Does Agriculture Matter for Environmental Kuznets Curve in Russia: Evidence from the ARDL Bounds Tests Approach

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Abstract

This study explores the relationship between carbon dioxide emissions and their main determinants, which include real income and energy consumption in Russia, employing data for the period 1990-2016. The hypothesis of agriculture being an important determinant of environmental quality in Russia is also tested. For estimating the short-run and long-run relationships the ARDL bounds test approach is employed in this study. The results are consistent with the Environmental Kuznets Curve (EKC) hypothesis and show that the real income and energy consumption have a statistically significant positive impact on the carbon emission and its square has a significant negative effect on the carbon emissions both in the short-run and long-run. Agricultural sector is found to be a relatively important statistically significant determinant of carbon emission in Russia as well. The pairwise Granger causality test also reveals unidirectional causality running from agriculture to the carbon emissions.

Keywords

Introduction

1. Environmental pollution: problem statement

Environmental pollution is one of the main areas of research in the field of the environmental economics. The problems of climate changes, global warming and worsening quality of environment, brought to life by an increased industrial output, are related to an increased greenhouse gases emission, which include carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) as well. According to the estimates of the World Bank (2018), agricultural sector is responsible for 15 % – 35 % of the global greenhouse gases emissions, depending on whether it is related with deforestation or not. On the other hand, agricultural sector remains on the main fields in the national economies, which helps to maintain the national security, at least in part of the food security, not to mention the function of meeting the basic demand of the households.

Given the above, the importance of agricultural sector for the national economy, as well as its role in the environmental pollution under certain assumptions is rather hard to overestimate. Concerning the studied country, one should notice, that Russia takes the 4th place among other countries, contributing in the world CO_2 emissions, after China, the United States of America and India in total kilotons (kt). Yet, in terms of kilogram (kg) of CO_2 emission per GDP, measured in 2010 US dollars, in 2014, according to the World Bank data (2018), Russia with 0.999 kg outplaced the US with 0.324 kg. According to the world tendency among developed countries, CO_2 steadily declines. However, in Russia CO_2 emissions continue to rise. Since 1998 minimum, the level of CO_2 emissions has increased on 14% up to 2014. If the GDP is taken into account, the picture changes: CO_2 emissions, measured as kg per 2010 US dollars of GDP, decline from 1.839 in 1998 to 0.999 in 2014. This tendency is the results of using more friendly-environmental technologies in some sectors of the national economy. However,

due to rising share of agriculture in Russian GDP from 3.9% in 2011 up to 5% in 2017, the question of potential increase in CO_2 emissions arises, which advocates the relevance of this study, given the potential threat of increasing CO_2 emissions.

2. Literature review

The problem of environmental pollution has already received much attention in the literature. Most empirical studies are based on the theoretical hypothesis of the environmental Kuznets curve (EKC). The EKC framework underlines the importance of energy consumption in producing the national GDP and assumes the existence of an inverted U-shaped relationship between environmental degradation and real income per capita. As national income rises, environmental pollution initially is rising as well. However, achieving a certain threshold in national economic development, the level of emissions declines and pollution is assumed to decrease (Kuznets, 1955).

The initial wave of empirical studies tested the EKC hypothesis in narrow sense, aiming to describe and explain environmental pollution solely by economic factors, including different proxies for economic growth (Grossman and Krueger, 1995; Heil and Selden, 1999; Akbostanci et al., 2009; Poudel et al., 2009; Narayan and Narayan, 2010; Onafowora and Owoye, 2014).

The second wave of the studies is different in a more deeply oriented approach, taking into consideration the structural issue: these studies seek for additional or structural factors that may amplify or accelerate the environment pollution process. Some studies accentuate importance of energy consumption as a leading factor of environmental degradation (Soytas and Sari, 2009; Acaravci and Ozturk, 2010; Pao and Tsai, 2010; Alam et al., 2012; Dagher and Yacoubian, 2012; Saboori and Sulaiman, 2013; Shahbaz et al., 2015; Benavides et al., 2017; Shahbaz et al., 2017). These studies bring evidence in favor of energy-induced EKC both for developed and developing countries, yet in some cases the results are heterogeneous due to differences in econometric techniques used.

