EFFECT OF ECONOMIC CHANGES ON TIME SERIES MODELLING AND TESTING OF BREAD WHEAT PRICES*

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The paper deals with the analysis of structural changes in the agricultural prices of bread wheat in the Czech Republic in the period 1996–2010 and explores the connection between those changes and changes in the economic and institutional environments. Furthermore, their effect on the results of selected unit root tests is examined herein. The results indicate a statistically significant structural change in July and August of 2008. No other significant change was found in the analyzed period, even in the year 2004 when the Czech Republic became a member of the EU. Despite this fact, there is evidence that prices of bread wheat are affected by the EU open market, because the significant increase in prices in 2008 was caused by international circumstances such as a record-breaking decrease in the stocks of the EU countries and a steeply increasing demand in the global market. The results also indicate that in the case of testing bread wheat prices, for a correct evaluation of integration order it is necessary to use, in addition to the Augmented Dickey-Fuller test, also other tests of stationarity; similarly, analysis of the Chow test results throughout the entire period is necessary.

agricultural prices; structural change; stationarity; AR process; QLR statistics; unit root tests

INTRODUCTION

When analyzing prices of agricultural commodities, it is very important to determine whether a time series is stationary or non-stationary. An appropriate model for analysis is chosen on the basis of that result. A faulty determination of the order of integration of a time series may lead to a wrong model selection, misleading results, and incorrect conclusions. On the basis of final estimates, an economic interpretation, structural analysis, prognosis or other applications are performed, and therefore a correct model creation is just as crucial as the way of its further use. The motivation to this paper was to find out an inconsistency in evaluating the stationarity of the time series according to the Augmented Dickey-Fuller test. The time series of the agricultural prices of bread wheat was determined to be non-stationary, i.e. I(1), in the period 2000–2010. However, the time series was found to be stationary when it was extended for the years 1996–2010. This inconsistency leads to the next step in the sequence and a much deeper analysis of the issue of time series stationarity testing.

The aim of this paper is to determine significant structural changes (shocks) in the agricultural prices of bread wheat in the period from 1996–2010, and to explore the connection between these changes and those in the economic and institutional environment, which took place in the analyzed period. Another aim is to analyze the impact of these changes on the results of selected unit root tests. Considering the changes in the institutional and economic environment in recent decades, such as the entrance of the Czech Republic into the EU, common agricultural politics, open markets, globalization etc., it is relevant to deal with the issue of what impact these changes had.

Note that the mentioned results in this paper are a part of a more comprehensive research to come, in which an investigation of all major agricultural commodity prices is planned. For easier understanding, the paper has a slightly different structure, in which the discussion and results part are interconnected, and follow in the same way as the whole testing and evaluation process.

The publications dealing with structural changes or shocks in time series in general are Zivot, Andrews (1992), Hansen (2001), and Eksi (2009), among others. Zivot, Andrews (1992) pointed out the endogeneity of the shock and argued that a test where the breakpoint is estimated rather than fixed is more appropriate. Hansen (2001) tested a time series of labour productivity in the USA. Based on the results,

* Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. MSM 6046070906 and by IGA (Internal Grant Agency of the Faculty of Economics and Management of CULS Prague), Project No. 20121050.

doi: 10.7160/sab.2013.440309

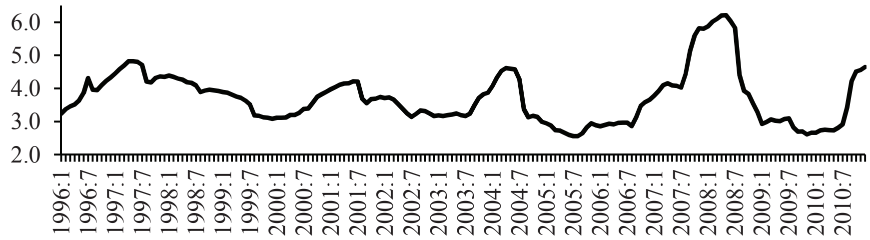

Fig. 1. Agricultural prices of bread wheat in CZK/kg, period 1996–2010
Source: Czech Statistical Office

he determined a structural change in labour and pointed out the danger of ignoring structural changes in time series modelling, i.e., that deductions of economic relationships can be misleading, predictions inaccurate, and political recommendations inappropriate E k s i (2009) provided a literature review of structural break estimation. Furthermore, he suggested starting with the Chow test at the potential date of change and then to continue with more complicated tests of unknown breakdate.

