Combustible renewables and waste consumption, agriculture, CO2 emissions and economic growth in Brazil

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Abstract: This paper employs the autoregressive distributed lag (ARDL) approach and Granger causality tests to examine the dynamic causal links between per capita combustible renewables and waste (CRW) consumption, agricultural value added (AVA), carbon dioxide (CO_2) emissions, and real gross domestic product (GDP) for the case of Brazil, spanning the period 1980-2011. The Fisher statistic of the Wald test confirms the existence of long-run cointegration between the considered variables. Short-run empirical findings reveal that there is a unidirectional causality running from agriculture to CO_2 emissions and to GDP. However, there is long-run bidirectional causality between all considered variables. The ARDL long-run estimates show that both CRW consumption and AVA contribute to increase economic growth and to decrease CO_2 emissions. Agricultural production and CRW consumption seem to play substitutable roles in the Brazilian economy as increasing CRW consumption reduces AVA in the long-run, and vice versa. In addition, economic growth increases agricultural production at the expense of CRW production. We recommend that Brazil should continue to encourage agricultural and biofuels productions. The actual substitutability between agricultural and biofuels production should be reduced or even stopped by encouraging second-generation biofuels and discouraging first-generation biofuels. This may be done by policies of subsidization or taxation, encouraging R&D, and giving competitive credits.

Keywords: Autoregressive distributed lag; Granger causality; combustible renewables and waste; agricultural value added; Brazil.

JEL classifications: C32; O13; O54 ; Q42 ; Q54

1. Introduction

Renewable energy use is expanding considerably throughout the world. Indeed, renewable energy accounted for more than 71% of total electric capacity additions in the European Union (EU) during 2011, while renewable energy markets and industries expanded into new countries and regions and all end-use sectors experienced significant growth (REN21, 2012). Growing concerns about GHG emissions and energy security led many countries to implement ambitious biofuels targets and encouraging measures to the biofuels sector. Biomass is a source of food, fibre, and feed for livestock. It accounts for over 10% of global primary energy supply and is the world's fourth important source of energy after oil, coal, and natural gas. Biomass feedstocks come in solid, gaseous, and liquid forms and can be converted through a variety of technologies to produce heat, electricity, and transport fuels. During 2007-2011 international liquid biofuels production increased at an average annual rate of 17% for ethanol and 27% for biodiesel.

Brazil has experienced a continuous important economic growth during the preceding decades ejecting millions of Brazilians out of poverty and redistributing the fruits of its abundant natural resources. Agriculture played a pivotal role in this transformation and government policies have been decisive. The comfortable agricultural position of Brazil today is due to courageous decisions taken decades ago by the government regarding agricultural and rural development policies through high investments in infrastructure and research and development (R&D). The productivity in the agricultural sector has considerably increased transforming Brazil from a net food importer into one of the largest exporters of agricultural goods in the world (Marques de Magalhaes and Lunas Lima, 2014). Brazil is the fourth largest greenhouse gas (GHG) emitter in the world. However, it is among the five countries with the biggest potential to curb emissions. Nowadays Agriculture in Brazil supplies almost half of the total energy supply. Renewable energy from agriculture comprises sugarcane biomass (42%), hydraulic energy (28%), firewood (20%) and other sources (10%). Through promoting environmentally and low carbon agricultural practices, and supporting biofuels production, agriculture is expected to make an increasing contribution to environmental sustainability (OECD/FAO, 2015). It is sure that there is a strong link between economic growth, agriculture, renewable energy use and carbon dioxide emissions in Brazil that deserves more attention.

To the best of our knowledge, there is no econometric study focusing on studying the relationship between agriculture and renewable energy in Brazil. The objective of the present paper is to investigate the dynamic causal links between per capita combustible renewables and waste (CRW) consumption, agricultural value added (AVA), CO_2 emissions, and real gross domestic product (GDP) for the case of Brazil. Our empirical analysis considers the autoregressive distributed lag (ARDL) bounds approach and Granger causality tests to examine the short and long-run relationships between the considered variables and to estimate their relative long-run elasticity.

Our paper is organized as follows: Section 2 deals with agriculture and CRW in Brazil. Section 3 is concerned by the literature review. Section 4 presents the data and empirical methodology used in the analysis. Section 5 reports the results of the empirical study, and Section 6 concludes.

2. CRW and Agriculture in Brazil

The gross domestic product (GDP) share of agriculture in Brazil is 5.4% during the period 2010-13 (OECD/FAO, 2015) and this sector absorbed about 13% of Brazil's employment in 2012. This relative low agriculture's labor productivity reflects in part the dualistic nature of farming in Brazil, where large-scale and capital intensive production co-exists with traditional farms. Brazilian agriculture has seen an important growth during the last three decades. Total agricultural production has more than doubled in volume compared to its 1990 level and the production of livestock has almost trebled, mainly because of productivity improvements. Agriculture contributes importantly to the Brazil's trade balance because exports by agriculture and agro-food industries totaled over US$ 86 billion in 2013, accounting for 36% of total exports. Brazil is a major player on international agricultural markets as it is the world's second largest agricultural exporter, an important exporter of soybeans, tobacco and poultry, and the first supplier of orange juice, sugar and coffee. It is also a major producer of maize, rice and beef and has a large consumer domestic market.

Brazil is the fourth largest greenhouse gas (GHG) emitter in the world. However, it represents one of the five countries with the biggest potential to curb emissions. The main sources of GHG emissions are power, transportation, and agriculture sectors. Agriculture (including cattle), accounts for 25% of the current Brazil emissions. Cattle represent the half of agriculture emissions and the other half comes from farming activities (McKinsey & Company, 2012). Agricultural policy in Brazil has increasingly focused on sustainable development. The increased productivity of agricultural production reduces the pressure on deforestation and the biofuels production increases the range of renewable sources that can be substituted to fossil fuels. Agricultural zoning is an important instrument conditioning agricultural support to environmental sustainability of farming activity (OECD/FAO, 2015).

The respect of zoning rules is a necessary condition for producers' eligibility for concessional credit and subsidized insurance programs. Brazil has voluntarily committed to reduce its GHG emissions by nearly 37% in 2020. To do this, the government launched in 2010 an important credit program named Plano ABC for low carbon agriculture and a range of other specific programs. These programs include credits for plantings on unproductive and degraded soils, or for forest planting including palm oil for biofuels production, or for modernizing production systems that preserve natural resources.

According to REN21 (2012) report, Brazil is ranked among the top five countries for renewable energy. Indeed, in 2011 it has the third renewable energy capacity (including hydro) after China and the United States, the second biomass power capacity and the second hydro power capacity after the United States and China. In terms of annual production addition in 2011, it is the fourth for biodiesel after the United States, Germany and Argentina, and is the second for ethanol after the United States. Most of the biodiesel in Brazil comes from soybean oil, although the use of palm oil is increasing. In 2011, the United States and Brazil accounted for 63% and 24% of global ethanol production, respectively. In Brazil, biomass accounts for 34% of final energy consumption in the cement industry and for 40% in the iron and steel industries.