The third wave of empirical research is aimed at mitigating the omitted variables bias and include various additional proxies for incorporation of changes in international environment and globalization processes. Recently, the importance of changes in energy prices and terms of international trade gain attention

in testing the EKC. The issue of trade liberalization and globalization has led to a rise in international trade, which spurred the total output, leading to a rise in environmental pollution (Halicioglu, 2009; Rabi et al., 2015; Halicioglu and Ketenci, 2016; El-Aasar and Hanafy, 2018). An increased volatility of energy prices and the export-import status of the country relative to energy resources also gained attention in empirical research. (Richmond and Kaufmann, 2006; He and Richard, 2010; Al-Mulali and Ozturk, 2016) In case when the country is an importer of energy resources and in times of rising energy prices, the stimulus to substitute energy-intensive technologies by renewable energy resources or more environmentally friendly ones, is supposed to be greater. In case of exporting countries, rising global energy prices lead to increased profit and greater output, which, in turn, may lead to higher level of pollution (He and Richard, 2010).

Also empirical research on the EKC hypothesis may be divided for developed and developing countries. The results of the studies are heterogeneous in nature. In some papers, authors find evidence in favor of the inverted U-shaped curve, while in others the N-shaped. E.g., Halicioglu and Ketenci (2016) provided evidence in favor of the existence of EKC only in three out of fifteen transition countries. Onafowora and Owoye (2014) found the N-shaped trajectory in six out of eight studied countries and only in two countries the inverted U-shaped curve was detected. The ambiguity of results may be the consequence of using total pollution as a proxy for environmental degradation, neglecting the differences in the emissions structure in the economy (Stern, 2004).

Although empirical studies, testing the EKC hypothesis, are common today, yet the number of papers, devoted to assessing the role of agriculture in the environmental pollution in the EKC framework are limited. Pretty (2008) stresses the importance of agriculture as an accumulator of carbon when the organic waste is aggregated in the soil, and when it is used as an energy source that substitutes for fossil fuels, thus avoiding carbon. Liu et al. (2017) tested the causality between CO_2, renewable energy and agriculture in selected ASEAN-4 countries. The results do not support the inverted U-shaped EKC hypothesis, as well as no causality is found from renewable energy to agriculture, giving evidence to pollution-inducing character of the agriculture. Zafeiriou et al. examined the intertemporal causal relationship between environmental damage from carbon

emissions released by agriculture per 1000 ha of utilized agriculture area and economic performance in the sector of agriculture as described by net value added per capita. The results of the study, which included Bulgaria, Czech Republic, and Hungary, show that the EKC hypothesis is present in the long run for Bulgaria and Czech Republic while in the short run is validated only for the case of Czech Republic, giving evidence in favor of agriculture being an important factor of environment pollution.

Despite the interest in testing the EKC hypothesis, empirical research of the EKC in Russian case is almost absent. Pao and Tsai (2010), testing the EKC hypothesis for BRIC countries, found that emissions are "output inelastic" and the EKC is not supported. Halicioğlu and Ketenci (2016) and Yang et al. (2017) found support for the EKC in Russia, where the economy-related greenhouse emissions are presented by energy consumption, emissions from industrial process, from animal husbandry and fugitive emissions. Ketenci (2018) also find support for the EKC in Russia, stressing importance of energy consumption, real income, education and urbanization levels for environmental pollution in Russia. Also mixed results for Russian case are found by Mihalischev and Raskina (2015), Rudenko (2018) on macro, regional and city-levels. The results of testing the EKC hypothesis are controversial, even when Russia is included in the panel of BRIC countries. The results of Pao and Tsai (2010) speak in favor of the EKC in Russia, while the results of Chang (2015) speak in favor of the U-shaped curve, which is controversial to conventional results.

Unfortunately, none of the studies, devoted to the Russian case, incorporate agriculture as an important variable and determinant of the environmental pollution. Given the above, this study is aimed to fill this gap in the literature.

