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The relationship between carbon dioxide emissions and Portuguese agricultural productivity

This study analyses the relationship among carbon dioxide emissions, energy consumption, agricultural labour productivity, agricultural land productivity and agricultural raw material exports using a time series for the period 1960-2015. In this article, some theroretical hypotheses are formulated, aiming to explain the bidirectional causality between agricultural productivity and climate change. These hypotheses are tested by using Vector Autoregression (VAR), Granger causality and Vector Error Correction Models (VECM). Results confirm revelant theoretical hypotheses between agricultural productivity and climate change and show that the variables used are stationary. Agricultural labour and land productivity as well as agricultural raw material exports are positively related to CO_2 emissions, meaning that these variables stimulate environmental pollution. Empirical results presented in the paper might be of interest to the academic community and also to policymakers.

Keywords: CO_2 emissions, Time Series, Agricultural Productivity, Portugal

JEL classifications: Q12, Q15

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Introduction

This paper examines the link between carbon dioxide emissions (CO_2) and Portuguese agricultural activity for the period 1960-2015. The relationship among energy consumption, agricultural labour productivity, agricultural land productivity and agricultural raw material exports are analysed by using time series models such as Unit Root Test, Vector Autoregression (VAR) and Vector Error Correction Model (VECM).

Indeed, there are numerous empirical studies that evaluate the relationship between energy consumption and growth (e.g. Altunbas and Kapusuzolu, 2011; Shahbaz *et al.*, 2013; Leitão, 2015; Leitão, 2014; Balogh and Jambor, 2017). These studies considered the arguments of the Environmental Kuznets Curve (ECK). Our research follows a different line, aiming to evaluate the impact of agricultural activity on CO_2 emissions. The literature is not unanimous in this field. Some authors, such as Asumadu-Sarkodie (2016), Filiz and Omer (2012) and Baktiari el al. (2015), have concluded that agricultural production increases the rate of environmental pollution, thereby intensifying climate change. However, there are other studies (e.g. Pant, 2009; Edoja *et al.*, 2016) concluding that agricultural productivity has a negative impact on CO_2 emissions.

Human ecology, energy economics, resource economics, international treaties and international conferences (Rio Earth Summit 1992, Kyoto Protocol 1997, Paris Agreement 2015) have alerted the international community and international economics to reduce greenhouse gas emissions, namely CO_2 emissions, accounting for most of the global warming and climate change.

This paper aims to contribute to the existing empirical literature in many ways. First, the link between energy consumption and CO_2 emissions is revisited. Second, the correlation between carbon dioxide emissions and agricultural production is also analysed. Third, assumptions are made based on the literature and they are tested by using modern econometrics techniques.

The study is structured as follows. The next section presents a literature review, followed by the demonstration of some descriptive statistics. Methodology and econometric specifications are presented in Section 4. Econometric results are presented in Section 5, while the last chapter draw some conclusions and policy recommendations.

Literature review

In this section, the most relevant literature is considered, explaining the link between agricultural productivity and environmental pollution. Literature in general has seen pollution as one of the major causes of climate change. Scientific articles in this area address this issue concerning the relationship among climate change, energy consumption, agricultural productivity, agricultural land productivity and international trade. Researchers have used different econometric approaches to analyse this issue. Empirical studies on the topic have more often used dynamic models, both concerning time series and panel data. However, as the literature review below suggests, time series using autoregressive vectors (VAR and vector error correction model - VECM) have been more frequently used because this methodology permits to estimate the causality between the variables used (see recent contributions of Asumadu-Sarkodie, 2016; Edoja *et al.*, 2016 and Ullah *et al.*, 2018).