These remarkable results of Brazil in terms of renewable fuels are due to many practical decisions: *i)* the Renewable Fuel Standard (RFS2), set in 2007 in the United States, qualified the Brazilian sugarcane based ethanol as an advanced fuel, and this increased the demand for Brazilian ethanol; *ii)* the introduction of flex-fuel vehicles in March 2003 contributed to the expansion of the ethanol industry. Flex-fuel vehicles represented 22% of light vehicles sales in Brazil in 2004, and this share reached more than 88% in 2014. Domestic Brazilian ethanol demand jumped from about four billion liters to 16.5 billion from 2003 to 2009, boosted by the increase in the use of fuel and by the competitive price of hydrous ethanol compared to gasohol. Total ethanol production increased from 14.5 to 26.1 billion liters during the same period mainly because increasing international demand; *iii)* extensive financing realized by the sugar and ethanol industries; *iv)* the Brazilian government gave strong support for biofuels production via incentive measures including credits to construct ethanol plants and storages, incentive taxes on flex-fuel cars running on any combination of ethanol and gasoline, mandatory blending ratios for both gasoline and diesel with ethanol and biodiesel, respectively; *v)* differentiated taxation in favor of renewable fuels. Indeed, the lowest tax rate for hydrous ethanol is charged in São Paulo State (12%), which is the largest producer and consumer state, and the average country tax rate is 16%. Comparatively, the average country tax rate is about 25% for gasoline (OECD/FAO, 2015).

To conclude this section we can say that Brazil has proved to the world that agricultural and environmental issues are not substitutes but rather are complements since increasing productivity and efficiency in agriculture benefits also to environmental protection. This reinforces the position of Brazil considered as an international environmental creditor because of its biomes (Amazon Forest, Pantanal, Cerrado, Caatinga, Atlantic Forest).

3. Literature review

Many empirical studies have been interested by the causal relationships between renewable energy consumption and other economic variables like economic growth, pollution emission, or international trade (Apergis and Payne, 2010b, 2011; Ben Jebli and Ben Youssef, 2015c; Ben Jebli et al., 2015b; Menyah and Wolde-Rufael, 2010; Sadorsky, 2009b; Tugcu et *al*., 2012). Sadorsky (2009a) examines the dynamic causal links between renewable energy consumption, economic growth and CO_2 emissions for G7 countries. Using panel cointegration techniques, he shows that in the long-run the increase in per capita real GDP and CO_2 emissions are two major drivers behind renewable energy increase. He also finds that an increase in oil price has a negative and small impact on renewable energy consumption. By considering a panel of twenty OECD countries, Apergis and Payne (2010a) study the causal relationships between renewable energy consumption, GDP, capital and labor. Their Granger causality tests reveal the existence of short and long-run bidirectional causalities between renewable energy consumption and economic growth. Al-Mulali et al. (2014) examine the impact of renewable and non-renewable electricity consumption on economic growth for 18 Latin American countries. They show the existence of long-run bidirectional causality between GDP, renewable and non-renewable electricity consumption, capital, labor and trade. They also come to the conclusion that renewable electricity is more significant than non-renewable electricity in promoting economic growth in both the short and long-run for this panel of countries.

Few studies have been interested by renewable energy in Brazil and its causal relationships with other variables as economic growth and pollution emission. Pao and Fu (2013a) examine the causal relationships between GDP and four types of energy consumption: non-hydroelectric renewable energy consumption (NHREC), total renewable energy consumption (TREC), non-renewable energy consumption (NREC), and the total primary energy consumption (TEC). Their results reveal the existence of short-run bidirectional causality between NHREC and GDP, long-run bidirectional causality between

TREC and GDP, and long-run unidirectional causality running from NHREC to GDP. Their long-run parameter estimates show that increasing NHREC or TREC increases GDP**.** Pao and Fu (2013b) investigate the relationships between different types of energy resources and economic growth. Their analysis suggests short and long-run negative bidirectional causality between new renewables and fossil fuels indicative of substitutability between these two energy sources.

To the best of our knowledge there is no econometric study investigating the relationship between energy consumption and agriculture in Brazil. However, there are some studies concerned by other countries (Karkacier et al., 2006; Mushtaq et al., 2007). Turkful and Unakitan (2011) study the relationship of per capita energy consumption (diesel, electricity) for agriculture, agricultural GDP, and energy prices for the case of Turkey. A unidirectional causality running from diesel and electricity consumption to agricultural GDP is found. Increasing agricultural GDP, increases diesel and electricity consumption in the long-run. These authors recommend continuing supporting energy use in Turkish agriculture in order to increase international market competitiveness, and balance the revenue of farmers. The causal relationships between AVA, consumption of energy (oil, electricity), and trade openness in Tunisia is studied by Sebri and Abid (2012). They show the existence of short and long-run unidirectional causality running from total energy and from oil energy to AVA, and a long-run unidirectional causality running from AVA to oil consumption. They conclude that energy can be considered as a limiting factor to agriculture and shocks to energy supply should be carefully managed.

Recently, two studies focused on the causal relationships between renewable energy and agriculture. The first one is Ben Jebli and Ben Youssef (2015a) investigating short and long-run relationships between per capita CO_2 emissions, economic growth, renewable and non-renewable energy consumption, trade openness and agricultural value added in Tunisia. Granger causality tests show the existence of short-run bidirectional causalities between AVA and pollution emissions, and between AVA and trade openness. There are also long-run bidirectional causalities between all considered variables. Long-run estimates confirm that non-renewable energy, trade and agriculture increase CO_2 emissions, whereas renewable energy consumption reduces it. These authors recommend subsidize renewable energy use in the agricultural sector because it helps it to become more competitive on the international markets while being more environmentally friendly. The second study is Ben Jebli and Ben Youssef (2015b) that uses panel cointegration techniques and investigates the dynamic causal links between per capita renewable energy consumption, agricultural value added, CO_2

emissions, and real gross domestic product for a panel of five North Africa countries. Short and long-run Granger causality tests show the existence of bidirectional causality between CO_2 emissions and AVA, and a unidirectional causality running from renewable energy consumption to AVA. Long-run parameter estimates indicate that an increase in economic growth and in renewable energy increase emissions, whereas an increase in AVA reduces emissions. Thus, North African authorities should encourage renewable energy use, and particularly clean renewable energy such as solar or wind, because this improves agricultural production and helps to mitigate global warming.

4. Data and empirical methodology

4.1. Data

Annual data are collected from the World Bank (2015) for the case of Brazil spanning the period 1980-2011. Data include CO_2 emissions (*e*) measured in metric tons, real GDP (*y*) measured in constant 2005 US dollars, combustible renewables and waste (*crw*) consumption measured in metric tons of oil equivalent (Mtoe), and agricultural value added (AVA, *agr*) measured in constant 2005 US dollars. CRW comprise solid biomass, liquid biomass, biogas, industrial waste, and municipal waste. Agriculture comprises forestry, hunting, fishing, cultivation of crops, and livestock production. The value added of a sector is its net output after adding up all outputs and subtracting intermediate inputs. The data concerning emissions and GDP are in per capita, and those concerning CRW and AVA are divided by the population number to get the per capita units. Data are collected to get the maximum number of observation depending on their availability and are converted into natural logarithms prior to conducting the empirical analysis. All estimates are done using Eviews 9.0.