The following are publications which deal with structural changes or shocks and bread wheat price modelling analysis. I r w i n , G o o d (2009) dealt with an analysis of the development of wheat and other commodities prices. The authors mentioned a big increase in the prices of wheat, maize, and soybean in the spring and summer of 2008, followed by a sharp drop. The price of wheat in the given area was the highest in March 2008. The most significant factor which influenced the prices of the mentioned commodities was the demand pressure, which caused serious problems in the USA and on the global credit markets. The authors analyze the history of wheat, corn, and soybean prices in Illinois in the period 1947–January 2009. Then they used the observed shift during the years 1973–1975, which was the last comparable period of structural change, to generate expectations about future price behaviour after January 2009. Finally, based on the analysis results, the authors speculate on the beginning of a new era and volatility in crop prices. B a r a s s i , G h o s h r a y (2007) focused on the long-term relationship between US and EU wheat export prices. They analyzed the period 1981–2000 and found a structural change in 1992 when Common Agricultural Policy reforms were applied. B r ü m m e r et al. (2009) modelled price transmission between the prices of bread wheat and wheat flour in Ukraine in the period June 2000–November 2004. These authors took into consideration the unstable political environment and used the Markov-switching vector error-correction model for estimation of multiple regime shifts. The analysis estimates four regimes, whose timing is identical with political and economic changes in Ukraine. These results highlight the influence of political and economic events on changes in price. A strong consensus between the'highly uncertain' regime and discretionary political interventions shows that the political reaction to fluctuations in harvest can amplify the instability.

MATERIAL AND METHODS

The time series of current agricultural prices for bread wheat in the Czech Republic was used for analysis, because it represents the main part of the value chain. The data set was obtained from the Czech Statistical Office and covers the period January 1996–December 2010 with monthly frequency. The total number of observations is 180. The time series is marked as AP_wheat in the models. The agricultural prices mentioned are shown in Fig. 1.

Fig. 1 shows considerable increases in the agricultural prices of bread wheat for the years 1997, 2001, and 2004, and subsequently the largest increase in the marketing year 2007/2008, when the price reached its maximum value in May 2008 and then began to fall again.

For the purposes of the article, unit root tests of stationarity were used for order integration evaluation of the time series (I(d)). The first one is the Augmented Dickey-Fuller (ADF) test (D i c k e y , F u l l e r , 1979), the most common test in this field. A model with a constant was chosen for testing as follows:

$$\Delta y_t = \rho_0 + \delta_1 y_{t-1} + \sum_{i=1}^{p-1} \gamma_i \Delta y_{t-i} + \varepsilon_{1t} \quad (1)$$

where

Δy_t = the first differences of time series y

y_t = agricultural prices of bread wheat

ε_{1t} = gauss process of white noise

Description of the test can also be found in the publication by A r l t , A r l t o v á (2007). The optimal lag of the endogenous variable in the model is determined on the basis of an automatic selection of Schwartz Info Criterion (SIC), where the maximum number of lags was twelve. Sufficient delay resolves the problems with autocorrelation of a random variable. The second unit root test applied is the Phillips-Perron (PP) test with a constant (P h i l l i p s , P e r r o n , 1988):

$$\Delta y_t = \rho_0 + \delta_1 y_{t-1} + \varepsilon_{2t} \quad (2)$$

where the tested statistics is modified so that it was not influenced by serial correlation, and the test is robust towards common types of heteroscedasticity. This test was based on a Bartlett-Kernel spectral estimate. The third test, Kwiatkowski-Phillips-Schmidt-Shin (KPSS) (Kwiatkowski et al., 1992), has stationarity of the time series under the null hypothesis. This distinguishes the KPSS test from the previous ones. The KPSS test was based on the AR spectral-OLS estimation method (EViews, Version 4.0, 2002). The last test of unit root was the Dickey-Pantula (DP) test, which can be found in the publication by Charemza, Deadman (1997). This test was chosen because it is based on the principle of using methods'from general to specific', in which we move from the general hypothesis to the more specific ones. In this case we consider the highest sensible order of integration and move downwards towards lower orders of integration. The advantage of this test is that if the time series has more than one unit root, the traditional testing procedure, which starts by verifying I(1) and I(0), could produce misleading results. The Dickey-Pantula test offers a simple remedy to this problem. It is unusual for economic series to be integrated at a higher order than two, therefore the highest sensible order of integration is considered to be I(2). The first tested model can be written as:

$$\Delta\Delta y_t = \beta_1 \Delta y_{t-1} + \varepsilon_{3t} \quad (3)$$

$\Delta\Delta y_t$ = the second differences of time series y
where the parameter β_1 is tested to be equal to zero. When the null hypothesis is rejected, it is not possible to evaluate the time series as I(2), and it is necessary to continue with testing the parameter β_2 in the equation:

$$\Delta\Delta y_t = \beta_1 \Delta y_{t-1} + \beta_2 y_{t-1} + \varepsilon_{4t} \quad (4)$$

If the null hypothesis of equality of the parameter to zero is rejected in the previous model (4), the time series is then stationary, i.e. I(0). A model without constant was chosen for testing purposes, because the second differences of bread wheat prices fluctuate around zero. The second tested equation is derived from the selected first equation of the DP test.

