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Analysis of multivariate time series for some linear models by using multi-dimensional wavelet shrinkage

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ABSTRACT

The wavelet transform for multivariate time-series analysis and prediction is performed using an automatic slow distribution model and the prediction accuracy is compared with the normal method through the use of statistical criteria. By taking the variables represented by the gross domestic product as a response variable and air pollutants as explanatory variables represented by the emissions of nitrous oxide and carbon dioxide in Iraq. The study showed that there is an inverse relationship between the emissions of carbon dioxide and gross domestic product, while a positive relationship between the emissions of nitrous oxide and gross domestic product. And that the variables analysis and prediction after performing the wavelet transform of the data is the best because it contains the lowest values of the mean square error criterion and the mean criterion of absolute error.

Keywords: Wavelet Transform, Prediction, ARDL Model

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1. Introduction

Building a standard model using time series analysis is one of the important topics in economic and statistical theory, because it attempts to link them through the analysis of some economic phenomena using statistical tools and advanced analysis. Recently, researchers' interest has focused on analysing the economic relationships between economic variables also studying the supply response to time series data using modern standard models beside the ordinary least squares method, which can give inaccurate estimates, especially when the data series used for economic variables is unstable as it must taking corrective measures to make these time series stable, such as taking the first difference of data, in most cases these time series become static at the first difference or they stabilize by taking the second difference. One of the appropriate standard models in this field is the auto-slow distribution model (ARDL), which is built on the basis of choosing the best error correction model by choosing the order of deceleration. Thus, it is a developed model for the unrestricted error correction model [1]. The study aims to analysis multivariate time series using ARDL models after performing the wavelet shunt on the time series to reduce the percentage of errors in interpreting the response variable and then predicting.

1.1. Wavelet transforms

In 1822, the scientist Joseph Fourier began producing what is known or called the Fourier Transform analysis, which he called his name, through which periodic signals are represented using a series of sine and cosine, and then began to develop them for any signal that could be obtained, as the series is moved or transformed from time to the frequency domain, which is known as the Fourier transform [2]. The wavelet transform was defined as the analysis of a variable in terms of dividing the frequency window in it with respect to time, as it gives it strength in the analysis compared to the Fourier transform, which uses a fixed-width window and is ineffective for non-fixed signals or the so-called variable frequency, as it provides us with information about Frequency content over time.

It is one of the modern methods which are used in transformation for many applications, including image processing. Great interest has emerged of this method because of its importance, also this technique showed very effective and useful results in many applications, including image compression and attribute extraction, as well as filtering nonlinear noise [3]. The wave was known by many researchers, led by the mathematician Haar, who was the first to introduce the concept of the wave in 1909, which was not known by scientists, as he named the wavelet Haar after his name. After that, studies about wavelets continued, as both scientists Grossman Alex & Jean Motlet presented in 1984 the name of the wavelet as a mathematical function. All research during that period was continuing to find different types of wavelets, as the wavelet Haar was the only wavelet in use during that period. After that, the wavelet was developed mathematically by the researcher Meyar Yaves, who put a wavelet named after him Meyar. There are many wavelets that have been known by researchers over the decades, so of these types [4]:

i) Haar Wavelet
ii) Daubechies Wavelet
iii) Coiflets Wavelet
iv) Symlets Wavelet

The wavelet of Haar is one of the oldest and simplest types of wavelets that were known by researchers, for its simplicity and ease, as it became one of the most important types of wavelets preferred by researchers, which wavelet was known by the scientist Alferd Haar in the period (1909-1910) on the grounds that it is the cornerstone in the generation of other types of wavelets [5].

2. Materials and methods

Multivariable time series represented by the gross domestic product as an internal variable (response variable) and polluting gases represented by nitrous oxide emissions and carbon dioxide emissions in Iraq were taken as external variables (illustrative variables), as the three series extend from 1972 to 2018. The three variables were analyzed and the gross domestic product value was predicted in Iraq after data purification was done using the wavelet transform and the results were compared with the usual method. The program Eviews 10 was used to estimate the ARDL model. The data is defined according to the following figure:
WPROD represents the gross domestic product in Iraq after purifying it using the wavelet transform.
WNTRO represents the emissions of nitrous oxide gas in Iraq after purification work using the wavelet transform. WCO2 represents carbon dioxide emissions in Iraq after purification was done using the wavelet transform.