Insert Figure 1 and Table 1 Here

Figure 1 and Table 1 present some graphical representation and descriptive statistics of the analysis variables in order to better understand their tendency during the selected period. According to these plots, almost all series have an upward trend across time, except for combustible renewables and waste consumption plots that have a drop trend across time. The level of CRW consumption reaches its peaked level in 1984 with 40.42 Mtoe, while its lowest level is reached in 2000 with 24.87 Mtoe. We also observe that the evolution of CO_2 emissions is too similar to that of economic growth across time indicative of a strong correlation between the two variables. Indeed, Brazil has reached the lowest levels of per capita economic growth in 1983 (3596.31 constant 2005 US dollars) and CO_2 emissions in

1984 (1.26 metric tons). However, the highest levels have been realized in 2011 for per capita GDP (5744.49 constant 2005 US dollars) and for emissions (2.19 metric tons). Regarding the AVA plot, we observe that the agricultural sector in Brazil is in positive growth across time. The lowest level of per capita agricultural added value is 150.77 constant 2005 US dollars in 1986, while the highest level is 260.72 constant 2005 US dollars in 2011.

4.2. Stationary tests

The Zivot and Andrews (1992) unit root test with structural break is considered to check for the integration order of each variable. This kind of test seems to be more powerful than traditional unit root tests (augmented Dickey and Fuller, 1979; Phillips and Perron, 1988, etc.) because it gives more information about structural change. Three models have been considered in this stationary test. The first model assumes that, at level, there is one-time change in the variable. The second model suggests that there is one-time change in the trend coefficient. The third model allows that there is one-time change in both intercept and deterministic trend. The null hypothesis of this test suggests that the series contain unit root with one-time change, while the alternative hypothesis suggests that the variable is stationary with one-time change. In the present study, unit root tests with structural change are done for the case with intercept and trend.

Insert Table 2 Here

The unit root test results reported in Table 2 indicate that, at level, all the variables are non-stationary except for agricultural value added variable. However, after first difference, all time series are stationary. Thus, we conclude that per capita CO_2 emissions, real GDP, CRW consumption and AVA variables are integrated of order one, i.e. are I(1).

4.3. Cointegration tests

The present empirical study employs the ARDL bounds approach to check for long-run cointegration between variables. This powerful cointegration technique has been developed by Pesaran and Pesaran (1997), Pesaran and Smith (1998), Pesaran and Shin (1999), and Pesaran et al. (2001). The ARDL technique has numerous advantages compared to other cointegration approaches, among which: *(a)* the series can be either integrated of order zero, of order one, or fractionally integrated; (*b)* the short and long-run parameters are estimated with the same model; (*c*) it provides interesting results even with small samples; *(d)* endogeneity problems are avoided.

The representations of the ARDL equations are as follows:

$$\Delta co_{2t} = \alpha + \sum_{i=1}^{q} \alpha_{1i} \Delta co_{2t-i} + \sum_{i=1}^{q} \alpha_{2i} \Delta y_{t-i} + \sum_{i=1}^{q} \alpha_{3i} \Delta crw_{t-i} + \sum_{i=1}^{q} \alpha_{4i} \Delta agr_{t-i} + \alpha_5 co_{2t-1} + \alpha_6 y_{t-1} + \alpha_7 crw_{t-1} + \alpha_8 agr_{t-1} + \varepsilon_{1t} \quad (1)$$

$$\Delta y_t = \beta + \sum_{i=1}^{q} \beta_{1i} \Delta co_{2t-i} + \sum_{i=1}^{q} \beta_{2i} \Delta y_{t-i} + \sum_{i=1}^{q} \beta_{3i} \Delta crw_{t-i} + \sum_{i=1}^{q} \beta_{4i} \Delta agr_{t-i} + \beta_5 co_{2t-1} + \beta_6 y_{t-1} + \beta_7 crw_{t-1} + \beta_8 agr_{t-1} + \varepsilon_{2t} \quad (2)$$

$$\Delta crw_t = \theta + \sum_{i=1}^{q} \theta_{1i} \Delta co_{2t-i} + \sum_{i=1}^{q} \theta_{2i} \Delta y_{t-i} + \sum_{i=1}^{q} \theta_{3i} \Delta crw_{t-i} + \sum_{i=1}^{q} \theta_{4i} \Delta agr_{t-i} + \theta_5 co_{2t-1} + \theta_6 y_{t-1} + \theta_7 crw_{t-1} + \theta_8 agr_{t-1} + \varepsilon_{3t} \quad (3)$$

$$\Delta agr_t = \lambda + \sum_{i=1}^{q} \lambda_{1i} \Delta co_{2t-i} + \sum_{i=1}^{q} \lambda_{2i} \Delta y_{t-i} + \sum_{i=1}^{q} \lambda_{3i} \Delta crw_{t-i} + \sum_{i=1}^{q} \lambda_{4i} \Delta agr_{t-i} + \lambda_5 co_{2t-1} + \lambda_6 y_{t-1} + \lambda_7 crw_{t-1} + \lambda_8 agr_{t-1} + \varepsilon_{4t} \quad (4)$$

where Δ, ε, and q are the first differences, error terms, and the number of lags, respectively. According to Pesaran et al. (2001), the ARDL bounds technique follows two steps: the first step consists in selecting the required number of lags. For the vector autoregressive (VAR) model, the number of lags selected is based on various criteria comprising the Log likelihood (LogL), Log likelihood ratio (LR), final prediction error (FPE), Akaike information criterion (AIC), Schwarz information criterion (SIC), and Hannan-Quinn information criterion (HQ). Once the number of lags has been selected, then in the second step, the ARDL bounds equations can be run for estimation using the ordinary least square (OLS) method.