In order to examine changes in the evaluation of integration order for various time series lengths, gradual estimations for the time periods of different length with a fixed last observation in December 2010 were performed. Tests were provided for the length of time series from 1996 to 2010: for 1998–2010, then 2000–2010, 2002–2010, 2004–2010, and 2006–2010 (in this case 60 observations are available, the minimum suitable for an estimate). On the basis of the results obtained, it can be assessed to what extent the selection of the period (and/or selection of the starting point of the estimate) influences the interpretation of the integration order of the time series. A traditional recurrent estimation, with the fixed first observation in January 1996, was also used for the ADF test.

For investigating the structural changes, econometric methods and an analysis of the time series were used. An autoregressive process (AR) was chosen for the modelling of time series. The number of lags was determined on the basis of the partial autocorrelation function (PACF) and, in addition, the lag was verified using statistical parameter testing (*t*-test). Assumptions of the linear regression model (LRM) were verified by traditional tests (Green, 2007, Hill et al., 2008), namely the Breusch-Godfrey test, White test, Jarque-Bera test, and RESET test. The Chow test (Chow, 1960), which is a statistical and econometric test of whether the parameters on different data sets or different time periods are equal, was applied for the testing of parameter stability. This test is an application of the *F*-test and requires the sum of squared errors from three regressions (from the full sample period as well as the sub-sample period). The Chow test was generated for all sub-samples, i.e. for every month the *F*-statistics was computed (with respect to sufficient observations, estimates were computed from January 1997 to December 2009) and the maximal value of Chow test *F*-statistics was found. This maximal value is also called Quandt (QLR) statistics. This statistics is documented in Bai (1997), Hansen (2001), and Stock, Watson (2003).

For the analyses and estimates the following software packages were used: EViews (Version 4.0, 2002), Gretl (Version 1.9.5cvs, 2011), and RATS (Version 7.0, 2007).

RESULTS AND DISCUSSION

Testing of time series stationarity

The first test of stationarity of the time series was the ADF test, which was used for time periods of different length. The last observation was always December 2010, and the term of the first observation changed. The results are shown in Table 1. The table contains computed test statistics, P-value, and information on the number of observations which were used for estimations and the number of lags of endogenous variables.

A difference in evaluation based on P-value is obvious in Table 1. If the period from 1996 or 1998 to 2010 is used for the estimates, the time series will be evaluated as stationary at a 5 or 10% level of significance according to the test (P-value < α). If we consider the year 2000 as the beginning of the time series, the series is non-stationary at a 5% level of significance, but is stationary at a 10% level of significance. The time series is non-stationary at both levels of significance if starting from 2002. The closer to the present day an observation is, the more the absolute value of the test statistics falls, and it becomes harder to reject the

Table 1. ADF test of stationarity, variable AP_wheat, various lengths of time series; last observation fixed in December, 2010

ADF test	Length of time series					
First observation Last observation	1996:01 2010:12	1998:01 2010:12	2000:01 2010:12	2002:01 2010:12	2004:01 2010:12	2006:01 2010:12
t-statistics	–3.0428	–3.0121	–2.7763	–2.4845	–2.2151	–1.8912
P-value	0.0329	0.0360	0.0645	0.1221	0.2026	0.3341
No. ob./lag	178/1	154/1	130/1	106/1	82/1	58/1
Results						
α = 0.05	ST	ST	NST	NST	NST	NST
α = 0.10	ST	ST	ST	NST	NST	NST

No. ob. = number of observations used for estimate, lag = number of delayed endogenous variables to eliminate an autocorrelation, α = level of significance, ST = stationary, NST = nonstationary. EViews, Version 4.0, 2002

Table 2. ADF test of stationarity, variable AP_wheat, various lengths of time series; first observation fixed in January, 1996

ADF test	Length of time series					
First observation Last observation	1996:01 2000:12	1996:01 2002:12	1996:01 2004:12	1996:01 2006:12	1996:01 2008:12	1996:01 2010:12
t-statistics	–1.5181	–1.5751	–2.4215	–2.4683	–2.7886	–3.0428
P-value	0.5175	0.4907	0.1383	0.1256	0.0622	0.0329
No. ob./lag	58/1	82/1	106/1	130/1	154/1	178/1
Results						
α = 0.05	NST	NST	NST	NST	NST	ST
α = 0.10	NST	NST	NST	NST	ST	ST

No. ob. = number of observations used for estimate, lag = number of delayed endogenous variables to eliminate an autocorrelation, α = level of significance; ST = stationary, NST = nonstationary. EViews, Version 4.0, 2002

Table 3. Phillips-Perron test, variable AP_wheat, various lengths of time series; last observation fixed in December, 2010

PP test	Length of time series					
First observation Last observation	1996:01 2010:12	1998:01 2010:12	2000:01 2010:12	2002:01 2010:12	2004:01 2010:12	2006:01 2010:12
t-statistics	–2.7647	–2.6458	–2.3472	–2.0770	–2.2223	–1.9570
P-value	0.0655	0.0861	0.1590	0.2544	0.2002	0.3047
No. ob.	179	155	131	107	83	59
Results						
α = 0.05	NST	NST	NST	NST	NST	NST
α = 0.10	ST	ST	NST	NST	NST	NST

No. ob. = number of observations used for estimate, lag = number of delayed endogenous variables to eliminate an autocorrelation, α = level of significance, ST = stationary, NST = nonstationary. EViews, Version 4.0, 2002

non-stationary hypothesis. Note that the time series, which are non-stationary according to the ADF test, are integrated by order one, i.e. I(1). It is generally agreed that the longer time series we take, the more likely it is to be stationary. Some authors have the opinion that all time series taken as a whole are stationary, but only appear to be non-stationary because we only analyze part of their development. According to the ADF test, the time series in the period 1996–2010 is stationary. But the question remains whether it is really correct to work with this time series as stationary.