A considerable part of the literature emphasizes the relationship between energy consumption (non renewable energy) and carbon dioxide emissions. The increase of economic activity assumes an increase in energy consumption and consequently an increase in carbon dioxide emissions. The empirical studies of Leitão and Shahbaz (2013), Leitão and Shahbaz (2016), Hamilton and Turton (2002), Friedl and Getzner (2003), Liu (2005), Ang and Liu (2001), Halicioglu (2009) as well as Jalil and Mahmud (2009) found a positive relationship between energy consumption (non-renewable energy) and CO_2 emissions, showing that energy demand has been continuously increasing in the world economy. The recent empirical studies of Mirza and Kanwal (2018) and Khobai and Roux (2017) consider the relationship between energy consumption, economic growth and carbon dioxide emissions, using time series analysis (unit root test, Granger causality, and VECM). Their econometric results show that there is causality between energy consumption and international trade. However, the empirical studies of Balogh and Jambor (2018), Kwakwa (2012), and Pant (2009) found that energy consumption is negatively related to CO_2 emissions.

Another part of the literature analyses causality between agricultural production and carbon dioxide emissions (CO_2). Such studies have been using more frequently the Ganger's causality and autoregressive vector models (VAR and VECM). In this context, carbon dioxide emissions and the agricultural ecosystem were investigated by Asumadu-Sarkodie and Owusu (2017) concerning the period 1961-2012. They have concluded that there was a bidirectional causality relationship between carbon dioxide emissions, agricultural production and non-renewable energy. The study of Khan *et al.* (2018) analyzes the relationship among agricultural productivity, energy consumption, renewable energies, forest area, vegetable area and carbon dioxide emissions from 1981 to 2015 and has shown causality between independent variables and carbon dioxide emissions (Khan *et al.*, 2018).

Ullah *et al.* (2018) analysed agricultural ecosystem and climate change in Pakistan. By using modern econometric methodologies such as Johansen cointegration and autoregressive tests, the authors proved that agricultural system was cointegrated with carbon dioxide emissions. The authors were also able to demonstrate that the use of fertilizers, energy consumption, agricultural machinery and agricultural production promoted the increase of carbon dioxide emissions. The Granger causality test found that there is a bidirectional causality between rice area and carbon dioxide emissions. The same was valid for cereal production and carbon dioxide emissions as well as crop production and carbon dioxide emissions.

The correlation between carbon dioxide emissions and the agriculture sector in Ghana was investigated by Asumadu-Sarkodie and Owusu (2016). This study compared the econometric results of Vector Error Correction Model (VECM) and Autoregressive and Distributed Lag (ARDL) model. The authors considered carbon dioxide emissions as a dependent variable and they introduced total livestock per change in area, annual change of agricultural area, total roots and tubers production, total primary vegetable production, total primary vegetables production, total pulses production, total fruit production, total coarse grain production and cocoa beans production as explanatory variables. Considering the long run results of VECM, the variables of cocoa beans production, fruit production, livestock per hectare and agricultural area showed multivariate causality with carbon dioxide emissions. All variables introduced in this regression caused carbon dioxide emissions except vegetable production. In this context, Bakhtiari *et al.* (2015) examined the relationship between energy and CO_2 emissions of saffron production using the arguments of Cobb-Douglas function and their results showed that saffron production stimulated CO_2 emissions.

However, there are studies showing that agricultural productivity is negatively correlated with carbon dioxide emissions. In fact, the empirical study of Edoja *et al.* (2016) analyzed the relationship between carbon dioxide emissions, agricultural production and food security in Nigeria for the period 1961-2010. The authors used times series analysis (unit root test, Johansen cointegration test, vector autoregressive model and Granger causality). Through unit root tests, the authors were able to demonstrate that agricultural productivity, food security and carbon dioxide emissions were stationary in first differences. The use of Johansen cointegration test showed that the variables used in this research were not in cointegration. By applying a VAR model, results showed that agricultural productivity and food security were negatively correlated with carbon dioxide emissions. However, when carbon dioxide emissions were used as the dependent variable, agricultural productivity and food security were not statistically significant as factors. The Granger causality test demonstrated an unidirectional causality between carbon dioxide emissions and agricultural productivity and food security. In this context, by using dynamic panel data, Balogh and Jambor (2017) concluded that the development of agricultural productivity contributed to a decrease in CO_2 emissions and also proved that agricultural land productivity contributed to environmental pollution growth.

The effects of agriculture on climate change were also investigated by Pant (2009). By applying a multiple regression model, results showed that agricultural land, irrigation, biomass and the efficient use of energy had a negative impact on carbon dioxide emissions. Fertilizer use had a positive effect on carbon dioxide emissions, showing that production and machinery contributed to climate change growth.