Based on the Wald test of the Fisher statistic, the joint significance of the long-run estimated coefficients are tested in order to check for long-run cointegration between variables. The null hypothesis of no long-run cointegration for each equation ($\alpha_5 = \alpha_6 = \alpha_7 = \alpha_8 = 0$; $\beta_5 = \beta_6 = \beta_7 = \beta_8 = 0$; $\theta_5 = \theta_6 = \theta_7 = \theta_8 = 0$; $\lambda_5 = \lambda_6 = \lambda_7 = \lambda_8 = 0$), against the alternative hypothesis of long-run cointegration ($\alpha_5 \neq \alpha_6 \neq \alpha_7 \neq \alpha_8 \neq 0$; $\beta_5 \neq \beta_6 \neq \beta_7 \neq \beta_8 \neq 0$; $\theta_5 \neq \theta_6 \neq \theta_7 \neq \theta_8 \neq 0$; $\lambda_5 \neq \lambda_6 \neq \lambda_7 \neq \lambda_8 \neq 0$). According to Pesaran et al. (2001), the estimated F-statistic of the Wald test should be compared to two terminal critical values: the lower critical value assumes that series are integrated of order zero, i.e. I(0), and the upper critical value assumes that series are integrated of order one, i.e. I(1). Thereby, if the computed value of F-statistic is greater than the upper critical value, then the null hypothesis of no cointegration is rejected. If the computed F-statistic falls between the lower and upper critical values, then the result is inconclusive. In this case, we run the vector error correction model (VECM) to test the significance of the error correction term (ECT) for the long-run cointegration. Finally, if the computed value of F-statistic is weaker than the lower critical value, then the null hypothesis of no cointegration is not rejected. Then, the robustness of the estimation will be examined through the statistics of serial correlation, residual heteroscedasticity, and normality tests.

Based on the two steps of the ARDL bounds test to cointegration, we first check for the number of lag length determined by the statistics of AIC and SIC criteria which are run through the unrestricted VAR model. The results show that the number of lags is equal to one (VAR(p=1)). In the second step, the OLS approach is used to estimate the ARDL equations in order to check for the significance of the Fisher test (Wald test).

Insert Table 3 Here

Table 3 reports the results from the Wald test indicating that all estimated Fisher statistics are statistically significant confirming the existence of long-run cointegration among our variables. All the Fisher statistics of the Wald test are estimated for the case of no trend and unrestricted intercept. Finally, diagnostic tests indicate no serial correlation, no white heteroscedasticity, and residuals are normally distributed confirming our results of cointegration.

5. Econometric results

5.1. Long-run estimates

Short and long-run ARDL estimates reported in Table 4 are established using the OLS method. All the long-run estimated coefficients are statistically significant at the 1% level, except for CO_2 emissions coefficient of the agricultural value added equation.

Insert Table 4 Here

When CO_2 emissions is the dependent variable (Eq. (1)), our long-run estimates show that any increase in GDP increases emissions. Indeed, economic growth needs more energy, and particularly more fossil energy, for production purposes leading to an increase in emissions. This result is similar to that of Apergis et al. (2010) demonstrated for a group of 19 developed and developing countries. We also show that increasing CRW consumption reduces emissions. This interesting result may be due to the fact that CRW resources are less polluting than fossil resources while being substitutes to them. This finding is contrary to that reached by Ben Jebli et al. (2015a) for Tunisia, because we think that in this last country CRW and fossil energy are not substitutes but rather complements, while in Brazil these two energy sources are in strong competition. Interestingly, increasing Brazilian agricultural production reduces emissions. This finding may be explained by the more efficient energy use and/or more renewable energy use of the agricultural sector compared to the other economic sectors in Brazil. This result is similar to that of Ben Jebli and Ben Youssef (2015b) for a panel of North Africa countries but it differs from that of Ben Jebli and Ben Youssef (2015a)'s study on Tunisia.

When GDP is the dependent variable (Eq. (2)), our long-run estimates show that increasing CRW consumption increases economic growth because energy is an essential input for production. This result is in accordance with that found by Pao and Fu (2013a, b) for Brazil as they show that increasing renewable energy consumption increases GDP in the long-run. In addition, increasing AVA generates economic growth. The long-run estimates of Eq. (3) and Eq. (4) show that increasing agricultural value added reduces combustible renewables and waste consumption, and increasing the latter reduces the former. Thus, agriculture production and CRW production appear to be substitute activities in Brazil. Indeed, arable lands could be either used for agricultural production or for CRW production like biofuels. This constitutes an interesting result that has not been previously demonstrated. In addition, these equations show that economic growth increases agricultural production but reduces CRW consumption in the long-run. Thus, it seems that economic growth pushes Brazil to abandon CRW production in favor of agricultural production.

Insert Figures 2-5 Here

It is worth interesting to test the stability of the short and long-run estimated coefficients by considering the cumulative sum (CUSUM) and the cumulative sum of squares (CUSUMSQ) statistics developed by Brown et al. (1975). These statistic tests are presented graphically. When the plots of these statistics fall inside the critical bounds of 5% significance, we can assume that the estimated coefficients of a given regression are stable. The results from these statistic tests are represented graphically in Figures 2-5 showing that the statistics are well within the critical values at the 5% significance level. Thus, all the ARDL short and long-run estimated coefficients are stable.

5.2. Granger causality

To investigate short and long-run dynamic causal links between our variables, the Engle and Granger (1987)'s two steps procedure is considered. The first step consists in the estimation of the long-run coefficients in order to recuperate the residuals. The second step estimates the parameters related to the short-run adjustment. Short-run relationships between variables are examined using the pairwise Granger causality tests (Fisher-statistics), while the long-run relationships between the variables are examined using the significance of the error correction terms (t-student statistics) corresponding to each equation. The VECM representation of the long-run equations is given as follows:

$$\Delta e_t = \phi_1 + \sum_{i=1}^{p} \phi_{11i} \Delta e_{t-i} + \sum_{i=1}^{p} \phi_{12i} \Delta y_{t-i} + \sum_{i=1}^{p} \phi_{13i} \Delta crw_{t-i} + \sum_{i=1}^{p} \phi_{14i} \Delta agr_{t-i} + \tau_1 ECT_{t-1} + \zeta_{1t} \quad (5)$$

$$\Delta y_t = \phi_2 + \sum_{i=1}^{p} \phi_{21i} \Delta e_{t-i} + \sum_{i=1}^{p} \phi_{22i} \Delta y_{t-i} + \sum_{i=1}^{p} \phi_{23i} \Delta crw_{t-i} + \sum_{i=1}^{p} \phi_{24i} \Delta agr_{t-i} + \tau_2 ECT_{t-1} + \zeta_{2t} \quad (6)$$

$$\Delta crw_t = \phi_3 + \sum_{i=1}^{p} \phi_{31i} \Delta e_{t-i} + \sum_{i=1}^{p} \phi_{32i} \Delta y_{t-i} + \sum_{i=1}^{p} \phi_{33i} \Delta crw_{t-i} + \sum_{i=1}^{p} \phi_{34i} \Delta agr_{t-i} + \tau_3 ECT_{t-1} + \zeta_{3t} \quad (7)$$

$$\Delta agr_t = \phi_4 + \sum_{i=1}^{p} \phi_{41i} \Delta e_{t-i} + \sum_{i=1}^{p} \phi_{42i} \Delta y_{t-i} + \sum_{i=1}^{p} \phi_{43i} \Delta crw_{t-i} + \sum_{i=1}^{p} \phi_{44i} \Delta agr_{t-i} + \tau_4 ECT_{t-1} + \zeta_{4t} \quad (8)$$

where Δ represents the first difference of variables; p denotes the VAR lag length; ECT_{t-1} indicates the lagged ECT corresponding to each equation; τ measures the speed of adjustment from the short to the long-run equilibrium.