Besides the approach used, the ADF test can also be performed with traditional recursive estimation, in which we gradually extend the time series from the first observation to the present. Using results from this method it is possible to approximately determine the period which causes a change in the time series order of integration. Results of the testing are shown in Table 2.

From Table 2 it is obvious that the last periods are the source of a change in the evaluation. The time series is non-stationary in the year 2006, but if we

Table 4. Kwiatkowski-Phillips-Schmidt-Shin test, variable AP_wheat, various lengths of time series, last observation fixed in December, 2010

KPSS test	Length of time series					
First observation Last observation	1996:01 2010:12	1998:01 2010:12	2000:01 2010:12	2002:01 2010:12	2004:01 2010:12	2006:01 2010:12
LM-statistics	3.427	1.8951	2.3559	3.0533	3.1689	3.9418
No. ob.	180	156	132	108	84	60
Critical values						
α = 0.05	0.463	0.463	0.463	0.463	0.463	0.463
α = 0.01	0.739	0.739	0.739	0.739	0.739	0.739
Results						
α = 0.05	NST	NST	NST	NST	NST	NST
α = 0.01	NST	NST	NST	NST	NST	NST

No. ob. = number of observations used for estimate, α = level of significance, ST = stationary, NST = nonstationary. EViews, Version 4.0, 2002

Table 5. Dickey-Pantula test, variable AP_wheat, various lengths of time series; last observation fixed in December, 2010

DP test		Length of time series					
		1996:01 2010:12	1998:01 2010:12	2000:01 2010:12	2002:01 2010:12	2004:01 2010:12	2006:01 2010:12
1st regression, testing I(2)	t-statistics	–7.541	–6.667	–6.075	–5.366	–4.782	–3.963
	crit. values (α = 0.05)	–1.98	–1.98	–1.98	–1.98	–1.98	–1.99
	autocorrelation	ok	ok	ok	ok	ok	ok
	heteroscedasticity	ok	ok	ok	ok	ok	ok
	No. ob.	178	155	131	107	83	59
	results[1]	reject H_0	reject H_0	reject H_0	reject H_0	reject H_0	reject H_0
2nd regression, testing I(1)	t-statistics	–0.3819	–0.4798*	–0.3147*	–0.3211*	–0.421*	–0.08779*
	crit. values (α = 0.05)	–1.98	–1.98	–1.98	–1.98	–1.98	–1.99
	autocorrelation	ok	ok	ok	ok	ok	ok
	heteroscedasticity	ok	nok	nok	nok	nok	nok
	No. ob.	178	155	131	107	83	59
	results[1]	no reject H_0	no reject H_0	no reject H_0	no reject H_0	no reject H_0	no reject H_0
Conclusion		I(1)	I(1)	I(1)	I(1)	I(1)	I(1)

No. ob. = number of observations used for estimate, α = level of significance, ok = result of the test is ok, no autocorrelation or homoscedasti city, nok = result of the test is not ok, autocorrelation or heteroscedasticity

[1]test results obtained according to comparison the t-statistics with critical value; *critical values obtained using robust estimates based on HACC errors; Gretl, Version 1.9.5cvs, 2011

take the period 1996–2008 or later, the evaluation of order of integration will change.

For verification of the results, it is appropriate to apply more unit root tests. Estimation for different lengths of time series with the last observation fixed in December, 2010 (2010:12) was used again. The question is whether the time series will again be evaluated as stationary in a longer period. There are PP test results in Table 3, and Table 4 contains results of the KPSS test.

The PP test indicates the non-stationarity of the time series at a 5% level of significance for all periods tested, i.e. even in the period from 1996. When the less strict level of significance α = 0.1 is chosen, the evaluation is the same as in the case of the ADF test used. The KPSS test is based on a hypothesis formed conversely compared to the ADF and PP tests. The time series is stationary under the null hypothesis. LM-statistics are higher than the critical values in all periods, and thus the KPSS test indicates non-stationarity for all lengths of the periods.

As a final test for stationarity verification, the Dickey-Pantula test was chosen. Table 5 contains the results of the test for a model without constants.

Statistical testing of parameters is used for the evaluation of integration order in the DP test. Therefore every model was tested for autocorrelation and heteroscedasticity so as not to produce misleading t-values. Autocorrelation was tested for the 1st, 6th, and 12th orders and did not appear in any model.