The link between international trade and environmental pollution is also analysed by the literature. In fact, the literature here is not unanimous. The dominant paradigm argues for a positive impact of trade on carbon dioxide emissions. If we consider that developed economies are concerned about climate change, then the expected signal will be negative (i.e. in this perspective, international trade discourages climate change). Mahmmood and Alkahateeb (2017) showed that trade permited to reduce pollution in Saudi Arabia, considering time series (unit root and cointegration tests). However, studies of Balogh and Jambor (2017), Shahbaz and Leitão (2013), Shahbaz *et al.* (2013) and Leitão (2015) found a positive relationship between international trade and carbon dioxide emissions. In this context, empirical studies of Amador *et al.* (2016), Andersson (2018) and Wang and Ang (2018) showed that trade liberalization and globalization accentuated global carbon dioxide emissions.

Descriptive statistics

According to the Bank of Portugal, agricultural sector represented 9% in the Portugese economy in 2015, corresponding to 35 thousand companies (Bank of Portugal, 2016), most of which were small and medium-sized enterprises (around 85%). Portuguese agricultural production is almost destined to meet domestic demand. Therefore, agricultural exports accounted only for 6% of total exports.

Table 1: Descriptive statistics for the variables used

Variable	1960	1970	1980	1990	2000	2015
CO_2 emissions (thousand kt)	8,225	14,613	25,031	41,210	64,426	45,053
Energy consumption, (kwh per capita)	320	764	1,466	2,399	3,795	4,663
Agricultural raw material exports (% of merchandise exports)	10.48	10.12	9.23	5.16	2.71	2.35
Agricultural Land Productivity in Portugal (USD/ha)	38,750	39,350	39,790	39,630	38,300	37,000

Source: own composition based on WDI (2018) data

Table 1 shows some descriptive statistics for carbon dioxide emissions, energy consumption, agricultural raw material exports and agricultural land productivity in the Portuguese economy. It is evident, for instance, that CO_2 emissions for the Portuguese economy increased from 1960 to 2000 but between 2000 to 2015, there was a decrease in air pollution, showing that the Portuguese economy was using mechanisms to reduce climate change.

According to Table 1, energy consumption was increasing in Portugal in 1960-2015, which indicates that energy demand was important for economic activity. Note that energy consumption actually grew by almost fifteen times from 1960 to 2015. Moreover, agricultural raw material exports have been declining in the period analysed. However, since the 1990s, exports have declined sharply, which shows that Portuguese agricultural production was fundamentally destined for the domestic market. Last but not least, agricultural land productivity decreased in 1960-2015, especially since the 1990s, suggesting decreasing yields.

Methodology and econometric specifications

The relationship between carbon dioxide emissions (CO_2) and Portuguese agricultural productivity is considered in this paper by using time series methods such as unit root tests, Vector Autoregression (VAR) and Vector Error Correction Model (VECM) with adjustable parameters and alpha notable. The dependent variable is CO_2 emissions, while the independent variables are energy consumption, agricultural productivity, agricultural land productivity and agricultural raw materials exports for the period 1960-2015. Granger causality test evaluates the relationship between the variables used, while the unit root test examine the stationarity between variables. If the variables are not stationary in levels, the test should be realized at the first differences. The paper also analyses the existence of cointegration by using Johansen test. Before the VAR model is applied, the test of lag order selection is used. The stability of VECM and the number of cointegration equations are considered. Moreover, the Lagrange-multiplier test checks for serial correction – VECM is stable if we do not have serial correlation. Based on the literature review, the following hypotheses are formulated.

H1: There is bidirectional causality between agricultural activity and climate change.

Research realized by Pant (2009), Cowan *et al.* (2014), Asumadu-Sarkodie (2017), Ulhah *et al.* (2018), Khan *et al.* (2018) and Jebli and Youssef (2017) proved that there was a link between agricultural activity and climate change. Thus, agricultural practices such as the use of fertilizers, stimulate global warming and CO_2 emissions. However, agricultural activity is negatively influenced by climate change and global warming.