Insert Table 5 Here

Table 5 reports the Granger causality tests and indicates that there are short-run unidirectional causalities running from per capita agricultural value added to per capita real GDP and to per capita CO_2 emissions, statistically significant at the 1% level. The estimated lagged error correction terms are comprised between -1 and 0 and are statistically significant indicating the existence of long-run bidirectional causalities between all considered variables.

There is a short-run unidirectional causality running from AVA to emissions, and there is long-run bidirectional causality between these two variables. Therefore, any change in the Brazilian agricultural production affects CO_2 emissions in both the short and long-run, and any measures taken to reduce emissions have a long-run impact on agricultural production. There is also a short-run unidirectional causality running from AVA to GDP alongside long-run bidirectional causality between these two variables. This means that any variation in agricultural production has an immediate, as well as a long-run, effect on GDP, and that economic growth impacts agricultural production in the long-run. These long-run causalities are similar to those found by Ben Jebli and Ben Youssef (2015a).

Interestingly, there is long-run bidirectional causality between agricultural value added and combustible renewables and waste consumption. Thus, in the long-run, any change in CRW consumption has an impact on agricultural production and vice versa. In Brazil, agricultural and CRW productions seem to be substitute activities and should be handled carefully. This result is different from that reached by Turkful and Unakitan (2011) who found a unidirectional causality running from diesel and electricity consumption to agricultural GDP. We also show that there is long-run bidirectional causality between CRW consumption and emissions signifying the existence of long-run mutual impact of these two variables.

6. Conclusion and policy implications

This paper tries to investigate the dynamic short and long-run relationships between per capita CO_2 emissions, real GDP, combustible renewables and waste consumption and agricultural value added for the case of Brazil over the period 1980-2011. We estimate the long-run elasticities of parameters by considering at each time one variable as dependent. Our empirical study employs the ARDL bounds for cointegration approach and Granger causality tests to examine the dynamic interactions between variables. Based on the Wald test (Fisher statistic), empirical estimates show that there is a long-run cointegration between variables for each considered equation.

Granger causality tests show the existence of short-run unidirectional causalities running from AVA to emissions and to GDP. There are long-run bidirectional causalities between all considered variables. The existence of long-run bidirectional causality between combustible renewables and waste consumption and agricultural value added in Brazil is a new and interesting result. It means that agricultural and CRW productions are in mutual long-run interactions.

Our long-run parameters estimates show that increasing CRW consumption reduces CO_2 emissions. This may be explained by the less polluting CRW resources compared to fossil resources while being substitutes to them. In addition, we show that increasing AVA reduces CO_2 emissions. This is probably due to the more efficient energy use and/or more renewable energy use in the Brazil's agricultural sector compared to the other economic sectors. We prove that increasing CRW consumption or AVA, increases GDP. Thus, combustible renewables and waste consumption and agricultural value added have a positive effect on both economic growth and the environment.

Our long-run parameter estimates show that increasing AVA reduces CRW consumption, and increasing CRW consumption reduces AVA. Therefore, agricultural production and combustible renewables and waste production seem to be substitute activities in Brazil. This new and interesting result may be due to the arable lands that could be used either for CRW production like biofuels or for agricultural production. We also show that economic growth increases agricultural production but reduces CRW consumption in the long-run. Thus, it seems that economic growth pushes Brazil to increase its agricultural production to the detriment of CRW production.

Based on our econometric results and on the agricultural and energy sectors of Brazil, we recommend that Brazil should continue to encourage agricultural and biofuels productions because both have a positive impact on its economic growth and on the environment as they contribute to less carbon dioxide emissions. The actual substitutability between agricultural production and biofuels production should be reduced or even stopped, because with economic growth expanding, Brazil will choose agricultural production and abandon gradually biofuels production. Agricultural production and biofuels production should become complementary activities. This may be done by encouraging second-generation biofuels production and discouraging first-generation biofuels production by appropriate subsidization or taxation. Indeed, first-generation biofuels are derived from sources such as sugarcane and corn starch and as such appear to be substitutes to agricultural production. In the contrary, second-generation biofuels utilize non-food-based biomass sources such as agriculture and municipal wastes and as such appear to be complementary to agricultural production. Unfortunately, this promoted alternative still face technological issues. This guides as to another policy recommendation consisting in that the Brazilian government should encourage R&D in renewable energy and especially in second-generation (or even in third-generation) biofuels production, and give competitive credits for installing the necessary production capacities. Tan et al. (2008) recommends policies or strategies that can help the second-generation biofuels, the cellulosic ethanol, to become the major biofuels in the world. Brazil has realized remarkable results during the last three decades in terms of biofuels due to its government policy and support and we think that if adequate courageous initiatives are taken for second-generation biofuels, we can expect interesting results in the following years in terms of economic growth, agricultural production and environmental protection.

References

Al-Mulali, U., Fereidouni, H.G., Lee, J.Y.M., 2014. Electricity consumption from renewable and non-renewable sources and economic growth: Evidence from Latin American countries. Renewable and Sustainable Energy Review, 30, 290-298.

Apergis, N., Payne, J.E., 2010a. Renewable energy consumption and economic growth evidence from a panel of OECD countries. Energy Policy, 38, 656-660.

Apergis, N., Payne, J.E., 2010b. Renewable energy consumption and growth in Eurasia. Energy Economics, 32, 1392-1397.

Apergis, N., Payne, J.E., 2011. The renewable energy consumption–growth nexus in Central America. Applied Energy, 88, 343-347.

Apergis, N., Payne, J.E., Menyah, K., Wolde-Rufael, Y., 2010. On the causal dynamics between emissions, nuclear energy, renewable energy, and economic growth. Ecological Economics, 69, 2255-2260.

Ben Jebli, M., Ben Youssef, S., 2015a. Renewable energy consumption and agriculture: evidence for cointegration and Granger causality for Tunisian economy. MPRA Paper 68018, University Library of Munich, Germany.

Ben Jebli, M., Ben Youssef, S., 2015b. The role of renewable energy and agriculture in reducing CO_2 emissions: evidence for North Africa countries. MPRA Paper 68477, University Library of Munich, Germany.

Ben Jebli, M., Ben Youssef, S., 2015c. Output, renewable and non-renewable energy consumption and international trade: Evidence from a panel of 69 countries. Renewable Energy, 83, 799-808.

Ben Jebli, M., Ben Youssef, S., Apergis, N., 2015a. The dynamic interaction between combustible renewables and waste consumption and international tourism: The case of Tunisia. Environmental Science and Pollution Research, 22, 12050-1201.

Ben Jebli, M., Ben Youssef, S., Ozturk, I., 2015b. The role of renewable energy consumption and trade: environmental Kuznets curve analysis for sub-Saharan Africa countries. African Development Review, 27, 288–300.

Brown, R.L., Durbin, J., Evans, J.M., 1975. Techniques for testing the constancy of regression relations over time. Journal of the Royal Statistical Society, Series B, 37, 149–63.

