

# Examination of the International Causal Directions between Rates of Return on the Price Indices of the Selected Real Estate Markets in the CEE Region Using Wavelet Analysis

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The objective of this study is to verify the existence of the spillover effects within the complex system of internationally co-integrated real estate and financial markets in the case of the growth rates of the price indices of the direct real estate and indirect real estate investment markets within the selected national economies in the CEE region and to discuss the time stability of their directions, using research methods with physics and econometrics origins. The article considers the case of potential spillover effects between the Polish and Austrian national economies. Presented results have been obtained using wavelet analysis methods, such as wavelet coherency, wavelet phase difference, and wavelet partial phase difference analyses, enabling to check the indicated stability both in the time and frequency domains and to detect any potential structural changes dates. The results have not confirmed the hypotheses that the directions of the mentioned spillover effects displayed time stability in the examined period (Q4 2004–Q4 2014), which disproves the usefulness of the knowledge of the current directions of the indicated effects in the scope of performing long term investment policy, as well as in the scope of projecting the long term internal housing policies and long term internal macroprudential policies within the complex system.

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## 1. Introduction

The systemic theory on the complex nature of growth and pricing phenomena present on real estate and financial markets operating within separate national economies, in terms of currently proceeding international co-integrating processes, should take into account not only internal but also external economic interdependences. Consequently, the theory should incorporate results of any international spillover effects between their separate subsystems, such as any transmission mechanisms present within the real estate financing systems that are determined by factors enlightened, inter alia, within the broad discounted cash flow theory framework.

Miller et al. published results of the research on the time stability of the causality direction between the housing and stock markets in the USA in the period 1890–2012 [1]. The results of the indicated research have confirmed the lack of the considered causality direction stability in the time and frequency domains, which was potentially caused by some structural changes on the above mentioned markets. Indicated research was performed using, derived from physics methodology [2], wavelet analysis methods, such as wavelet coherency and wavelet phase-difference. Contemporarily, such methods are also used by economists in order to simultaneously examine changes in terms of co-movement strength, causality sign and causality direction between some economic phenomena in the time and frequency domains [3–8], which is

strictly useful in terms of strong diversification of different groups of stakeholders' interest horizons.

Such economic relations were previously examined mainly using the traditional methodology of econometrics, especially including Granger causality direction tests and tests on existence of long term linear or nonlinear co-integration [1, 9–32], despite the fact that these methods do not provide an appropriate setup to check time stability of considered systemic relationship characteristics, as well as require examining only one cross-correlation lag horizon at once. Consequently, such methods are strictly dominated by wavelet analysis methods.

Such a research has not yet been conducted using the analogical methodology in case of international spillover effects between real estate markets and in case of spillover effects between direct and securitized property markets.

In terms of strengthening internationalization processes among the emerging national economies in the CEE region, located there direct real estate investments underlie increased FDI processes, which would cause further intensification of the integration processes in the scope of their international asset pricing, even among national economies characterized by different stages of economic development, such as the Polish emerging economy and Austrian developed ones. Simultaneously, the CEE indirect real estate markets underlie processes of development as a separate asset class. Indicated factors, in terms of growing economic openness in the CEE region, leading, inter alia, to the growing resemblance of the property enterprises stocks listings at the Vienna and at the Warsaw Stock Exchanges, motivate to check the existence of the international spillover effects between the growth rates of the direct real estate markets and indirect real estate

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market price indices among the indicated economies and to discuss the time stability of their directions, as well as the existence of any structural changes on these underlying transformation processes markets.

The study comprises both into economics, including finance, and econophysics [2], as well as into statistical finance, which is a part of econophysics devoted to empirically resolving research problems by corroborating any stylized facts in the field of finance, using complementarily time series analysis methodologies derived both from econometrics and physics (including wavelet analysis originated with the Fourier transform redevelopments) to analyse common features of financial time series pairs that would not be observed using only traditional setup of econometrics in order to explain transmission mechanisms present within complex systems [2], such as financial markets; debt and equity real estate financing subsystems, as well as real estate markets treated as a complementary element of broader complex economic or financial system, such as any pricing change impulses, however assuming taking into account economic theory background, as well as compliance with some base research practices of econometrics, such as detrending nonstationary signals using first differencing of natural logarithms of considered time series [2].

## 2. Research aim and hypotheses

The study aim was to verify the existence of the international spillover effects between the changes in the levels of the rates of return on the price indices on the direct and indirect real estate markets within the national economies of Poland and Austria and to check the stability of their directions.

Research hypotheses:

- There exists a stable international spillover effect direction between the levels of the rates of return on the price indices of the direct real estate markets in the considered economies.
- There exists a stable international spillover effect direction between the levels of the rates of return on the price indices of the indirect real estate markets in the considered economies.
- There exists a pair of stable international spillover effects directions between the levels of the rates of return on the price indices of the securitized equity real estate market in one of the considered national economies and of the direct real estate market in the other of the considered national economies.