2.1. ARDL(p,q) model building steps

2.1.1. Unit root testing for time-series static

Most of the macroeconomic variables are not static in the level, which makes the use of the Ordinary Least Squares (OLS) method inappropriate, as it is possible to obtain high values for each of the values of (T,F) and the regression determination coefficient (R^2). So the time series z_t is stationary when its arithmetic mean and variance are constant and its common variance depends on time [6]. The following two tests will be used to determine stability:

Augmented Dickey-Fuller test (ADF)

The DF test can be performed according to the following equation, given the constant (∂_1) and the time direction (t) of the variable (z):

$$\Delta z_t = \partial_1 + \partial_2 t + \omega z_{t-1} + \epsilon_t \qquad (1)$$

It was assumed in this model that there is no autocorrelation between the error limits, but in the case of autocorrelation, in this case the model becomes inappropriate and makes the estimation results inaccurate. In order to overcome this situation, this model has been developed or expanded by adding lagging values to the time series under analysis to be known later as (Augmented Dickey- Fuller Test), and the model takes the following form:

$$\Delta z_t = \partial_1 + \partial_2 t + \omega z_{t-1} + \sum_{i=1}^{h} \delta_i \Delta z_{t-i} + \epsilon_t \qquad (2)$$

The time series static test depends on the significance of the parameter (ω), by comparing the calculated (t) with the tabular (τ) (tau-statistic), if the calculated value is greater than the tabular (in absolute values), this means that the time series is stationary at the level.

Phillips-Perron Test (PP):

The PP test [7] depends in its estimation on Eq.1, but differs from the ADF test in treating serial correlation of the highest degree, as it uses non-parametric statistical methods to take into account the serial correlation Within error limits without adding lagging difference limits.

2.1.2. Co-integration test

The second step is to conduct a co-integration test [8]. If the time series are not static at the level, this means that they may be integrated of the first degree, or higher. In general, if there is co-integration, this means that the two series move together through time, and there can be co-integration between them that results in a long-term equilibrium relationship between the study variables. In order to test the co-integration between the variables, there is a set of tests represented by the Johansen and Juselius test. To perform this test, the variables must be of the same degree and cannot be performed in the case of the presence of integrated variables of different degrees. This test includes two tests, namely (Trace Test) and (Maximum Eigenvalue), If the null hypothesis which states that there is no simultaneous integration is rejected and the alternative hypothesis which states that there is simultaneous integration is accepted if the calculated values of the tests (Trace Test) and (Maximum Eigenvalue) are greater than the tabular values at the significance level of 0.05, this indicates that there is a long-term equilibrium relationship between the time series and thus the error correction model is used to clarify the long-term relationship between the ARDL variables [9]. But in the case of the presence of integrated variables of different degrees, the boundary test will be used to test the co-integration that depends on the calculation of F-statistic. If the calculated F-statistic value is greater than the tabular upper bound value, then the null hypothesis is rejected, which states that there is a co-integration relationship between the variables and vice versa [10].

2.1.3. Estimating an autoregressive model with a distributed slowdown (ARDL)

The ARDL model is known as one of the time series analysis models, which combines the slowdown variables as endogenous variables in the time series with another external variable that is affected by it in the general autoregressive model with a constant and (p) of endogenous variables and (q) of the exogenous variables and symbolizes it ARDL(p,q) which can be defined as:

$$z_t = \partial_0 + \sum_{i=0}^{p} \delta_i z_{t-i} + \sum_{i=0}^{q} \sum_{j=1}^{m} \tau_{ij} x_{j,t-i} + \epsilon_t \qquad (3)$$

As each of τ, δ, ∂ denotes the parameters of the model, z_t represents the response variable which is an endogenous variable at the time period (t), z_{t-i} the slowdown variables for (p) of the endogenous variables, $x_{j,t-i}$ the slowing variables for (q) From the exogenous variables, ϵ_t represents the limit of the random error, $\epsilon_t \approx N(0, \sigma^2)$. The ARDL model is a mixture of two models, the Distributed- Lag and the Autoregressive. The ARDL methodology gives efficient and unbiased estimates [11].

The rank of the slowdown is selected in the ARDL(p,q) model according to the Akaki Information criterion (AIC), where the rank that corresponds to the lowest value of the AIC is selected[13], then, the parameters are estimated using the least squares (OLS) method.

2.1.4. Estimated model validity test

The following tests were used to verify the fit of the model [13]:

i. Serial Correlation LM test which tests the null hypothesis which states that there is no serial autocorrelation problem for the residuals of the ARDL model (p,q) against the alternative hypothesis which states that there is a autocorrelation problem.
ii. Heteroskedasticity ARCH Tests, which tests the null hypothesis that homogenization of errors. in the model against the alternative hypothesis that heterogeneity of errors.