Dickey, D.A., Fuller, W.A., 1979. Distribution of the estimators for autoregressive time series with a unit root. Journal of the American Statistical Association, 74, 427-431.

Engle, R.F., Granger C.W.J., 1987. Co-integration and error correction: Representation, estimation, and testing. Econometrica, 55, 251-276.

Karkacier, O., Goktolga, Z.G., Cicek, A., 2006. A regression analysis of the effect of energy use in agriculture. Energy Policy, 34, 3796-3800.

Marques de Magalhaes, M., Lunas Lima, D.A.L., 2014. Low-carbon agriculture in Brazil: the environmental and trade impact of current farm policies. Issue Paper No. 54, International Centre for Trade and Sustainable Development, Geneva, Switzerland. Available at: www.ictsd.org.

McKinsey & Company, 2012. Pathways to a Low-Carbon Economy for Brazil. Accessed at: https://www.mckinsey.com.

Menyah, K., Wolde-Rufael, Y., 2010. CO_2 emissions, nuclear energy, renewable energy and economic growth in the US. Energy Policy, 38, 2911-2915.

Mushtaq, K., Abbas, F., Ghafour, A., 2007. Energy use for economic growth: Cointegration and causality analysis from the agriculture sector of Pakistan. The Pakistan Development Review, 46, 1065–1073.

OECD/FAO, 2015. Brazilian Agriculture: Prospects and Challenges. In OECD-FAO Agricultural Outlook 2015, OECD Publishing, Paris. DOI: http://dx.doi.org/10.1787/agr_outlook-2015-en.

Pao, H.T., Fu, H.C., 2013a. Renewable energy, non-renewable energy and economic growth in Brazil. Renewable and Sustainable Energy Reviews, 25, 381-392.

Pao, H.T., Fu, H.C., 2013b. The causal relationship between energy resources and economic growth in Brazil. Energy Policy, 61, 793-801.

Pesaran, M.H., Pesaran, B., 1997. Working With Microfit 4.0: Interactive Econo- metric Analysis. Oxford University Press, Oxford.

Pesaran, M.H., Shin, Y., 1999. An autoregressive distributed lag modeling approach to cointegration analysis. In: Strom S (ed) Econometrics and economic theory in 20th century: the Ragnar Frisch centennial symposium, vol. 11. Cambridge University Press, Cambridge.

Pesaran, M.H., Shin, Y., Smith, R.J., 2001. Bounds testing approaches to the analysis of level relationships. Journal of Applied Econometrics, 16, 289–326.

Pesaran, M.H., Smith, R.P., 1998. Structural analysis of cointegrating VARs. Journal of Economic Survey, 12, 471–505.

Phillips, P.C.B., Perron, P., 1988. Testing for a unit root in time series regressions. Biometrika, 75, 335-346.

REN21, 2012. Renewables 2012 Global Status Report. Accessed at: www.ren21.net.

Sadorsky, P., 2009a. Renewable energy consumption, CO2 emissions and oil prices in the G7 countries. Energy Economics, 31, 456-462.

Sadorsky, P., 2009b. Renewable energy consumption and income in emerging economies. Energy policy, 37, 4021-4028.

Sebri, M., Abid, M., 2012. Energy use for economic growth: A trivariate analysis from Tunisian agriculture sector. Energy Policy, 48, 711-716.

Tan, K.T., Lee, K.T., Mohamed, A.R., 2008. Role of energy policy in renewable energy accomplishment: The case of second-generation bioethanol. Energy Policy, 36, 3360–3365.

Tugcu, C.T., Ozturk, I., Aslan, A., 2012. Renewable and non-renewable energy consumption and economic growth relationship revisited: Evidence from G7 countries. Energy Economics, 34, 1942-1950.

Turkekul, B., Unakitan, G., 2011. A co-integration analysis of the price and income elasticities of energy demand in Turkish agriculture. Energy Policy, 39, 2416–2423.

World Bank, 2015. World Development Indicators. Accessed at: http://www.worldbank.org/data/onlinedatabases/onlinedatabases.html.

Zivot, E., Andrews D., 1992. Further evidence of great crash, the oil price shock and the unit root hypothesis. Journal of Business and Economic Statistics, 10, 251-270.

Tables

Table 1. Descriptive statistics of the data

Variables	per capita CO_2 emissions	per capita real GDP	per capita CRW	per capita AVA
Mean	1.648282	4382.835	32.00604	187.7807
Median	1.655065	4282.685	31.47338	173.5836
Maximum	2.191394	5744.487	40.42528	260.7172
Minimum	1.260216	3596.312	24.87103	150.7679
Std. Dev.	0.257127	531.1017	4.436251	33.92508
Skewness	0.215921	1.006751	0.270622	0.746654
Kurtosis	1.924077	3.372222	1.922459	2.118170
Jarque-Bera	1.792132	5.590318	1.938719	4.010122
Probability	0.408172	0.061105	0.379326	0.134652
Sum	52.74502	140250.7	1024.193	6008.982
Sum Sq. Dev.	2.049547	8744139.	610.0900	35678.25

Notes: CRW and AVA represent the combustible renewables and waste consumption, and agricultural value added variables, respectively.

Table 2. Zivot and Andrews's unit root test

Variables	**Levels**		**1st differences**	
	t-statitics	**Time break**	**t-statitics**	**Time break**
e	-4.239330	2003	-5.940670*	2001
y	-3.846140	2003	-4.894539*	2003
crw	-3.664378	1995	-5.056935***	2001
agr	-5.043443***	1991	-8.083465**	1988

Notes: ***, **, and * indicate statistical significance at the 1%, 5%, and 10%, respectively.

Table 3. ARDL bounds to cointegration

Estimated model	Bounds testing to cointegration		F-statistics	Prob (F.stat)
	optimal lag length			
F_1(e/y,crw,agr)	5,4,5,5		9.833827	0.094400*
F_2(y/e,crw,agr)	5,5,5,5		431.3887	0.036100**
F_3(crw/y,e,agr)	4,5,5,3		11.29091	0.018800**
F_4(agr/y,e,crw)	3,3,2,1		4.127866	0.020500**
Critical values	Lower bounds I(0)			Upper bounds I(1)
1%	4.310			5.544
5%	3.100			4.088
10%	2.592			3.454
	Diagnostic tests			
	LM-test	ARCH test	Normality test	
F_1(e/y,crw,agr)	0.367839	0.060162	0.014735	
F_2(y/e,crw,agr)	0.625857	0.155069	1.484399	
F_3(crw/y,e,agr)	0.556444	0.661218	1.460348	
F_4(agr/y,e,crw)	1.440433	1.068674	0.134940	

Notes: ** and * indicate statistical significance at the 5% and 10% levels, respectively. Critical values are obtained from Pesaran et al. (2001). The F(.) statistics are estimated for the case of unrestricted intercept and no trend. Diagnostic tests cover serial correlation (Breusch-Godfrey Serial Correlation LM test), heteroscedasticity (ARCH test) and normality (Jarque-Bera) tests.