The empirical studies of Leitão and Shahbaz (2013), Leitão and Shahbaz (2016), Hamilton and Turton (2002), Friedl and Getzner (2003), Liu (2005), Ang and Liu (2001), Halicioglu (2009) and Jalil and Mahmud (2009) showed that an increase in productivity assumes an intensification of energy consumption and subsequently an increase of CO_2 emissions. Agriculture activity is measured by agricultural labour productivity (AG) and by agricultural land productivity (LAND) – we expect a positive impact of these variables on CO_2 emissions.

H2: Non-renewable energy consumption causes CO_2 emissions.

The use of non-renewable energy (coal, oil and natural gas) is considered to be the main reason behind climate change. The use of energy causes economic growth which leads to climate change and global warming. According to the literature, there is a positive relationship between energy consumption and CO_2 emissions. The studies of Balogh and Jambor (2017), Linh and Khanh (2017), Mirza and Kanwal (2017), and Leitão and Shahbaz (2016) support to this hypothesis. Considering the contributions of Javid and Sharif (2016), Nain *et al.* (2015) and Hwang and Yoo (2014), causality exists between energy consumption and CO_2 emissions. Energy is measured by electric power consumption (kWh per capita).

H3: International trade encourages climate change.

The studies of Amador *et al.* (2018), Andersson (2018) and Wang and Ang (2018) demonstrate that international trade is associated with environmental pollution. In this context, Balogh and Jambor (2017), Shahbaz and Leitão (2013), Shahbaz *et al.* (2013) and Leitão (2015) found a positive relationship between international trade and carbon dioxide emissions. Variable for agricultural raw material exports was introduced in empirical studies, suggesting two different perspectives. The dominant paradigm considers that there is a positive relationship between international trade and carbon dioxide emissions. However, some studies argue that there is a negative relationship between this variable and carbon dioxide emissions, implying that developed economies are less polluting as they require less energy use. The variable here is measured by agricultural raw material exports as a percentage of merchandise exports.

The paper use carbon dioxide emissions (CO_2) as the dependent variable, measured in metric tons per capita and data is coming from the World Bank WDI database. Independent variables introduced in the regression are energy consumption (ENG), agricultural labour productivity (AG), agricultural land productivity (LAND) and agricultural raw materials exports (EXP). Environmental pollution (CO_2) is thought to be directly related to this function:

$$CO_2 = f\,(ENG, AG, LAND, EXP) \quad (1)$$

Mathematically, the following model is run:

$$LogCO_2 = \alpha_0 + \alpha_1 LogENG + \alpha_2 LogAG + \alpha_3 LogLAND + \alpha_4 LogEXP + ut_{it} \quad (2)$$

where *ENG* represents energy consumption, measured by electric power consumption (kWh per capita); *AG* represents agricultural labour productivity, measured as agricultural value added per worker (current USD per worker); *LAND* represents agricultural land productivity (agricultural value added per hectare in current USD per hectare) and *EXP* represents agricultural raw materials exports as a share of merchandise exports.

Table 2 summarises all independent variables used with sources and expected signs.

Table 2: List of independent variables

Variables used in this research	Expected Signs	Source
ENG - Energy consumption	[+]	World Bank
AG - Agricultural labour productivity	[+]	World Bank
LAND - Agricultural land productivity	[+]	World Bank
EXP - Agricultural raw materials exports	[+]	World Bank

Source: own composition

Table 3: Correlation between variables

	$LogCO_2$	LogENG	LogAG	Log-LAND	LogEXP
$LogCO_2$	1.000				
LogENG	0.165	1.000			
LogAG	0.352	0.635	1.000		
LogLAND	0.263	-0.522	-0.613	1.000	
LogEXP	-0.184	-0.691	-0.591	0.365	1.000

Source: own composition

Table 4: Augmented Dickey-Fuller (ADF) unit root test results

Augmented Dickey-Fuller test	ADF at Level	
Variables	Statistic	P-value
$LogCO_2$	-6.537	0.000
LogENG	-5.756	0.000
LogAG	-4.152	0.000
LogLAND	-7.005	0.000
LogEXP	-2.639	0.085