Materials and methods

1. Research methodology

Given the heterogeneity of the obtained results on the EKC hypothesis, discussed in the previous section, we aim to fill the gap by enquiring into the nature of the relationship between CO_2 emission and agriculture as a share of GDP in the EKC framework. Following methodology for the Russian case, proposed by Ketenci (2018), the basic EKC hypothesis then can be presented as follows:

$$c_t = \beta_0 + \beta_1 e_t + \beta_2 i_t + \beta 3 i_t^2 + \beta_4 a_t + \varepsilon_t \qquad (1)$$

where c_t represents CO_2 emission per capita in the sampled country; e_t is commercial energy use per capita; i_t is the real income, measured as national GDP per capita; i_t^2 represents the square of per capita income; a_t is the agriculture, measured as its share in GDP.

Then we transform linear specification of the model into log-linear specification. The log-linear specification provides more appropriate and efficient results compared to simple linear functional form of the model (Cameron, 1994). Moreover, logarithmic form of variables gives direct elasticities for interpretations. Therefore, we specify the estimated equation in log-linear form:

$$Lc_t = \beta_1 + \beta_{et} Le_t + \beta_{it} Li_t + \beta_{i_t^2} Li_t^2 + \beta_{a_t} La_t + \mu_t \qquad (2)$$

The theoretical foundation of the EKC hypothesis states that the energy consumption is the primary source of shifts and changes in emissions. Then, it is expected the regression coefficient β_{et} to have a positive sign (Suri and Chapman, 1998). Also the EKC hypothesis states that β_{it} is positive, while $\beta_{i_t^2}$ is negative in sign, demonstrating a rise in CO_2 emissions goes alongside the economic growth till the certain threshold, after achieving of which, the emission declines due to technological changes, leading to increasing environment quality. Coefficient β_{a_t} may be positive or negative, depending on the current stage of development of the national economy, political and institutional factors, stimulating introduction of environment-friendly technologies in the economy and agricultural sector particularly. On the one hand, increasing share of agriculture in Russian GDP is expected to negatively affect the environmental quality due to its energy intensive production cycle. On the other hand, the results may be opposite as well, given the introduction of environment-friendly technologies in the agricultural sector.

In this study we employ the ARDL bound test approach, which allows for I(0), I(1) or fractionally integrated variables. Yet, if the variables are I(2) integrated, the use of this methodology is unacceptable. That is why the first step of this study is to check the stationarity of the sampled variables and determine whether it us achieved without second differencing procedure. For this we employ four alternative unit root tests: the Augmented Dickey-Fuller (ADF) test (Dickey

and Fuller, 1979), the Dickey–Fuller generalized least squares (DF-GLS) test proposed by Elliot et al. (1996), the Phillips and Perron (1988) PP test and the KPSS (Kwiatkowski et al., 1992) test. The null hypothesis of the ADF, DF-GLS and PP tests states that the there exists a unit root, while the alternative hypothesis states that the series are generated by a stationary process. The null hypothesis of the KPSS test is of reverse nature – it states that the series are stationary, while the alternative hypothesis states that the unit root is present.

After determining the stationary character of the series, the study employs the bounds testing approach, proposed by Pesaran et al. (2001) for cases with low span of data. The bounds testing approach is also known as the autoregressive distributed lag model (ARDL), which has some important advantages over the Johansen cointegration test (Pesaran and Shin, 1999). The most important advantage of the ARDL approach is that the ARDL approach can be used regardless the integration order of variables I(0), I(1) or both. Yet, the approach is invalid in case when the I(2) integrated variables are present. Also of great importance is that the ARDL approach allows differences in lags of the sampled variables in the data generating process. Endogenuity problem is absent in the ARDL approach because it also corrects for residual serial correlation. Also the ARDL approach allows to estimate short-run parameters by the means of the error correction model (ECM) adjustments.