2.1.5. Forecasting

The last stage that comes after conducting all the examinations and tests is forecasting, as doing the forecasting process has a great and very important benefit, especially in the economic fields. The accuracy of forecasting is the main criterion in choosing the most appropriate forecasting method and judging the quality of the method used. Accuracy in forecasting means the extent to which the proposed model is able to reproduce the available data. It must be taken into account that the prediction cannot be highly accurate, but always deviates from the actual values of the phenomenon studied. This deviation is what is called the prediction error. Although this error is predicted, the goal of forecasting is to reduce the error to the lowest value possible. Among the most important of these criteria that were used for the purpose of measuring the effectiveness of forecasting in evaluating the approved forecasting method [14-19]: Mean Square Error Criterion (MSE), which is expressed according to the following mathematical formula:

$$\text{MSE} = \frac{1}{n}\sum_{t=1}^{n}(z_t - \hat{z}_t)^2 \qquad (4)$$

and Mean Absolute Error Criterion (MAE) which is expressed according to the following mathematical formula:

$$\text{MSE} = \frac{1}{n}\sum_{t=1}^{n}|z_t - \hat{z}_t| \qquad (5)$$

3. Results and discussions

The Haar Wavelet was used at level 5 to purify the three-time series and the purification result is shown in Figure 1.