Table 4. Short and long-run ARDL estimates

	Dependent variable: *e*	*y*	*crw*	*agr*	*c*
	ARDL estimates	3.367726	-1.278594	-0.848186	-16.78045
	p-value	0.000***	0.000***	0.000***	0.000***
	Dependent variable: *y*	*e*	*crw*	*agr*	*c*
	ARDL estimates	0.296936	0.379661	0.251857	4.982725
	p-value	0.000***	0.000***	0.000***	0.000***
Long-run estimates	Dependent variable: *crw*	*y*	*e*	*agr*	*c*
	ARDL estimates	-2.633930	-0.782109	-0.663374	-13.12415
	p-value	0.000***	0.000***	0.000***	0.000***
	Dependent variable: *agr*	*y*	*e*	*crw*	*c*
	ARDL estimates	3.970504	-1.178987	-1.507445	-19.78393
	p-value	0.000***	NS	0.000***	0.000***
	Dependent variable: *d(y)*	*d(e)*	*d(crw)*	*d(agr)*	*c*
		-0.133248	-0.174087	-0.018091	0.010390
	p-value	NS	NS	NS	NS
	Dependent variable: *d(e)*	*d(y)*	*d(crw)*	*d(agr)*	*c*
		0.738532	-0.674871	-0.010074	0.010423
Short-run estimates	p-value	0.0582*	0.0234**	NS	NS
	Dependent variable: *d(crw)*	*d(y)*	*d(e)*	*d(agr)*	*c*
		0.145054	-0.155840	-0.239733	0.005347
	p-value	NS	NS	NS	NS
	Dependent variable: *d(agr)*	*d(y)*	*d(e)*	*d(crw)*	*c*
		0.682646	-0.096903	0.719116	0.064585
	p-value	0.0692*	NS	0.0125**	0.000***

Notes: ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. P-values are listed in parentheses. NS indicates that the estimated coefficient is statistically not significant.

Table 5. Granger causality tests

	Short-run				**Long-run**
Variables	***Δe***	***Δy***	***Δcrw***	***Δagr***	**ECT**
Δe	-	1.97321	0.09699	9.35642	-0.414451
		(0.1711)	(0.7578)	(0.0049)***	[-2.70286]***
Δy	0.24709	-	0.00076	10.4981	-0.665918
	(0.6230)		(0.9782)	(0.0031)***	[-2.70010]***
Δcrw	0.02345	0.25548	-	0.17898	-0.087880
	(0.8794)	(0.6172)		(0.6755)	[-1.73675]*
Δagr	1.79401	0.85871	0.38965	-	-0.181266
	(0.1912)	(0.3620)	(0.5375)		[-2.00355]**

Notes: ***, **, and* indicate statistical significance at the 1%, 5%, and 10% levels, respectively. P-values are listed in parenthesis and t-statistics are presented in brackets.