## 3. Literature review

Results of the previous research on the relationships between the considered indices, which have been systematically conducted since 1990, have referred almost solely to some developed economies. The indicated studies especially have had on purpose to verify existence of long term relationships between the above mentioned indices or between them and some stock market price indices,

especially including in this scope research on the *wealth* or the *credit-price* effects, using the Granger causality tests [9–12, 14–17].

The majority of these studies have referred to the definitions of co-integration between the indicated markets introduced by Liu et al. in 1990 [18].

Review of the literature on co-integration between considered markets on domestic scale has shown that, in quantitative terms, co-integration or segmentation have been confirmed in a comparable number of cases.

Domestic co-integration between indicated investment markets was confirmed, inter alia, by: Myer and Webb [14], MacKinnon and Clayton [19], Liow [20], Morawski et al. [21], Lin and Lin (in the case of the selected economies) [22], Hoesli and Oikarinen [23], Kołtuński in the case of Poland [9].

Domestic segmentation between indicated investment markets was confirmed, inter alia, by: Liu et al. [18], Gyourko and Keim [24], Okunew et al. [25], Ling and Naranjo [26], Lin and Lin (in the case of the selected economies) [22].

Wilson and Okunew [27] have found the international segmentation between the UK, the US and Australian indirect securitized real estate markets, controlling for the foreign exchange rates volatility. Myer et al. [28] have confirmed, using linear Johansen tests, the existence of the international co-integration between the UK, the US and Canadian indirect property price indices.

Liow [29] has simultaneously confirmed the existence of the statistically significant co-integrating equations between local, regional and global securitized property market price indices. Voronkova and Schindler [30] have confirmed the existence of the regional co-integration relationships between securitized property market price indices, considering several structural break dates.

Ling and Naranjo [31] have confirmed the existence of global securitized property markets risk diversification potential and existence of the worldwide and country specific factors in securitized property returns. Roca et al. [32] have confirmed the existence of global linear co-integrating relationships between domestic real estate stock market price indices in the selected developed economies, including the US economy, and world property market price indices estimated by the MSCI Inc., using the international capital asset pricing model (CAPM).

On the basis of the above literature review, it should be noticed that the existence of the indicated discrepancies between mentioned results could be explained by any differences in frequencies of measurement, selection and methodology of used market price indices, taken into account scopes in time and place dimensions and qualitative time changes in terms of market portfolios compositions. Such discrepancies could be triggered by the relatively constant occurrence of the flows of capital into specialized real estate investment funds — REITs markets, which have caused their split as a separate asset class [21], as well as by the existence of some structural changes

between taken into consideration investment markets. These discrepancies could have also been involved by applying different research methodologies (regression techniques, including the CAPM, the international CAPM, autoregressive models, linear co-integration tests, fractional co-integration tests, etc.).

Literature on the causality directions between the considered markets refers especially to the Granger causality tests, vector autoregressive models, vector error correction models and threshold error correction models [9–17], also delivering often mutually exclusive results.

#### 4. Methodology

Traditional methodology of econometrics, as well as traditional spectral Fourier analysis do not provide tools to analyse economic phenomena both in the time and frequency domains simultaneously. Econometric methods, including the Granger causality direction tests, require creation of a time constant model in form of one or more equations, using at once only one interval of cross-correlations lag. The Fourier transform does not require creation of a model and gives a possibility to analyse simultaneously different lag intervals, however its use results in loss of the time domain information, which makes identification of transient changes dates impossible. It is strictly important in terms of recurring structural changes occurrences, which may cause temporal reversals of causality directions within even well scientifically identified economic transmission mechanisms. Furthermore, traditional Fourier analysis refers only to stationary time series, whereas the price indices considered in the current study, as well as a large number of macroeconomic data, exhibit nonstationarity. As a result, the research aim has been achieved using both the traditional methods of econometrics, such as the Granger causality tests, as well as wavelet analysis tools, commonly used, inter alia, in signal processing and geophysics applications [2, 33–45]. The toolbox contributed by Aguiar-Conraria and Soares (ASToolbox) [8] has been used to perform simultaneous analysis of the considered time series in both the time and frequency domains, allowing to detect any potential structural changes dates on the considered investment markets.

Further part of this section (based on [1, 3, 7, 8, 33–40]) refers to the continuous wavelet transform (CWT), which enables to extract self-similarities of data sets. The discrete wavelet transforms (DWT), such as the maximum overlap discrete wavelet transform, that enable to perform noise reduction and to compress considered data sets, constitute an another approach to solve the research problem, however requiring more computational time than the CWT [8].