Source: own composition

Table 5: Lag order selection criteria

Lag	LL	LR	FPE	AIC	HQIC	SBIC
0	195.903	n.a.	3.5e-150	-19.090	-19.042	-18.841
1	296.831	201.860	2.0e-180	-26.683	-26.392	-25.189
2	348.800	103.940*	2.4e-190*	-29.380*	-28.846*	-26.642*

Note: LL- Lag order selected by the criterion; LR- Sequential modified; LR test statistic (each at 5% level); FPE- Final prediction error, AIC: Akaike information criterion, SC: Schwarz information criterion, HQ: Hannan Quinn information criterion. *: significant at 10% level.
Source: own composition.

Econometric results

The empirical results are presented in this section. We use STATA software to estimate the econometric results. Correlations between variables is showed in Table 3. The explanatory variables present a positive correlation with CO_2 emissions, except for agricultural raw materials exports. Energy consumption is positively related to agricultural labour productivity and negatively to agricultural land productivity and exports. Agricultural land productivity is positively related to agricultural exports.

Table 4 shows unit roots test for each variable used in the model, considering the Augmented Dickey-Fuller test. Results demonstrate that all variables are stationary.

Table 5 reports lag selection and order criteria. According to Table 5, a maximum of lag 2 is observable.

Table 6 presents results of the VAR model. The second lagged variable of carbon dioxide emissions [$LogCO_2$ (-2)] is statistically significant at 5% level. This result shows that climate change should be analysed in the long run. Balogh and Jambor (2017) as well as Leitão and Shahbaz (2016) also found a positive effect.

According to Table 6, agricultural labour productivity is positively related to CO_2 emissions. The second order lag [LogAG (-2)] is statistically significant at 5% level. This result is also supported by previous studies (Edoja *et al.*, 2016; Asumadu-Sarkodie and Owusu, 2016; Balogh and Jambor, 2017), showing that agricultural labour productivity encourages climate change. When the vector of energy

Table 6: Portuguese agriculture development and climate change with the VAR model

Variables	$LogCO_2$	LogENG	LogAG	LogLAND	LogEXP
$LogCO_2$(-1)	0.246 (0.237)	0.052 (0.430)	1.518** (0.001)	-0.010 (0.730)	1.959*** (0.000)
$LogCO_2$(-2)	0.429** (0.036)	-0.008 (0.901)	-0.644 (0.145)	0.036 (0.804)	1.338** (0.013)
LogENG(-1)	0.526 (0.432)	0.839*** (0.000)	-1.499 (-1.04)	0.036 (0.804)	3.173* (0.073)
LogENG(-2)	-0.747 (0.217)	0.037 (0.846)	1.536 (0.240)	-0.149 (0.257)	3.209* (0.044)
LogAG(-1)	-0.005 (0.898)	-0.006 (0.658)	-0.031** (0.002)	-0.001* (0.096)	-0.048*** (0.000)
LogAG(-2)	0.006** (0.002)	0.001** (0.002)	-0.011** (0.010)	0.002*** (0.000)	-0.002 (0.644)
LogLAND(-1)	1.832* (0.005)	0.193 (0.354)	-4.670** (0.001)	0.314** (0.028)	-6.976*** (0.000)
LogLAND(-2)	0.152 (0.742)	0.254* (0.084)	-1.665* (0.095)	-0.202** (0.045)	-3.169*** (0.009)
LogEXP(-1)	0.161** (0.021)	0.053** (0.016)	0.105 (0.485)	-0.030** (0.045)	0.674*** (0.000)
LogEXP(-2)	-0.083 (0.424)	0.002 (0.938)	-0.495** (0.028)	-0.040* (0.062)	-0.889*** (0.000)
C	-6.830* (0.043)	-1.835* (0.088)	34.951 (0.000)	4.388*** (0.000)	44.573*** (0.000)
Adj. R^2	0.960	0.990	0.760	0.930	0.770
P>chi2	0.000	0.000	0.000	0.000	0.000
Log likelihood			348.800		
AIC			-29.380		
HQIC			-28.845		
SBIC			-26.642		

Note: Statistically significant at 1%(***), 5% (**), and 10% (*). Standard errors are in parenthesis.
Source: own composition

consumption (LogENG) is observed, one can conclude that the coefficients of agricultural labour productivity, land productivity and the lagged variable of energy are statistically significant. These results demonstrate that energy consumption is necessary to agriculture activity.