The first step in the ARDL procedure is the determining the co-integration existence between the sampled variables. The bounds test examines long-run relationships, where the ARDL framework of the model (Equation 2) is expressed in Equation 3:

$$\Delta lnc_t = \gamma_1 + \sum_{i=1}^{p}\gamma_i\Delta lnc_{2t-i} + \sum_{j=0}^{q}\gamma_j\Delta lne_{t-j}$$
$$+ \sum_{k=o}^{m}\gamma_k\Delta lni_{t-k} + \sum_{l=0}^{n}\gamma_l\Delta lni_{t-l}{}^2$$
$$+ \sum_{s=0}^{o}\gamma_5\Delta lna_{t-s} + \gamma_{c_{t-1}}lnc_{t-1}$$
$$+ \gamma_{e_{t-1}}lne_{t-1} + \gamma_{i_{t-1}}lni_{t-1}$$
$$+ \gamma_{i_{t-1}}{}^2 lni_{t-1}{}^2 + \gamma_{a_{t-1}}lna_{t-1} + \mu_t \qquad (3)$$

where $\gamma_{c_{t-1}} = \gamma_{e_{t-1}} = \gamma_{i_{t-1}} = \gamma_{i_{t-1}}{}^2 = \gamma_{a_{t-1}} = 0.$ represent short-term coefficients of the sampled variables in the logarithmic forms and γ_i, γ_j, γ_k, γ_l, γ_s represent the long-term coefficients

of the sampled variables in the logarithmic forms. Presence or absence of the relationship is tested by employing the joint F or statistics of the Wald test. The null hypothesis of nocointegration in the model is $\gamma_{c_{t-1}} = \gamma_{e_{t-1}} = \gamma_{i_{t-1}} = \gamma_{i_{t-1}}{}^2 = \gamma_{a_{t-1}} = 0.$

The alternative hypothesis of cointegration between the variables is $\gamma_{c_{t-1}} \neq \gamma_{e_{t-1}} \neq \gamma_{i_{t-1}} \neq \gamma_{i_{t-1}}{}^2 \neq \gamma_{a_{t-1}} \neq 0.$ To test the significance of the obtained results, the critical values for the bound test, reported in Pesaran et al. (2001) are used. The critical bounds are set as if the variables are of I(0) and are of I(1). If the F-statistics is above the upper bound of the critical values, the null hypothesis is rejected. If the F-statistics is below the lower critical bound, the null hypothesis is accepted. If the F-statistics is between the bounds, the results of the test are inconclusive.

In case of the presence of co-integration between the variables, the next stage is the estimation of the ECM of the following type (Equation 3):

$$\Delta lnc_t = \theta_1 + \sum_{i=0}^{p}\theta_2\Delta lnc_{t-i} + \sum_{k=0}^{q}\theta_3\Delta lne_{t-k}$$
$$+ \sum_{i=o}^{r}\theta_3\Delta lni_{t-r} + \sum_{i=0}^{s}\theta_4\Delta lni_{t-s}{}^2$$
$$+ \sum_{i=0}^{l}\theta_5\Delta lna_{t-l} + \delta_1 ECM_{t-1} + \varphi_t \qquad (4)$$

where ECM_{t-1} represents the error correction term and δ_1 is the coefficient, estimating the speed of variables adjustment towards the equilibrium. This coefficient has to be statistically significant and negative in sign. The existence of an ECT implies the changes in dependent variable. These changes are a function of both the levels of disequilibrium in the cointegration relationship and the changes in the other explanatory variables. This indicates the deviation in dependent variable from short span of time to long-run equilibrium path (Masih and Masih, 1997). The goodness of fit for ARDL model is checked through stability tests such as cumulative sum of recursive residuals (CUSUM) and cumulative sum of squares of recursive residuals (CUSUMSQ).

2. Data

The study aims to test the short and long-run relationships between carbon emission and their determinants in the framework of the EKC hypothesis. The variables include energy consumption, real income and agriculture

in the Russian case for the period 1990-2016. The study employs annual data. The data are collected from the World Bank's World Development Indicators database and Russian statistical database when and where needed.