Figures

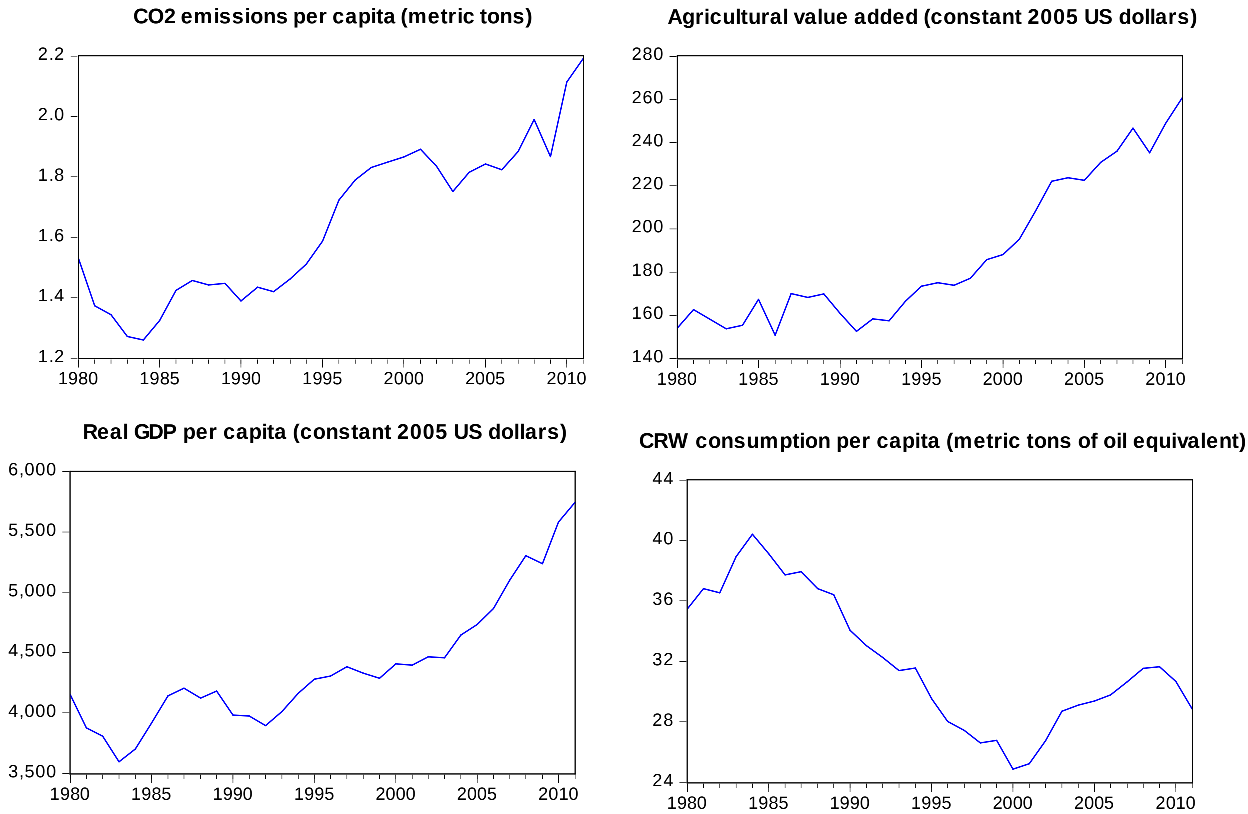

Fig.1. Graphical representation of data variables

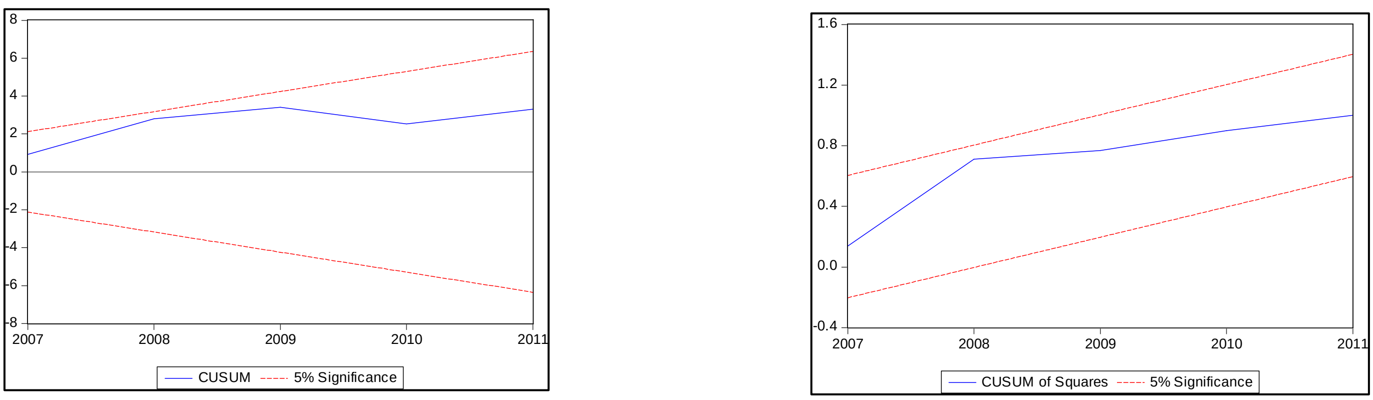

Fig.2. CUSUM and CUSUM of Squares plots for per capita real GDP model

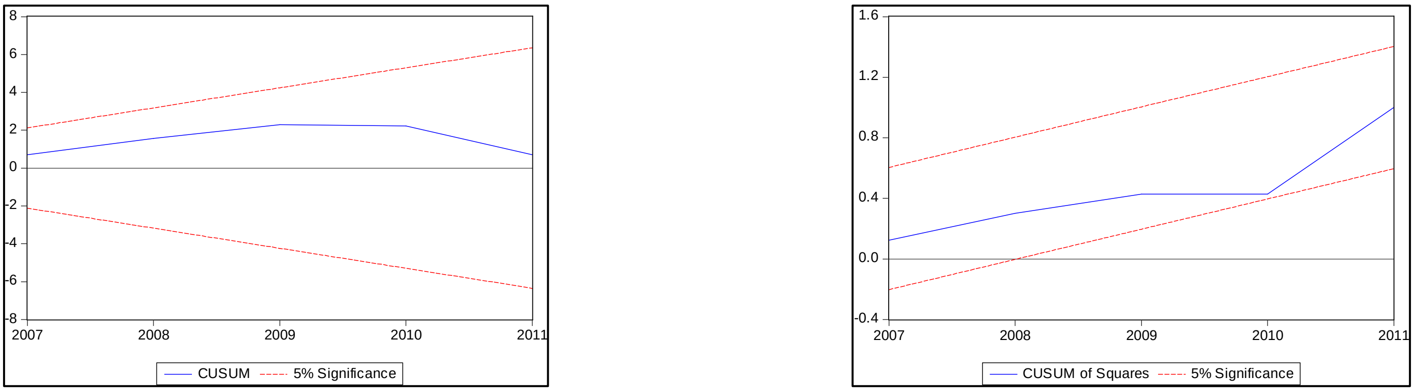

Fig.3. CUSUM and CUSUM of Squares plots for per capita CO_2 emissions model

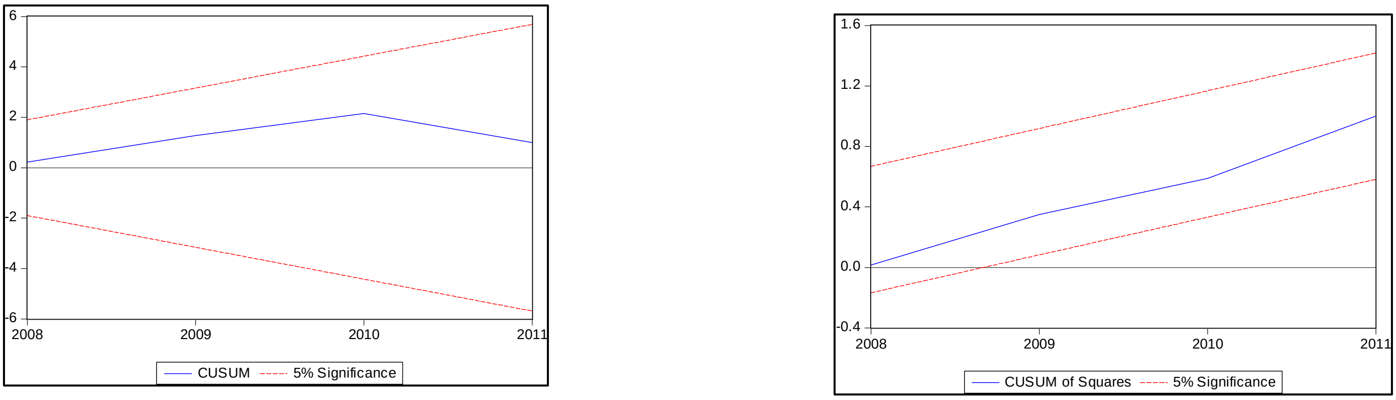

Fig.4. CUSUM and CUSUM of Squares plots for per capita CRW consumption model

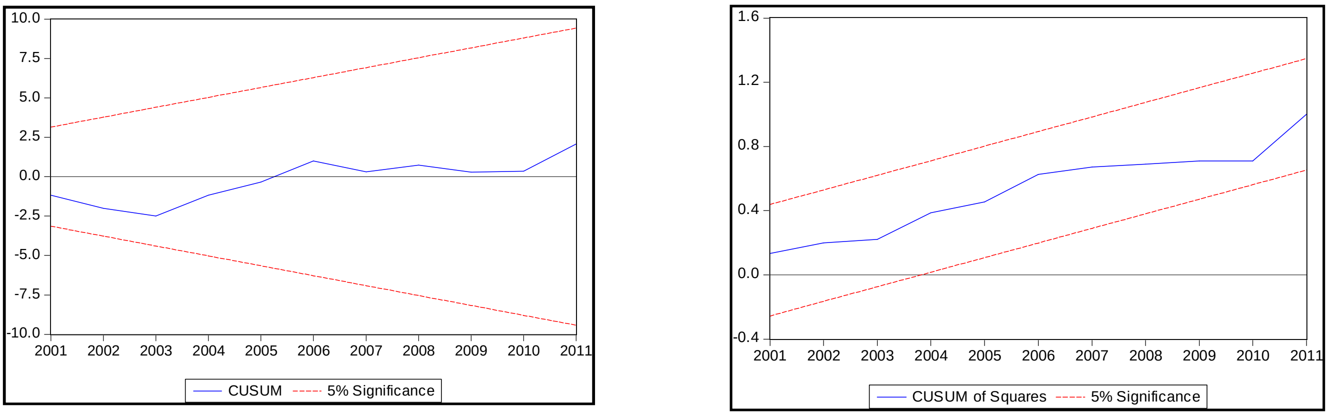

Fig.5. CUSUM and CUSUM of Squares plots for per capita agricultural value added model