Regarding the vector of agriculture labour productivity, we can infer that carbon dioxide emissions [LogCO_2 (-1)] are positively related to agricultural labour productivity. The coefficient is statistically significant at 5% level. When the first and second lag of agricultural labour productivity[LogAG(-1); LogAG(-2)] are considered, a negative sign is observable, confirming that carbon dioxide emissions are prejudicial to agricultural activity. Filiz and Omer (2012), Ullah *et al.* (2018) and Balogh and Jambor (2017) ended up in the same result.

CO_2 emissions and energy use have a positive effect on agricultural raw material exports. This result is also supported in previous studies of Leitão and Shahbaz (2013), Leitão and Shahbaz (2016), Balogh and Jambor (2017), Hamilton and Turton (2002), Friedl and Getzner (2003) and Liu (2005).

Table 7: Portuguese agricultural development and climate change with Granger causality

Null Hypothesis	Chi 2	Df	Prob > chi 2
LogCO_2 does not Granger Cause LogENG	28.914	2	0.000
LogENG does not Granger Cause LogCO_2	2.022	2	0.364
LogCO_2 does not Granger Cause LogAG	11.905	2	0.003
LogAG does not Granger Cause LogCO_2	21.168	2	0.000
LogCO_2 does not Granger Cause LogLAND	8.113	2	0.017
LogLAND does not Granger Cause Log CO_2	*1.458*	2	0.483
LogCO_2 does not Granger Cause LogEXP	6.020	2	0.049
LogEXP does not Granger Cause LogCO_2	14.550	2	0.001
LogENG does not Granger Cause LogAG	10.571	2	0.005
LogAG does not Granger Cause LogENG	3.886	2	0.143
LogENG does not Granger Cause LogLAND	4.135	2	0.127
LogLAND does not Granger Cause LogENG	108.900	2	0.000
LogLAND does not Granger Cause LogEXP	20.006	2	0.000
LogEXP does not Granger Cause LogLANG	24.920	2	0.000
LogENG does not Granger Cause LogEXP	9.909	2	0.007
LogEXP does not Granger Cause LogENG	9.988	2	0.007
LogAG does not Granger Cause LogLAND	14.677	2	0.001
LogLAND does not Granger Cause LogAND	39.520	2	0.000
LogAG does not Granger Cause LogEXP	5.548	2	0.062
LogEXP does not Granger Cause LogAG	22.244	2	0.000

Source: own composition

Table 8: VECM rank: Johansen tests for cointegration

Nº of CE(s)	LL	Eigenvalue	Trace Statistic	5% Critical value
0	205.262	n.a.	287.077	68.520
1	305.869	0.999	85.861	47.210
2	327.733	0.888	42.135	29.680
3	341.594	0.749	14.412	15.410
4	345.962	0.354	5.677	3.760
5	348.800	0.247	n.a.	n.a.

Source: own composition

Table 7 presents results of Granger causality tests, suggesting that there is causality between carbon dioxide emissions and energy consumption in line with works of Leitão and Shahbaz (2013), Leitão and Shahbaz (2016), Balogh and Jambor (2017), Hamilton and Turton (2002), Friedl and Getzner (2003), Liu (2005), Ang and Liu (2001), Halicioglu (2009) and Jalil and Mahmud (2009). It seems that there exists an unidirectional causality between CO_2 emissions and land productivity, demonstrating that increased land productivity accentuates climate change. The same conclusions is valid to energy consumption and agricultural labour productivity.

Granger causality also shows that there is a bidirectional causality between carbon dioxide emissions (LogCO_2) and agricultural labour productivity (LogAG). The same is valid for the bidirectional causality between CO_2 emissions and agricultural raw exports (LogEXP). The relationship between agricultural land productivity (LogLAND) and agricultural raw material exports (LogEXP); energy consumption (LogENG) and agricultural raw material exports (LogEXP); agricultural labour productivity (LogAG) and agricultural raw material exports (LogEXP) also present a bidirectional causality.