Carbon emissions are measured by CO_2 emissions per capita in the sampled country, metric tonnes; energy consumption is measured by commercial energy use in Russia per capita, kg of oil equivalent; real income is represented by Russian GDP per capita, constant 2010 US dollars; agriculture is measured as a percentage share of value added by agricultural sector in Russian GDP. All variables then are transformed in natural logarithms.

Results and discussion

Descriptive statistics for the sampled variables are presented in Table 1. Carbon emissions in Russia amounts 11.77 metric tonnes per capita for the period from 1990 to 2016. Commercial energy consumption is 4711.48 kg of oil equivalent per capita. The average share of agriculture in Russian GDP is 5.67 % with the tendency to decrease from 15 % to 3% in the long-run. Yet, beginning from 2011 statistics show a rise in the share of agriculture in Russian GDP up to about 5 %.

The study is based on the usage of Russian data for the sampled variables for the period 1990-

2016 and aimed to explore the long and short-run relationships between CO_2 emissions and variables which have the potential to affect the changes in the environmental pollution process under the EKC hypothesis. These include energy consumption, real income and agriculture. For the purposes of the study the ARDL bounds test approach is employed, that assumes the use of the variables with different order of integration, except integration of order above I(1). The first goal, then, should be the investigation of the order of sampled variables integration, achieving which supposes testing the variables for stationarity in order to determine if the ARDL approach suits the study. We employ four different unit root tests, including the ADF, the DF-GLS, the PP and the KPSS tests. The results of testing the variables for stationarity are presented in Table 2.

The results of the tests for stationarity show that all the sampled variables of the study are generated by a stationary process. Given the results of the different unit root tests, we can assume that the variables in the study are integrated of the order 0 or 1 and none is integrated of the order above 1.

Given that the variables of the study are not integrated of the order 2 we can proceed with the ARDL cointegration approach. The first step in the ARDL co-integration analysis requires identification of the optimal lag length

Variable	Mean	Max.	Min.	St. dev.	Obs.
c	11.77003	16.08000	10.12730	1.339353	27
e	4711.481	5928.661	3981.502	497.5094	27
i	8707.101	11803.71	5505.628	2226.278	27
a	5.675496	15.46104	3.160549	2.900097	27

Note: Max. is the abbreviation for maximum value of a variable, Min. is for the minimum value, St. dev. is referred to a standard deviation, Obs. is the number of observations, c is the abbreviation for carbon emission, e is for energy consumption, r is for real income and a is for agriculture share of value added (as a % of GDP).
Source: own calculations

Table 1: Descriptive statistics.

Variable	ADF	DF-GLS	PP	KPSS
c	-3.852911*	-3.003408*	-3.655386**	0.174587
e	-3.207594**	-3.280949*	-3.216722**	0.369353
i	-3.687551**	-2.261857**	-2.358914**	0.308785
a	-3.324449**	-5.386401*	-3.573855**	0.712689

Note: The null hypothesis of ADF, DF-GLS and PP unit root tests is the presence of the unit root. The null hypothesis of the KPSS test is the stationarity of an estimated variable. * and ** denote the rejection of the null hypothesis at the 1% and 5% significance levels, respectively.
Source: own calculations

Table 2: Results of unit root tests.

under the unrestricted vector autoregression. For these purposes we use the Schwarz Criterion (SC), the Akaike Information Criterion (AIC) and the Hannan-Quinn Information criterion (HQ). All the information criteria stand for the lag length of 2 years (Table 3).

Lag	AIC	SC	HQ
0	-10.41324	-10.21822	-10.35915
1	-15.17782	-13.81442	-14.90737
2	-15.56960*	-14.20272*	-15.08278*

Note: * indicates lag order selected by the criterion AIC - Akaike information criterion, SC - Schwarz information criterion, HQ: Hannan-Quinn information criterion.
Source: own calculations

Table 3. Results of optimal lag length selection.

Then we can proceed to determining the long-run relationships between the variables of the study. To check the variables on the existence of the long-run relationship we employ the bound F-test for Equation 2. The results of the bounds test for the estimated equation are presented in Table 4.