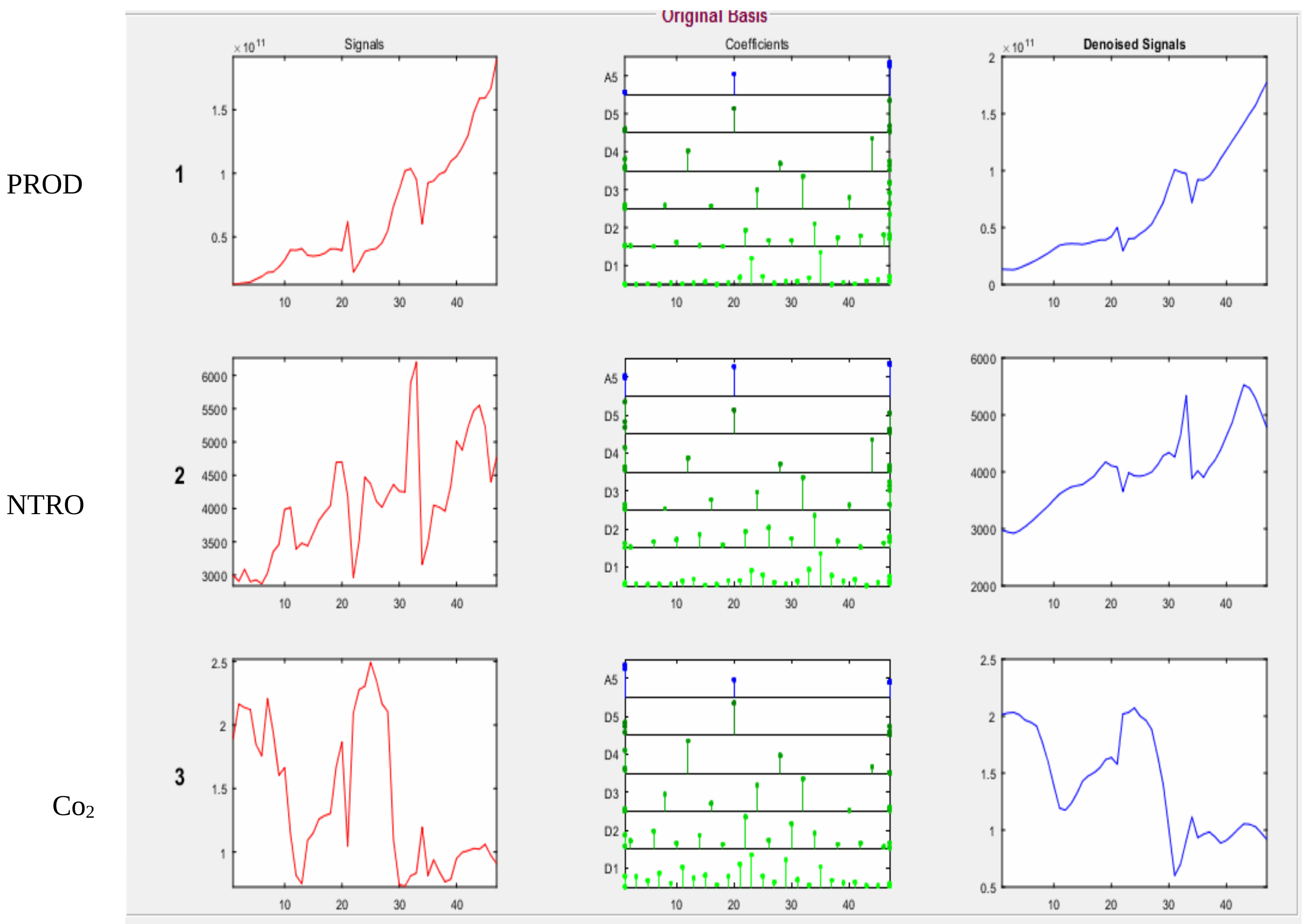

Figure 1. Result of data smoothing using Haar Wavelet in Matlab17

From Figure 1 the time series after their purification were unstable. Their stability was checked by using the unit roots tests (ADF) and (PP) and Table (1) shows the results of the two tests, if we notice that the t-statistic value is greater than the tabular values, and the p-value is greater than the significant level (0.01, 0.05, 0.10) for the three-time series, as we cannot reject the null hypothesis which indicates the existence of a unit root in the three series, meaning that the three time series are unstable. After taking the first difference for the series (WPROD), (WNTRO) and (WCO2) and repeating the two tests, the chains stabilized.

Table 1. Two Unit Root Tests (ADF) and (PP) for Strings (WPROD), (WNTRO) and (WCO2)

Series	**ADF test**				**PP test**			
	Original series		**Series after different**		**Original series**		**Series after different**	
	t-Stat.	**Pr.**	**t-Stat.**	**Pr.**	**Adj. t-Stat**	**Pr.**	**Adj. t-Stat**	**Pr.**
WPROD	2.297067	0.9999	-9.695870	0.0000	4.606962	1.0000	-9.553856	0.0000
WNTRO	-0.922520	0.7720	-7.627648	0.0000	-1.069601	0.7199	-30.72797	0.0001
WCO2	-1.204536	0.6647	-6.800141	0.0000	-1.238957	0.6496	-6.800222	0.0000
C.V								
1% level	-3.584743		-3.588509		-3.581152		-3.584743	
5% level	-2.928142		-2.929734		-2.926622		-2.928142	
10% level	-2.602225		-2.603064		-2.601424		-2.602225	

By depending on the previous two tests (ADF) and (PP) for stability, we found that the degree of stability is similar for the three-time series at the same level. We can conduct the Juselius-Johansen test, and the test was carried out in the absence of the general and constant direction vehicle, the first time and the second time in the absence of the general direction and the presence of the constant. As we note, through Tables 2 and 3, which show the results of the two cases test that the calculated values for the (Trace Test) and (Maximum Eigenvalue) tests in the two cases of the co-integration test are greater than the tabular values at the significance level of 0.05, thus rejecting the null hypothesis that states The absence of simultaneous integration, and this indicates that there is a long-term equilibrium relationship between the three variable.

Table 2. Co-integration test in the absence of general and constant trend

No. of CE(s)	Eigenvalue	Trace statistic	C.V= 0.05	Pr.	Max- Eigen statistic	C.V= 0.05	Pr.
None	0.494950	4789936	24.27596	0.0000	30.05635	17.79730	0.0005
At most 1	0.228529	17.84301	12.32090	0.0054	11.41609	11.22480	0.0463
At most 2	0.135900	6.426923	4.129906	0.0134	6.426923	4.129906	0.0134

Table 3. Co-integration test in the absence of the general trend and the presence of the constant.

No. of CE(s)	Eigenvalue	Trace statistic	C.V= 0.05	Pr.	Max- Eigen statistic	C.V= 0.05	Pr.
None	0.536049	56.71225	35.19275	0.0001	33.79101	22.29962	0.0008
At most 1	0.234700	22.92125	20.26184	0.0210	11.76945	15.89210	0.1997
At most 2	0.2223881	11.15179	9.164546	0.0207	11.15179	9.164546	0.0207

The number of lags was determined by relying on Akaki's information criterion as shown in Figure 2, it was concluded that the slowdown periods for the variables are ARDL(4,1,1), meaning that the dependent variable (WPROD) has four degrees of delay, while the explanatory variables (WNTRO) and (WCO2) have one degree of delay.