Moreover, the Johansen cointegration test shows that there is one cointegration relationship between all variables used in the equation in the multivariate model (Table 8).

In Table 9 and 10, results of the VECM model are presented for carbon dioxide emissions, energy consumption, agricultural labour productivity, agricultural land productivity, and agricultural raw material exports with trend, one cointegration rank, and two lags in VAR. Table 9 exhibits the adjustment parameters, while Table 10 shows estimations of adjustment parameters, considering alpha notable with trend (long-run multivariate of VECM). The coefficients of carbon

Table 9: Portuguese agricultural development and climate change with Adjustment parameters

Equation	Parms	chi2	P>chi2
DLogCO_2	1	13.664	0.057
DLogENG	1	108.281	0.000
DLogAG	1	62,211.430	0.000
DLogLAND	1	15.336	0.031
DLogEXP	1	1.392	0.985
N. of cointegration rank	1		
Max lag in VAR	2		

Source: own composition

Table 10: Portuguese agricultural development and climate change with the VEC model

alpha nobtable with trend	Coef.	Std. Err	Z	P>|z|	[95% Conf. Interval]
DLogCO_2_ce1	0.009**	0.004	2.340	0.019	0.001 0.015
DLogENG_ce1	0.009***	0.002	3.660	0.000	0.004 0.013
DLogAG_ce1	1.258***	0.006	199.590	0.000	1.245 1.270
D LogLAND_ce1	-0.003***	0.001	-2.650	0.008	-0.006 -0.001
DLogEXP_ce1	- 0.001	0.009	-0.060	0.950	-0.019 0.018

Note: Statistically significant at 1%(***); 5%(**).
Source: own composition

dioxide emissions, energy consumption, agricultural labour productivity, and agricultural land productivity are statistically significant in the first cointegration equation, with exception of agricultural raw material exports. According to the Lagrange-multiplier test, the VECM is stable.

On the whole, based on our results, neither of our hypotheses can be rejected.

Conclusions

This study analysed the relationship between carbon dioxide emissions, energy consumption, agricultural labour productivity, agricultural land productivity and agricultural raw materials exports, using time series for the period 1960-2015. A number of results were achieved as follows.

The unit root test (Augment Dickey-Fuller, ADF) showed that all variables used in this paper were stationary. Results showed that agricultural labour productivity, agricultural land productivity and agricultural raw material exports had a positive impact on CO_2 emissions (i.e. these variables increased environmental pollution). Agricultural productivity measured by two variables (agricultural labour productivity and agricultural land productivity) showed that agricultural activity stimulated global warming and CO_2 emissions. Results obtained for the variable agricultural raw materials exports were in line with the perspective that international trade fostered climate change and global warming. The empirical studies of Amador *et al.* (2016), Andersson (2018) and Wang and Ang (2018) supported these arguments.

Results also empirically proved that there existed a bidirectional causality between CO_2 emissions and agricultural raw material exports and agricultural land productivity and agricultural labour productivity. The empirical studies of Cowan *et al.* (2014), Asumadu-Sarkodie (2017), Ulhah *et al.* (2018) and Jebli, and Youssef (2017) showed that energy consumption was essential to agricultural activity; however, non-renewable energies encouraged climate change. Our results are in line with studies by Linh and Khanh (2017), Mirza and Kanwal (2017) and Leitão and Shahbaz (2016).

The Johansen cointegration test demonstrated that the multivariate model is cointegrated among all variables. Variables of carbon dioxide emissions, energy consumption, agricultural labour productivity and agricultural land productivity were statistically significant in the first cointegration equation.

It is possible to present some ideas for future work. It might be interesting to extend the research by comparing the Portuguese economy with Spain and Greece and to understand the impact of the Common Agricultural Policy on the issues analysed in the paper. It will, therefore, be necessary to understand whether or not the supply of food at lower prices stimulates climate change. This research can also be extended by incorporating new agriculture-related variables (e.g. the use of fertilizers) into the models in order to see their impacts on carbon dioxide emissions.

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