x_t + \sum_{i=1}^{p} \psi_i' \Delta z_{t-i} + \varepsilon_t \tag{12}$$

The null hypothesis of no cointegration for this test is shown as H_0: δ = 0. The following regression equation is estimated to produce the tNEG statistic:

$$\Delta \widehat{u}_t = \delta \widehat{u}_{t-1}^3 + \sum_{i=1}^{p} \varphi_i \Delta \widehat{u}_{t-i} + \varepsilon_t \tag{13}$$

The null hypothesis of the absence of cointegration for this test is indicated as H_0: δ = 0. If these test statistics are higher than the critical values produced by Kapetanios et al. [73], it is determined that there occurs cointegration in the model.

5. Results, discussions, and suggestions for future research

The empirical findings for the Kapetanios et al. [74] unit root test are exhibited in Table 4. As seen, the results of the test imply that the null hypothesis of a unit root can be rejected at the first difference, implying

Table 4

Kapetanios et al. [74] unit root test.

Variables		Test statistic	
		Level	1st difference
Corn_P		−1.092	−10.376*
Ethanol_P		0.576	−2.174***
Oil_P		−0.734	−4.207*
Population		−0.926	−2.710**
Exchange_R		−0.133	−2.793**
Critical values			
1%	5%	10%	
−2.82	−2.22	−1.92	

*, **, and *** respectively indicate 1%, 5%, and 10% statistical significance.

all variables in the model are stationary at their first difference forms. Hence, the possible presence of cointegration in the model could be searched for via the Kapetanios et al. [75] cointegration test.

Finally, the results obtained from the Kapetanios et al. [75] cointegration test and the long-run coefficients of the explanatory variables are depicted in Table 5. As seen, panel A of the table indicates the null hypothesis of no cointegration is rejected at 1% level of significance regarding all test statistics. This finding presents strong evidence about the presence of cointegration in the model. In other words, ethanol production, crude oil, population, exchange rate and corn prices in the US have a co-movement in the long run and there is a steady equilibrium relation between them. After determining the existence of cointegration, panel B of the table reports the long-run parameters. According to the findings, (i) ethanol production ($\beta_1 = 0.072$, $p < 0.01$) causes the rise in corn prices. We confirm that ethanol production is a significant reason for the rise in corn prices. (ii) Oil prices ($\beta_2 = 0.064$, $p < 0.05$) and population ($\beta_3 = 0.851$, $p < 0.01$) put a pressure on corn prices. (iii) The increase in the real exchange rate ($\beta_4 = -2.142$, $p < 0.01$) has a decreasing effect on corn prices. Therefore, the empirical output of the Kapetanios et al. [75] cointegration test implies that Corn_P is positively related to Ethanol_P, Oil_P, Population and is negatively related to Exchange_R. It is seen that the findings on the impact of crude oil, population and exchange rate on corn prices are in line with expectations.

The estimation results have important implications about ethanol-food competition within the framework of sustainable development policies. Our findings are in line with papers confirming that biofuels have a negative impact on food prices/security [9,29,30,34,68,69,74]. According to the arguments against biofuels, the main causes for the rise in food prices are briefly as follows. (i) When agricultural commodities/food products are used as raw materials for biofuel production, an additional demand for these products arises [10,12]. Rapid population growth and industrialization increase the demand for ethanol, while this increase supports the use of more traditional crops such as corn and sugarcane [33]. (iii) As a result of the rise in biofuel production, an additional demand arises in the use of land use, water, fertilizer, pesticides, machinery-equipment and agricultural labour [26]. (iv) There is competition for food and energy in land use. With the increasing demand for ethanol, land use shifts from food to energy [10,15]. (v) Farmers turn to energy agriculture instead of food-based agriculture. Food production is reduced [15]. Also, advocates of arguments against biofuels cite booms in biofuel production as a possible cause of the 2007–2008 World Food Crisis [84]. In addition, empirical papers predominantly estimate the relationship between biofuels and food prices based on linearity assumption. We followed a nonlinear econometric method to provide robust evidence for the discussions in the literature. After all, our findings provide strong evidence for demand- and supply-side arguments against biofuels.

Table 5

Kapetanios et al. [75] cointegration test and long-run parameters.