The estimated equation includes both dependent and independent variables. Dependent variables include energy consumption, real income and square of the real income, while agriculture stands as an independent variable. The results of the cointegration F-test show that the resulting F-statistics are above the upper bound and statistically significant at 10 %, 5 % and 1% significance level. The results show that the sampled variables are cointegrated and the long-run relationship between the variables exists in the Russian case. The obtained results are in line with the results of Ketenci (2018).

Given that the sampled variables are cointegrated in the long-run, we can proceed to the next stage, that requires estimation of the long and short-run coefficients. Given that the ARDL model was estimated in the logarithmic form, we can estimate how a shock in 1% of the explanatory variables affect the control

variable both in the long and short run.

The estimates for the short-run relationships are presented in Table 5.

Regressor	Coefficient	t-statistics
$\Delta \ln e$	0.894	7.674*
$\Delta \ln i$	0.009	1.908*
$\Delta \ln i^2$	-0.014	-2.671*
$\Delta \ln a$	0.082	2.177*
ECM_{t-1}	-0.728	-5.726*
Diagnostic test statistics		
R^2	0.934	
DW-statistic	2.47	
F-statistic	4.69	
RSS	0.01	

Note: * and ** denote the rejection of the null hypothesis at the 1 % and 5 % significance levels respectively. β column reports estimated coefficients.
Source: own calculations

Table 5: ARDL short-run results.

As can be seen from the results of the short-run relationship estimation, the error correction term is negative in sign and statistically significant at 1 % level. This result confirms the presence of the co-integration. The value of the ECM coefficient is 0.728, that allows to assume that in Russia about 73 % of the CO_2 emissions disequilibrium in the short-run is rectified. The diagnostic test results imply the acceptable fit of the model, given the appropriate R^2 and significant F-statistic. Durbin-Watson statistics coefficient shows that the error terms are not correlated. The absence of autocorrelation in the disturbance of the error term is proved by the Breusch-Godfrey test. The normality criterion of the model is also met.

Given the results of the short-run estimates, we obtain evidence in favor of the EKC hypothesis in Russia. Particularly, the energy consumption and the real income have a small yet positive effect on the CO_2 emissions during the sampled

F-statistics	90 % LB	90 % UB	95 % LB	95 % UB	99 % LB	99 % UB
6.46	3.47*	4.45*	4.01*	5.07*	5.17	6.36

Note: Null hypothesis of the ARDL bounds test is: No long-run relationship exists. LB – low bound, UB – upper bound. If the F test statistic falls between lower and upper bounds the result is inconclusive. If it is below lower bound, the null hypothesis cannot be rejected. If the test statistics is above upper bound , the null hypothesis of no co-integration is rejected (*).
Source: own calculations

Table 4: Cointegration F-test, $F(c| e,i,i^2,a)$.

period. E.g., a 1 % rise in energy consumption increases CO_2 emissions by 0.89 %. The signs of the coefficients of GDP and GDP square also speak in favor of the EKC hypothesis in Russia at 1 % significance level: a 1% rise in GDP increases CO_2 emissions by 0.01 %. The square of the real income coefficient has a negative sign, that speaks in favor of the EKC hypothesis in Russia, confirms the results of Ketenci (2018) and supports the results of Halicioglu and Ketenci (2016) as well as Yang et al. (2017) and Chang (2015).

Another finding indicates that agriculture plays a statistically significant role in environmental pollution in Russia, given the positive sign of the β coefficient, that confirms the relative importance of agricultural sector as a short-run source of environmental pollution in Russia. A 1 % rise of agriculture as a share of the national GDP increases CO_2 emissions in Russia by almost 0.1 %. The result is relatively small yet statistically significant, which gives us the right to accept the hypothesis of agriculture being a source of environmental pollution in Russia.

The estimates of the long-run relationship between the studied variables are presented in Table 6.