Table 6. Results of the model for agricultural prices of wheat, dependent variable AP_wheat

Estimates of parameters, OLS, HCC errors				
Variable	coefficient	standard error	*t*-statistics	significance
1st constant	0.192384	0.094314	2.0398	0.04136633
2nd AP_WHEAT{1}	1.489875	0.095754	15.5594	0.00000000
3rd AP_WHEAT{2}	–0.54080	0.107249	–5.0425	0.00000046

Basic characteristics of the model[1]	
Usable observations	178
Degrees of freedom	175
Centered R**2	0.952245
R bar **	0.951699
Mean of dependent variable	3.722916
Standard error of dependent variable	0.807404
Standard error of estimate	0.177447
Sum of squared residuals	5.510275
Log likelihood	56.71898
Durbin-Watson statistics	1.972443

[1]monthly data from 1996:03 to 2010:12

RATS, Version 7.0, 2007

LRM assumption verification		
Autocorrelation		
Test	test. stat.	*P*-value
Breusch-Godfrey SC Test, 1st order	0.09749	0.75486
Breusch-Godfrey SC Test, 4th order	7.87279	0.09635
Heteroscedasticity		
Test	test. stat.	*P*-value
White test	24.80951	0.00015
ARCH(1) test	1.33723	0.24752
Function form		
Test	test. stat.	*P*-value
Reset test, quadratic form	0.26870	0.60486
Reset test, quadratic and cubic form	0.84313	0.43212
Normal distribution of random variable		
Test	test. stat.	*P*-value
Jarque-Bera test	1621.25	0.00000

Table 7. Results of the model for the first differences in the agricultural prices of wheat, dependent variable DAP_wheat

Estimates of parameters, OLS				
Variable	coefficient	standard error	*t*-statistics	significance
1st DAP_WHEAT{1}	0.514309	0.0941451	5.4629	0.00000005

Basic characteristics of the model[1]	
Usable observations	178
Degrees of freedom	177
Centered R**2	0.263986
R bar **2	0.263986
Mean of dependent variable	0.007163
Standard error of dependent variable	0.211070
Standard error of estimate	0.181079
Sum of squared residuals	5.803814
Log likelihood	52.09982
Durbin-Watson statistics	1.922790

[1]monthly data from 1996:03 to 2010:12

RATS, Version 7.0, 2007

LRM assumption verification		
Autocorrelation		
Test	test. stat.	*P*-value
Breusch-Godfrey SC test, 1st order	0.98952	0.31986
Breusch-Godfrey SC test, 4th order	3.52515	0.47407
Heteroscedasticity		
Test	test. stat.	*P*-value
White test	2.44939	0.11757
ARCH(1) test	0.63845	0.42427
Function form		
Test	test. stat.	*P*-value
Reset test, quadratic form	4.91002	0.02798
Reset test, quadratic and cubic form	2.85249	0.06039
Normal distribution of random variable		
Test	test. stat.	*P*-value
Jarque-Bera test	2616.41	0.00000

Heteroscedasticity however did appear in some cases. In the case of the presence of heteroscedasticity, robust estimations based on HACC errors were used. In Table 5, the unbiased values of t-statistics of robust estimation are already mentioned (marked with an asterisk). The Dickey-Pantula test without constant indicates the level of integration I(1) for each period, and the time series is non-stationary for original data by all lengths.

If we resume the results, the KPSS test, PP test, and DP test without constant show evidence of complete non-stationarity of the time series in all period lengths at a 5% level of significance. The PP test at a 10% level of significance and the ADF test show evidence of the stationarity of the time series from 1996 or 1998. A majority of tests indicates non-stationarity, therefore we could conclude that time series is non-stationary and the ADF test was misleading in its evaluation. But it would not be appropriate to come to any strict conclusion, based only on those results. We cannot completely reject utilization of the ADF test. One possible way to decide whether the time series is stationary or not, and whether the ADF test is misleading or not in this case, is to apply the test of stability. In the problematic period, i.e., the time series from 1996 to 2010, we do not know whether we should work with this time series as stationary or non-stationary, i.e. I(1). Unit root tests evaluate the level of integration differently. We will consider both variants (the first – time series is stationary, the second – time series is non-stationary) and model them using a basic AR process. We will subsequently test whether there are problems with parameter stability in the models. If the time series of wheat prices is stationary and we treat it as such, no parameter stability problem should appear. In this case the ADF test detects the stationarity correctly. If a problem with parameter stability does appear, it indicates that there has been a structural change in the time series, and the use of other models is necessary to resolve the problem. In this particular case the treating with the time series as a stationary according to the ADF test would be misleading.