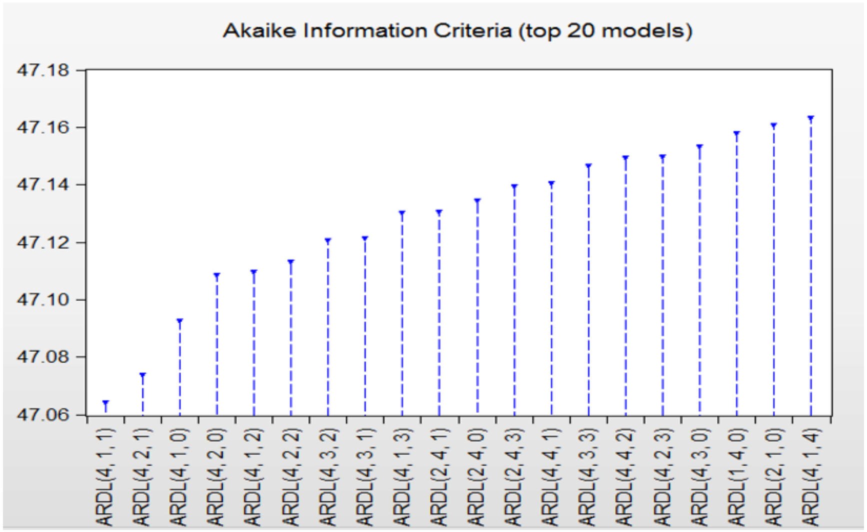

Figure 2. Evaluating Akaki's information criterion to choose the best data model after purifying it

The following table shows the result of the boundary test, as we note through the following table that the calculated Fisher Value F=27.00339 is greater than the upper limits at significant levels (10%, 5%, 1%, 2.5%), this indicates that the variables have a long-term equilibrium relationship.

Table 4. The result of the boundary test.

Test	Val.	Sig.	down	upper
F-stat.	27.00339	10%	3.17	4.14
k	2	5%	3.79	4.85
		2.5%	4.41	5.52
		1%	5.15	6.36

After determining the number of time lags ARDL (4,1,1), the model was estimated as shown in the following table.

Table 5. Estimation of ARDL (4,1,1) model

Vari.	Coef.	Std. Error	t-Stat.	Pr.
DWPROD(-1)	0.290990	0.159693	1.822183	0.0775
DWPROD(-2)	0.142631	0.067185	2.122959	0.0413
DWPROD(-3)	0.056358	0.070462	0.799843	0.4295
DWPROD(-4)	0.195090	0.072267	2.699569	0.0109
DWNTRO	31077294	3705799.	8.386125	0.0000
DWNTRO(-1)	4564333.	2823405.	1.616606	0.1155
DWCO2	-3.70E+10	3.28E+09	-11.28059	0.0000
DWCO2(-1)	2.94E+10	8.09E+09	3.631646	0.0009
C	-4.08E+08	8.32E+08	-0.490280	0.6272
R^2	0.893991	D.W		2.396706

We note from the results of the above table that the corrected determination coefficient R^2 = 0.893991 means that changes in the values of observations for (WPROD) are explained by 89.39% by the independent variables, which is a strong percentage, and an estimated percentage of 10.61% remains explained by other factors, including random error. The Darbin Watson (D.W) value equal to 2.396706 is also an indication of the absence of the autocorrelation problem for first-degree errors as it is greater than the value 2. We also find that in the long run it is possible to determine the extent of the response of the variable that expresses WPROD to fluctuations in the explanatory variables, as it becomes clear through the following table, which shows the results of estimating the long-term equilibrium relationship that the parameter (WCO2) has a negative sign, that is, there is an inverse relationship between (WCO2) and (WPROD). As for the parameter (WNTRO), its sign is positive, meaning that there is a positive relationship between (WNTRO) and (WPROD) in the long run. We also find that all parameters of the long-term equilibrium relationship are statistically significant, meaning that the estimated parameters are significantly different from zero.

Table 6. Estimation of long-term equilibrium movement parameters

Vari.	Coef.	Std. Error	t-Stat.	Pr.
C	-4.08E+8	5.53E+8	0.000000	0.0000
D(DWPROD(-1))	-0.394079	0.071020	-5.548874	0.0000
D(DWPROD(-2))	-0.251449	0.077814	-3.231388	0.0028
D(DWPROD(-3))	-0.195090	0.056092	-3.478048	0.0014
D(DWNTRO)	31077294	2124989.	0.000000	0.0000
D(DWCO2)	-3.70E+10	2.75E+9	0.000000	0.0000
CointEq(-1)*	-0.314931	0.033976	-9.269297	0.0000