Regressor	Coefficient	t-statistics
$\Delta \ln e$	0.923	10.263*
$\Delta \ln i$	0.008	1.732*
$\Delta \ln i^2$	-0.017	-2.844*
$\Delta \ln a$	0.091	2.351*
ECM_{t-1}	6.178	5.806*
Diagnostic test statistics		
	t-statistics	p-value
χ^2_{SC}	1.85	0.213
χ^2_{FF}	0.12	0.893
χ^2_{N}	3.49	0.294
χ^2_{H}	0.89	0.928

Note: * and ** denote the rejection of the null hypothesis at the 1 % and 5 % significance levels respectively. β column reports estimated coefficients. χ^2_{SC}, χ^2_{FF}, χ^2_{N}, χ^2_{H} present the Breusch-Godfrey serial correlation LM test, the Ramsey RESET test of functional form misspecification, the Jarque-Bera normality test and the Breusch-Pagan-Godfrey heteroscedasticity test, respectively.
Source: own calculations

Table 6: ARDL long-run results.

As can be seen from the results, presented in Table 6, the estimates of the ARDL model are found to be statistically significant. The long-run estimates, as the short-run ones, of the energy consumption, real income and agriculture positively affect the CO_2 emissions in Russia. The impact

of the energy consumption is stronger than that of the GDP, which supports the energy-induced pollution hypothesis. An increase in energy consumption per capita in Russia by 1 % leads to an increase in the CO_2 emissions per capita by 0.923 %, while an increase of the real income in 1 % leads to 0.01 % of environmental pollution. A 1 % increase in agriculture as a share of GDP leads to only almost 0.01% increase in the CO_2 emissions in Russia.

These results need interpretation. The presence of the impact of energy consumption on CO_2 emissions in Russia is quite logical, given low energy efficiency and high energy intensity of the Russian economy. Second, the low impact of the GDP on environmental pollution is achieved because of the structure of the Russian economy, where energy intensive and "toxic" sectors (such as oil and gas industry, agriculture and metal industry) account for less than 50 % of the GDP: the share of agriculture being around 5 %, the share of oil and gas industry being around 10 % on average. Then the low impact of the β-coefficient for the Russian GDP becomes quite logical. The impact of the agriculture as a source of the environmental pollution is also relatively small (almost 0.1%) given the national authorities' policies, stimulating the use of environment-friendly technologies, e.g. reducing emissions of NH_3, CO, CO_2, SO_2, CH_4, N_2O, SF, as well as the negative impact of benzene and wood dust from agrarian enterprises.

Given the above results, the EKC hypothesis finds support: the positive sign of the real income is changed by the negative sign of the squared real income, showing an inverted U-shaped relationship between CO_2 emissions and the real income in the Russian case, as well as supporting the relative importance of the agricultural sector as a source of environmental pollution and necessity to increase the level of environment-friendly technologies used in agriculture.

Another important aspect of the long-run estimates is the magnitude of the positive and negative impacts of the real income and the square of the real income on the CO_2 emissions. The magnitude of the positive impact of the GDP on CO_2 emissions in Russia is less than the negative impact of the squared GDP per capita. This implies that the environmental improvement takes its place in the Russian economy after achieving a certain threshold, compared to the initial environment degradation process. This result is confirmed

by the World Bank (2018), according to which CO_2 emissions, measured as kg per 2010 US dollars of GDP, have declined in Russia from 1.839 in 1998 to 0.999 in 2014.

Another important test to explore the relationships between the sampled variables is the pairwise Granger causality test. The results of the causality test are presented in Table 7.

Null hypothesis	F-statistic	p-value
ln e does not Granger cause ln c	3.076	0.001
ln c does not Granger cause ln e	8.962	0.004
ln i does not Granger cause ln c	5.901	0.022
ln c does not Granger cause ln i	4.093	0.049
ln i^2 does not Granger cause ln c	5.084	0.002
ln c does not Granger cause ln i^2	4.212	0.052
ln a does not Granger cause ln c	7.209	0.005
ln c does not Granger cause ln a	0.953	0.431

Source: own calculations

Table 7: Pairwise granger causality test.

According to the results of the pairwise Granger causality test, the unidirectional causality running from agriculture to the CO_2 emissions in Russia exists. Moreover, the bidirectional causality between CO_2 emissions and energy consumption, real income and real income squared has been revealed.