Modelling of bread wheat prices according to the AR model

Firstly, we will consider the agricultural prices of bread wheat as a stationary time series. The best model for this case is AR(2) with a constant term. A delay equal to two is indicated by PACF. Note that in the model with three lags, the last lag is insignificant (P-value = 0.758). The results of LRM assumption testing are as follows: an autocorrelation of the 1st and 4th order is not present in the model. Heteroscedasticity is present in the model, according to the White test, so the robust estimate is used to check the significance of the lags. The linear form of the model was selected correctly according to the RESET test. The Jarque-Bera test indicates non-normal distribution of random variable, but economic time series often have problems with the assumption of normal distribution. In the final robust model AR(2) with a constant, all coefficients are statistically significant, the degree of explanation is 95% according to R-square, and the model is statistically significant as a complex according to the F-test. The model assumption concerning normality of residuals is not fulfilled, but this fact does not affect the sum of squared residuals of the model, which is needed for stability testing. Moreover, nonnormality does not affect the properties of estimated parameters and covariance matrices, and thus this assumption is not crucial for the model and its future utilization. The heteroscedasticity could be caused by the presence of a shock in the time series. Therefore the model is still unbiased, but no longer the best with regard to the Gauss-Markov theorem. Unfortunately, the shock in this step is unknown and needs to be estimated first. After detection of the shock we will examine whether the shock was the reason for the heteroscedasticity problem. Another reason for the heteroscedasticity and nonnormality in the model could be the selection of an incorrect function form, but according to the RESET test, the function form is correct. Therefore a linear model will be used for stability testing. The results of the robust model, basic characteristics of the model, and the LRM assumption verification are shown in Table 6.

When we consider the time series to be stationary, the final model of agricultural bread wheat prices can be written as follows:

$$AP\_wheat = 0.19238 + 1.48988 AP\_wheat_{t-1} - 0.5408 AP\_wheat_{t-2} + e_{1t} \quad (5)$$

Modelling of the first differences in bread wheat prices according to the AR model

Secondly, we will consider the agricultural prices of bread wheat to be a non-stationary time series, namely I(1). The best model for this case is AR(1) without a constant. A delay equal to one is indicated by PACF. If we estimate the model with another delay, the second delay is statistically insignificant (P-value = 0.321). The constant term is also statistically insignificant (P-value = 0.798). According to the tests performed, there is no heteroscedasticity or autocorrelation of the 1st or 4th order in the model. Nevertheless, the suitability of linear form was rejected in the case of the RESET test for quadratic form. A second-degree polynomial was created; an additional explanatory variable was statistically significant, but the model's quality improved by only about 2%. Since the model was not created for structural analysis or prognosis but rather for the study of structural changes and shocks in the time series, the model AR(1) without a constant was chosen for the next analysis. This model is sufficient for the purposes of the paper. The null hypothesis about the normal distribution was rejected according to the Jarque-Bera test. The results of the model estimates, basic characteristics of the model, and the LRM assumption verification can be seen in Table 7. Testing of parameter stability is presented further in the text.

The final model of the first differences in agricultural bread wheat prices, namely when we consider the time series to be non-stationary, can be written as follows:

$$dAP\_wheat = 0.51430871\, dAP\_wheat_{t-1} + e_{2t} \quad (6)$$

The models created will not be interpreted in detail, because they are instruments not for structural analysis, but rather for an investigation into whether the choice of stationarity or non-stationarity of time series affects parameter stability. Use of these models for complex parameter stability testing is given below.

Table 8. *F*-statistics of the Chow test for the model AP_wheat from February 2008 to September 2008

Split point[1]	2008:2	2008:3	2008:4	2008:5	2008:6	2008:7	2008:8	2008:9
F-statistics	0.02192	1.05131	1.59563	2.77752	3.87091	4.48936	6.43984	0.74538
P-value	0.99559	0.37136	0.19225	0.04281	0.01035	0.00463	0.00037	0.52642

[1]the first observation of the second sub-sample for F-test; year: month

RATS, Version 7.0, 2007

Model parameter stability testing

First we take into consideration the model for stationary time series, i.e. model (5). If we split the time series in half and calculate the F-statistics of the Chow test, we will conclude that the parameters are stable. The F-statistics is equal to 1.171 and the P-value is equal to 0.32255. But if we focus on the greatest change in this time series, when agricultural prices reached their maximum in May of 2008, and we calculate F-statistics for the period around this date, we will obtain different results in the end. Test statistics are shown in Table 8.

From Table 8 we can see that the Chow F-statistics exceeds the critical value at a 5% level of significance (i.e. 2.65714) in the period from May to August of 2008. According to the traditional Chow test the model (5) has unstable parameters in this period. More precisely, the QLR statistics should be found and compared with corresponding critical values. The maximal value of the Chow statistics, i.e. a QLR statistis, was detected in August 2008 (6.43984). . The QLR statistics should not be compared with the critical values of the traditional F-test when we treat the structural shock/break as unknown. In this case F-critical values are inappropriate (see Hansen, 2001; Stock, Watson, 2003). The critical value given by Stock, Watson (2003) is 4.09 for a 10% level of significance and 4.71 for a 5% level of significance. The QLR statistics exceeded critical values and then the structural change was identified as statistically significant in August 2008 at both levels of significance. The value in July 2008 is also higher than the critical value at a 10% level of significance. These values indicate an important structural change (shock), which affects the quality of the result estimation. It is also possible to conclude that if we treat the time series in the period 1996–2010 as a stationary time series, we will gain a model which does not meet the assumption of stability. According to the results obtained, it is also obvious that simply