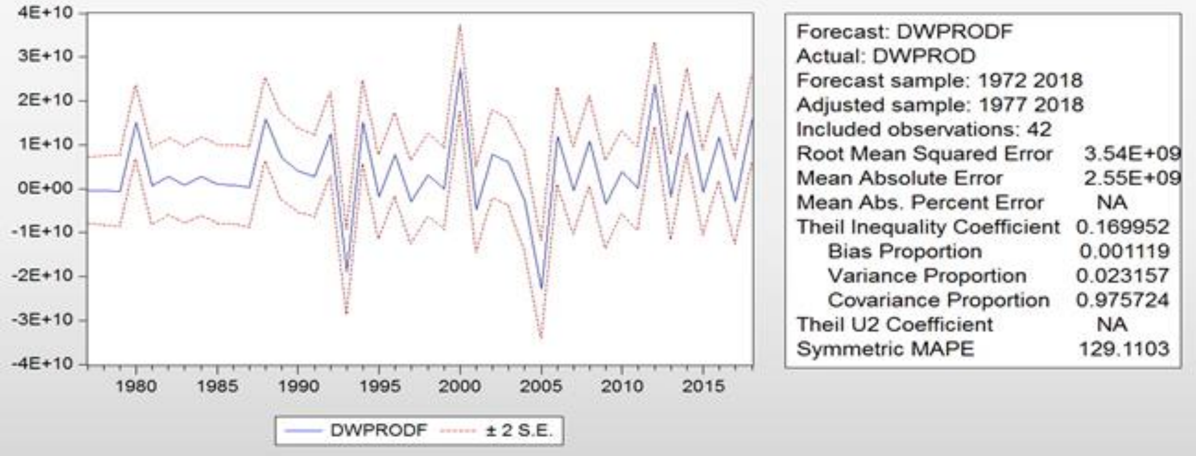

Figure 3. Predictive values of gross domestic product with forecast accuracy criteria

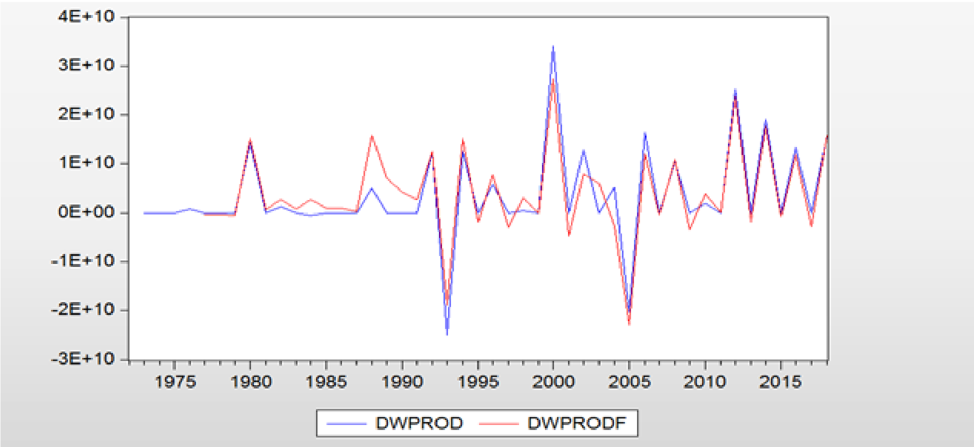

Figure 4. The predictive value with the original values of gross domestic product.

The ARDL model was diagnosed on the original data to compare prediction accuracy. It was found that the data were unstable, and after stability was achieved, the co-integration test was performed using the Juselius-Johansen test. also in the absence of both the general and constant component of the first and second time in the absence of the general trend and the presence of the constant, it was that the calculated values for the two tests (Trace Test) and (Maximum Eigenvalue) in the two cases of the co-integration test It is greater than the tabular values at the significance level of 0.05, which is evidence of the existence of a long-term equilibrium relationship between the three time series. Relying on Akaki's information criterion, it was concluded that the delay gaps for the variables are ARDL(1,1,3) as shown in the following figure.