The last step in the ARDL approach is estimating the stability of the model. For this purpose, we employ the cumulative (CUSUM) and the cumulative sum of squares (CUSUMSQ) stability tests, proposed by Brown et al. (1975). The results of the CUSUM and CUSUMSQ tests are presented in Figures 1 and 2.
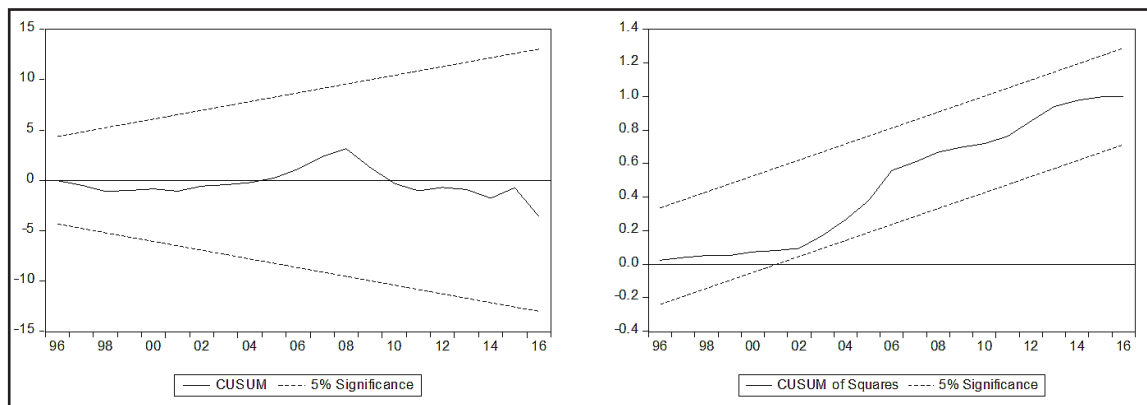
As can be seen from Figures 1 and 2, the plots of the CUSUM and the CUSUMSQ statistics are located within the 5% significance critical bounds, which proves the stability of the developed model.

Conclusion

This study explores the relationship between carbon dioxide emissions and their main determinants, which include real income and energy consumption in Russia, employing data for the period 1990-2016. The hypothesis of agriculture being an important determinant of environmental quality in Russia is also tested. For estimating the short-run and long-run relationships the ARDL bounds test is employed in this study. To check the causal relationship, the pairwise Granger causality test is employed.

The results of the cointegration F-test show that the resulting F-statistics are above the upper bound and statistically significant at 10 %, 5 % and 1 % significance level. The results show that the sampled variables are cointegrated and the long-run relationship between CO_2 emissions, energy consumption, real income and agriculture exists in the Russian case. According to the results of the short-run relationship estimation, the value of the ECM coefficient is 0.728, that allows to assume that in Russia about 73 % of the CO_2 emissions disequilibrium in the short-run is rectified, which also gives evidence in favor of the EKC hypothesis in Russia. Another empirical finding is that agriculture plays a small yet statistically significant role in environmental pollution in Russia, that confirms the importance of agricultural sector as a short-run source of environmental pollution in Russia. The long-run estimates, as the short-run ones, of the energy consumption, real income and agriculture positively affect CO_2 emissions

Source: own calculations

Figures 1 and 2: Results of the stability tests.

in Russia. E.g., an increase in energy consumption per capita in Russia by 1 % leads to an increase in the CO_2 emissions per capita by 0.923 %. An increase of the real income in 1 % causes only 0.01 % of environmental pollution. A 1 % increase in agriculture as a share of GDP leads to an almost 0.1% increase in the CO_2 emissions in Russia. The results of the pairwise Granger causality test also confirm the unidirectional causality running from agriculture to the CO_2 emissions in Russia.

Given above, the present study supports the existence of the inverted U-shaped relationship between CO_2 emissions, real income an energy consumption, providing evidence in favor of the EKC hypothesis in Russia. Moreover, agricultural sector in Russia is found to be a statistically significant variable in explaining environmental pollution despite the small share in the national GDP.

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