Panel $_A$: Kapetanios et al. (2006) cointegration test			
F_{NEC}	F^*_{NEC}	t_{NEC}	t_{NEG}
45.379[a]	68.190[a]	−11.691[a]	−8.494[a]
Panel $_B$: Long-run parameters			
Variables	Coefficient	Std. error	t-statistic
Ethanol_P	0.072[a]	0.019	3.815
Oil_P	0.064**	0.036	1.778
Population	0.851[a]	0.077	10.964
Exchange_R	−2.142[a]	0.192	−11.131

[a] and ** respectively illustrate 1% and 5% statistical significance.

After the oil crisis, the interrelationships between the energy sector and the food sector have attracted the attention of the literature, and tremendous research has been provided on this topic. Until recently, the literature generally addressed the impact of oil price shocks on food price and security. However, the explosion in biofuel production in the 2000s raised the question that biofuels could be a possible cause for the increase in food prices [85]. The findings of this paper provide empirical evidence to this question that biofuel production puts pressure on food prices. However, despite the new evidence it provides to the field, this research has some limitations. Firstly, since the global market is the most important producer, we focus on ethanol production in the US. Future research may consider other important producers such as Brazil, Canada, China, EU countries. Or a global panel of data on biofuel-food competition could be examined. Second, researchers can provide new evidence to the literature by following various statistical and econometric methods. This paper also might suggest that future research on the nexus between biofuels and food follow continuous wavelet analyses to observe co-movements during different subsamples at different frequencies or consider employing structural VAR methodology to decompose income and substitution effects of biofuels and fossils on food prices. Another possible future work might consider panel linear and nonlinear TAR unit root analyses for the biofuels energy supply [86] and the food prices of several states of the US and/or European countries. Third, policy-oriented research on biofuel-food competition is critical as well as empirical research on what policies should be followed to ensure sustainability. Fourth, indicators such as economic growth, urbanization, total factor productivity, energy security, economic policy uncertainty, pandemic uncertainty, trade, and R&D can be included to provide new perspectives on the energy-biofuel-food relationship. New perspectives are undoubtedly required in designing sustainable policies on the food-energy competition. Finally, the US ethanol industry is still in an ongoing process of expansion and transformation. In this context, future research will be needed to reveal the effect of ethanol on corn prices [9].

6. Conclusion and policy recommendations

Does biofuel production put pressure on food prices? This question, which has been discussed recently, undermines the critical importance of biofuels in achieving sustainable development goals such as energy security, climate change action and economic development. To answer this question, the paper examines the effect of ethanol on corn prices in the US employing oil prices, population and exchange rate control variables and a non-linear smooth transition model. The estimation results provide strong evidence that ethanol production is putting pressure on corn prices. In addition, while oil prices and population have an increasing effect on corn prices, increases in the exchange rate index have a decreasing effect on corn prices. As a result, while biofuels support critical sustainable development goals such as economic growth, reducing greenhouse gas emissions and contributing to energy security, they have distorting effects on food prices and therefore on food security. The output of this paper supports the arguments that biofuels are putting pressure on food prices. Supporting these arguments, some of the papers provide evidence with general equilibrium–partial equilibrium analysis [68,69,72], some with ARCH–GARCH models [87], and others with time series and panel data analyses [9,25,29,30,34]. On the other hand, papers generally provide evidence based on the assumption that the relationship between variables is linear. This paper supports the same result with a nonlinear smooth transition model. After all, there is a need for policies to mitigate the negative effects of biofuels on food prices/security.

This paper offers some recommendations to the authorities. (i) The global biofuel industry produces predominantly first-generation fuels. But the promotion of second-generation and third-generation biofuels that are not based on agricultural raw materials could moderate competition for land use and commodities and the impact on food prices [12,39,88]. (ii) Energy policies, agricultural policies and food policies should be considered together. Because there is substantial evidence of interconnections in the energy, agriculture, and food sectors [74,75]. (iii) One of its main solutions is to increase the supply of commodity crops in an economically, socially, and environmentally sustainable and responsible manner. It is of great importance to apply and develop new technologies to increase the yield of crops by assuming the amount of land used in agriculture as constant. There is substantial evidence that new technologies increase crop yields [32,89,90]. Similar efforts could mitigate the effects of biofuels on food prices/security.

CRediT authorship contribution statement

Emrah Kocak: Conceptualization, Methodology, Validation, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Faik Bilgili:** Conceptualization, Validation, Investigation, Resources, Writing – original draft, Writing – review & editing, Visualization, Supervision, Project administration. **Umit Bulut:** Conceptualization, Methodology, Software, Validation, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing. **Sevda Kuskaya:** Methodology, Software, Validation, Investigation, Resources, Data curation, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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