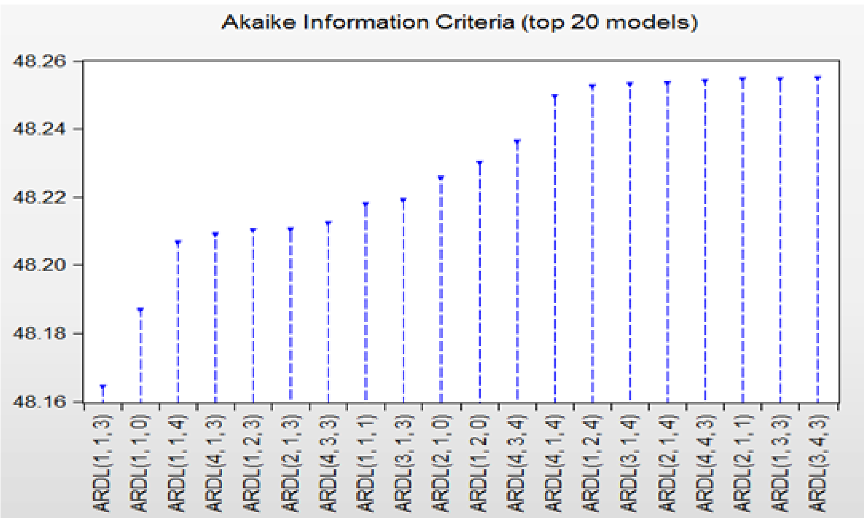

Figure 5. Akaki's information criterion to choose the best data model before purifying it

The boundary test has been estimated as shown in Table (8), as we note that the value of F = 12.70178 is greater than the upper limits at significant levels (10%, 5%, 1%, 2.5%). This indicates that the variables have a long-term equilibrium relationship.

Figure 5. Values for Akaki's information criterion to choose the best data model before purifying it

Test	Val.	Sig.	down	upper
F-stat.	12.70178	10%	3.17	4.14
k	2	5%	3.79	4.85
		2.5%	4.41	5.52
		1%	5.15	6.36

After determining the number of time lags ARDL (1,1,3), the model was estimated as shown in the following table:

Table 9. Estimation of the ARDL (1,1,3) Model

Vari.	Coef.	Std. Error	t-Stat.	Pr.
DPROD(-1)	0.133913	0.163344	0.819820	0.4179
DNTRO	8480258.	1728116.	4.907229	0.0000
DNTRO(-1)	-5537919.	2011919.	-2.752556	0.0093
DCO2	-2.29E+10	3.17E+09	-7.223630	0.0000
DCO2(-1)	4.31E+09	4.98E+09	0.865205	0.3928
DCO2(-2)	-1.76E+08	3.22E+09	-0.054837	0.9566
DCO2(-3)	6.59E+09	3.22E+09	2.045635	0.0484
C	3.00E+09	1.10E+09	2.720173	0.0101
R^2	0.757566	D.W state.		1.801532

We note by estimating the values of the ARDL (1,1,3) model that the value of (R^2=0.757566), that is, the changes in the observation values of the gross domestic product are explained by 75.75% by the independent variables, and an estimated percentage of 24.25% remains explained by other factors, including them random error. The results of estimating the long-term equilibrium relationship showed the same results that were reached in the case of data purification, that is, the parameter (CO2) has a negative sign, that is, there is an inverse relationship between (CO2) and (PROD). For the parameter (NTRO), its sign is positive, that is, there is a positive relationship between (NTRO) and (PROD) in the long run. On the other hand, all parameters of the long-term equilibrium relationship are statistically significant. We also note from the results of the following table that there is no autocorrelation to the residuals, and that the model does not suffer from the problem of heterogeneity of errors.

Table 10. Results of LM Tests and ARCH Tests before the wavelet transformation of the data

LM Test:			
F-stat.	0.191483	Pr. F(2,33)	0.8266
R^2	0.493291	Pr. x^2	0.7814
ARCH Test:			
F-stat.	0.102599	Pr. F(1,40)	0.7504
R^2	0.107453	Pr. x^2	0.7431

After confirming the validity of the ARDL (1,1,3) model, the forecast was made, and the result of the prediction of gross domestic product was as shown in Figure 6. We note through Figure 7, which illustrates the drawing of the gross domestic product series with the corresponding predictive values, as we note the convergence of the values Predictive of actual values.