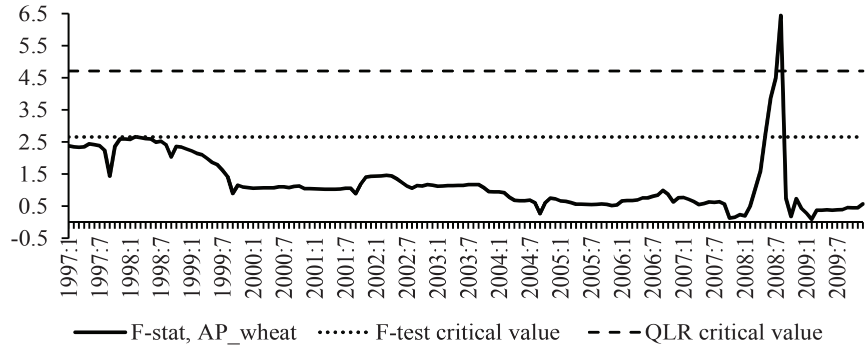

Fig. 2. F-statistics of the Chow test for the model AP_wheat from January, 1997 to December, 2009
Note: critical values are for 5 % level of signifikance
Source: author, RATS

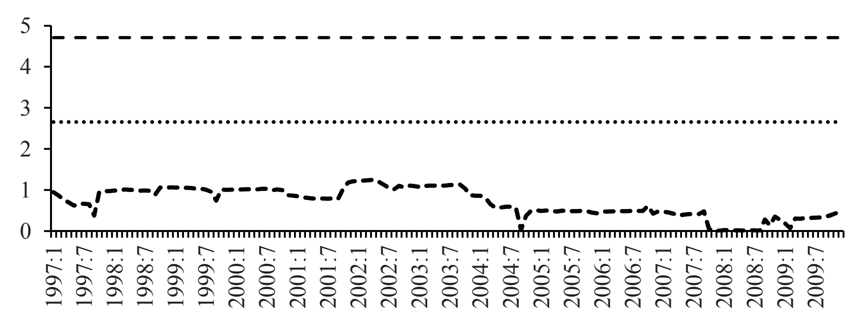

Fig. 3. F-statistics of the Chow test for the model dAP_wheat from January,1997 to December, 2009
Note: critical values are for 5 % level of significance
Source: author, RATS

splitting the data in the middle of the set period is insufficient for testing of parameter stability, because it is too sensitive to the fact, whether the change is near the middle or not. This situation is also mentioned in the H a n s e n (2001) publication. In order to find out if there is some other shock or structural change in the time series, the F-statistics was calculated for all observations of the time series, except the months of 1996 and 2010. Cutting at the beginning and the end of the time series is important in order to have enough observations for testing. Results are shown in Fig. 2.

If we look at the development of the Chow test F-statistics, we will notice that they exceed the critical value of F-test in the periods from May to August 2008. Counted F-statistics also exceed the critical value of QLR statistics in July and August of 2008. The maximal value was reached in August 2008. The computed values of the test have already been shown in Table 8. Although the original time series had price fluctuations, with local maxima appearing around April of 1997, July of 2001, and April of 2004 (see Fig. 1), none of these price increases were shown as a structural change in the calculated statistics. The next increase in prices happened in the mentioned year of 2008 and a significant shock was determined there, according to the calculated statistics.

Because more than one shock could appear in the time series, the time series was split in the period where the first shock was detected, and the model was estimated and tested in sub-periods. In the first period, from January 1996 to June 2008, no statistically significant structural change, at a 5% level of significance, was detected. It can be noted that the greatest value of the Chow F-statistics in the year 2004 came in November and made 2.90425, which did not exceed the critical values of the QLR statistics. No significant change in the period of Czech Republic's accession to the EU (2004) was found. Therefore only one structural shock was detected in the period 1996–2010, in the second third of the year 2008.

Because we know about this shock at the present, it is possible to verify whether the problem of heteroscedasticity was caused by this shock. The model considering the shock in the year 2008 was estimated and heteroscedasticity was not detected at a 5% level of significance. This result suggests that heteroscedasticity in the model (5) was caused by a change in the time series.

When model (6), in which we consider the time series of bread wheat prices to be non-stationary is applied and Chow statistics for all periods is generated, the parameter stability problem does not occur in any period. Results are shown in Fig. 3. Model (6) is therefore more convenient from the viewpoint of meeting the model requirements.

The stated results of stability testing imply that if we work with bread wheat prices in the period 1996–2010 as a stationary time series, stability problems arise. If we work with the time series as non-stationary, stability of the parameters is not violated. In this case the ADF test incorrectly detected the stationarity of the time series.