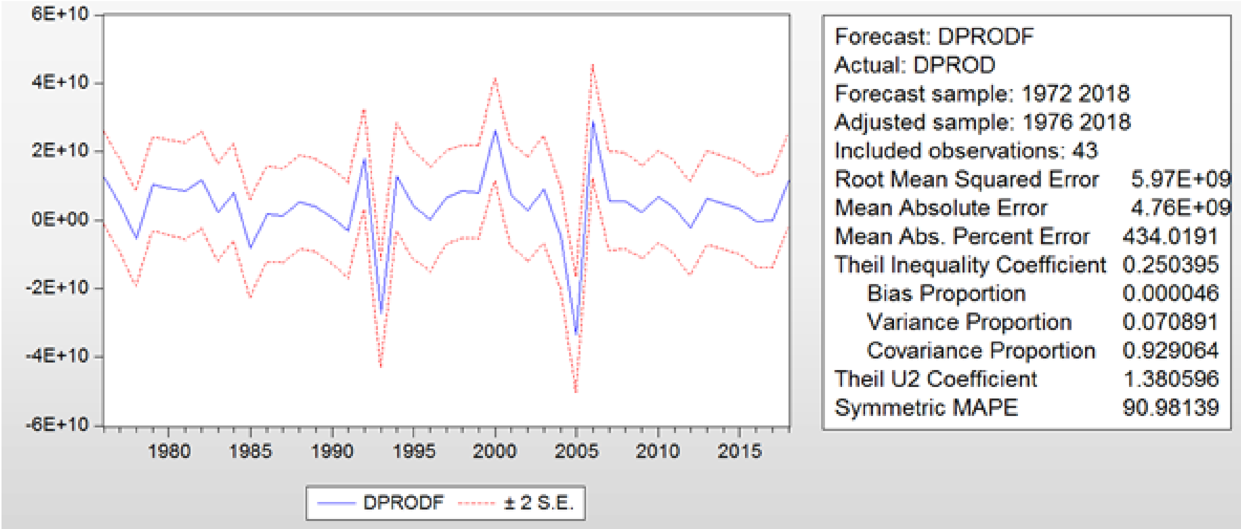

Figure 6. Predictive values of gross domestic product with prediction accuracy criteria before the wavelet shunt

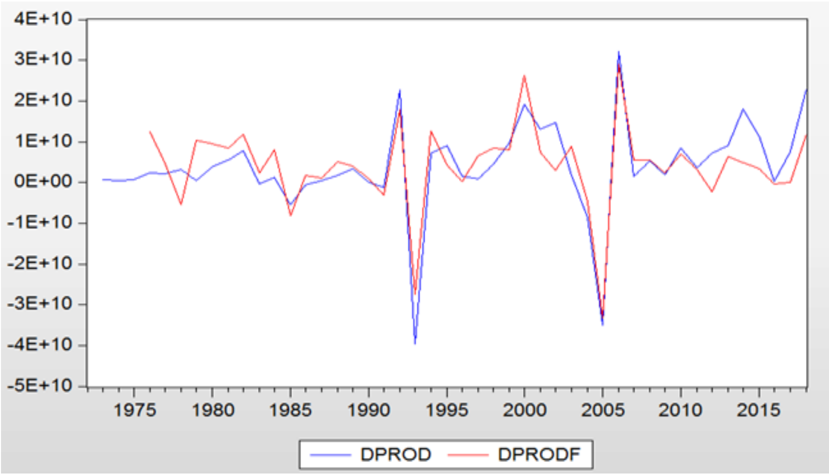

Figure 7. The predictive value with the original values of gross domestic product before the wavelet shunt

4. Conclusions

1. The time series of gross domestic product, carbon dioxide emissions, and nitrous oxide emissions in Iraq are unstable, and they were stable when taking the first difference of the series.
2. By using the juselius - johansen test and the border test, it was concluded that there is a long-term equilibrium relationship between GDP and carbon dioxide emissions and nitrous oxide emissions in Iraq.
3. through The comparison was made between the two models WARDL(4,1,1) and ARDL(1,1,3) through the use of the coefficient of determination criterion, so we find that the wavelet transformation had a significant impact in reducing the interpretation of errors to the gross domestic product, as well as we find that the gross domestic product rate was explained by an estimated 24.25% by errors in the case of ARDL(1,1,3), while in the case of the WARDL(4,1,1) model, the errors were explained in the gross domestic product by a lower rate of 10.61%.
4. A comparison was made between the two models WARDL(4,1,1) and ARDL(1,1,3) in terms of prediction accuracy based on the square root of mean errors and the mean absolute error standard, and the result was that the WARDL(4,1,1) model It has the lowest values for the criteria.
5. The results of estimating the two models WARDL(4,1,1) and ARDL(1,1,3) in the long term showed that there is an inverse relationship between carbon dioxide and gross domestic product. An increase in carbon dioxide leads to a decrease in gross domestic product, if it was the sign of the carbon dioxide parameter is negative. There is a direct relationship between nitrous oxide and gross domestic product. An increase in nitrous oxide leads to an increase in gross domestic product in the long term, as the nitrous oxide parameter sign is positive.

Declaration of competing interest
The authors declare that they have no any known financial or non-financial competing interests in any material discussed in this paper.

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