It is appropriate to mention which changes happened in the period, when a significant shock was determined, and the reason of these changes. According to annual grain sector reports (M i n i s t r y o f A g r i c u l t u r e o f t h e C z e c h R e p u b l i c , 2008, 2009), there were large increases in the price of wheat in the marketing year 2007/2008. Although there was a 2% increase in the global production of wheat if compared to 2006/2007 (increase in production in the USA, Russia, China, and other countries), in most EU countries and Canada the harvest of wheat declined. The harvest was adversely affected by unfavourable weather conditions. As a result of the state of the international market, there was a record decrease in stocks and a steep increase in prices when the increasing demand in the global market exceeded supply. On the other hand, the production of grain in the year 2008 was a record harvest. As a result, there was a sharp decrease in prices due to the large and high-quality production of grain in the Czech Republic in the marketing year 2008/2009.

Now we can evaluate the results of the analysis with respect to the stated goals. The aim of the paper was to determine significant structural changes (shocks) in agricultural prices of bread wheat in the period 1996–2010, and their connection with economic and institutional changes which happened in the analyzed period. The results achieved in the paper indicate a significant structural change from July to August of 2008. Instability of estimated parameters occurred also in the May and June of 2008. In the period 1996–2010 there were several swings in the time series of prices, but only the increase in 2008 was shown to be a significant structural shock during the time series stability testing, while the previous changes and swings in price were not evaluated in the same way. In spite of the fact that the Czech Republic entered the EU in 2004, the shock in this year is not statistically significant. The main reason for this could be that the market of the Czech Republic has been opened since the second half of the 1990s. The start of the CAP implementation also falls in with the period preceding the year 2004. Therefore no significant structural change occurred.

Since a significant structural change took place in 2008 during the Czech Republic's membership in the EU, and the price increase was caused by international circumstances (such as production in EU countries, increasing demand in the global market, etc.) at that time, it is possible to assume that prices and the agricultural market are affected by an open market, but the first significant change was to appear in 2008. It must be noted that in order to verify this theory, it would be necessary to estimate the relationship between Czech prices and prices of different countries in the EU, or investigate the structural changes in the prices of other countries and compare the results with the results obtained in this paper. Other agricultural commodities should be tested as well to see whether a similar phenomenon also happened with them. This could be an idea for future research.

The further objective of the paper was to analyze the impact of these changes on the results of selected unit roots tests. According to the results obtained, it is evident that structural changes influenced several results of the unit tests. The time series of bread wheat from 1996 to 2010 is evaluated as stationary if only a traditional ADF test is used. Subsequent stability tests confirmed that the stationary model was incorrect, and a better model was obtained when the time series was treated as a non-stationary. The execution of additional stationarity tests pointed to differences in the evaluation of the integration order. The analysis indicates that for time series testing of bread wheat prices, it is necessary to use more unit root tests to achieve real familiarization with the time series and appropriate handling. Analogously, it is evident that for stability testing, more F-statistics of the Chow test must be evaluated in order to find a shock or change.

CONCLUSION

One of the paper's objectives was to determine significant structural changes in the agricultural prices of bread wheat between the years 1996 and 2010, and to explore whether these changes are related to changes in the economic and institutional environment. The detailed Chow test sequence confirmed significant structural changes from July to August of 2008. This situation in the marketing year 2007/2008 was caused not only by climatic changes, but also by the open market, increasing demand, insufficient supply or, on the contrary, surplus harvest in other countries. Despite the preceding price changes, the structural change had not been identified until the year 2008. On the basis of the results, there is evidence that changes in the economic and institutional environment influence the modelling and testing of bread wheat agricultural price time series. This change affects time series stationary testing as well. Although the ADF test evaluated this time series as stationary, it is not appropriate to handle it this way because the parameters are not stable. Note that dummy variables do not reduce this instability. When we treated the bread wheat prices like a non-stationary time series, the stability problem did not appear. This implies that it is better to deal with the time series as being non-stationary. Other tests, meaning the PP test at a 5% level of significance, KPSS test, and Dickley-Pantula test, correctly refer to the non-stationarity of the time series. Therefore, in connection with the further aim of the paper, i.e. to analyze the impact of changes in bread wheat price on the results of selected unit root tests, the analysis results indicate that it is appropriate to use more tests for stationarity verification in the case of bread wheat agricultural prices. Analogously, it is necessary to investigate changes not only randomly but also across the whole time series, in order to avoid missing a structural break. The current results are only part of an ongoing investigation. To verify whether it is necessary to employ several tests every time to find out whether the time series is stationary or not, it is necessary to apply the previous approach in more time series of prices. After that, it could be possible to generalize the results for the time series of agricultural prices. Also the next plan should be to analyze the structural changes and perform integration order evaluation in more time series of agricultural commodities, and discover whether economic and institutional changes influence these commodity prices. Another idea for research in connection with the structural changes is to apply a Threshold model, which should represent particular regimes in times series. Regimes in short-run and long-run dynamics, two or more, should be alternated within this research.

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Received for publication on March 5, 2012
Accepted for publication on June 4, 2013

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