It is assumed that a function  $x(t)$ , which represents considered time series, has a finite energy

$$\int_{-\infty}^{\infty} |x(t)|^2 dt < \infty \quad (1)$$

and is defined in the finite energy space  $L^2(R)$ .

On the contrary to used by the Fourier transform infinite duration sine and cosine waves functions, a periodic mother wavelet function is a localized in the time and frequency domains finite duration wave function  $\psi(t) \in L^2(R)$ , which satisfies the so-called admissibility condition

$$\int_{-\infty}^{\infty} \psi(t) dt = 0. \quad (2)$$

Subsequently, the indicated function is translated by a constant translation parameter ( $\tau$ ) and scaled with a constant scaling or dilating parameter ( $s$ ) in order to obtain a proper time location and a proper width, respectively, as follows:

$$\psi(t) = \frac{1}{\sqrt{|s|}} \psi\left(\frac{t-\tau}{s}\right). \quad (3)$$

Larger windows are obtained when  $|s| > 1$  and narrower when  $|s| < 1$ .

On the purpose of the currently presented research it has been assumed that the wavelet function is given by the often used in economic applications equation of the Morlet function

$$\psi(t) = \pi^{-1/4} e^{i\omega_0 t} e^{-\frac{t^2}{2}}, \quad (4)$$

and that the angular Fourier frequency  $\omega_0$  equals 6 in order to facilitate the frequency–period reversion analysis [8, 33–35]; advantages of this function are listed in [38].

The continuous wavelet transform — CWT of a function  $x(t)$ , which can be thought as a cross-correlation of a signal  $x(t)$  with a set of wavelets [40], using  $\psi(t) \in L^2(R)$  is

$$W(\tau, s) = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{\infty} x(t) \psi\left(\frac{t-\tau}{s}\right) dt, \quad (5)$$

$\tau, s \in R \wedge s \neq 0.$

The wavelet power spectrum (WPS), depicting localized variance of a time series, is defined as follows:

$$\text{WPS}(\tau, s) = |\text{WPS}(\tau, s)|^2. \quad (6)$$

The wavelet phase angle could be obtained in case of a complex valued  $\psi(t)$  functions as

$$\varphi_x(\tau, s) = \tan^{-1} \frac{J(W_x(\tau, s))}{R(W_x(\tau, s))}, \quad (7)$$

where  $J, R$  refer to the imaginary and real parts, respectively.

In order to analyse relationships between two time series  $x(t)$  and  $y(t)$  in both the time and frequency domains the cross wavelet transform (XWT) is introduced as

$$W_{xy}(\tau, s) = W_x(\tau, s) W_y(\bar{\tau}, s), \quad (8)$$

where  $W_x(\tau, s)$  is a CWT of a  $x(t)$  function and  $W_y(\tau, s)$  is a CWT of a  $y(t)$  function.

The cross wavelet power (cross wavelet spectrum) (XWP), depicting a localized covariance between two time series  $x(t)$  and  $y(t)$ , is defined as:

$$\text{XWP}_{xy}(\tau, s) = |W_{xy}(\tau, s)|. \quad (9)$$

The squared wavelet coherency as a direct measure of cross-correlation, which detects similarity level of two time series as a function of lag of one relative to the other spectra of two time-series [35, 40], gives information on time and frequency localized co-movement (cross-correlations) between a pair of analysed time series and is defined as:

$$R_{xy}^2(\tau, s) = \frac{|S(s^{-1}W_{xy}(\tau, s))|^2}{S(s^{-1}|W_x(\tau, s)|^2)S(s^{-1}|W_y(\tau, s)|^2)}, \quad (10)$$

where  $S$  is a smoothing operator and

$$0 \leq R_{xy}(\tau, s) \leq 1, \quad (11)$$

where 0 indicates low cross-correlation and 1 indicates high cross-correlation [35, 40].

Taking into account that wavelet analyses would be performed both in case of stationary, as well as in case of globally nonstationary but locally stationary time series, it should be stressed that in case of analyzing any nonstationary time series numerically stable methodology of detrending its fluctuations should be used (such as introduced in [41–43]). It is worth noticing that Eq. (10) resembles a cross-correlation coefficient used in case of analysing any nonstationary time series (introduced in [41]). It should be underlined that the study, in order to keep the conformity with the methodology used by Miller et al. [1], as well as to keep the possibility of comparison with the results of the econometric Granger causality test results [9, 11], which require stationarity of analysed signals, was limited to the analysis of the first differences of the natural logarithms of the considered indices (their logarithmic paces of growth), which after check using congruent statistical tests have turned out to be stationary ones [9]. However, such filtering should be conducted in case of analyzing any non detrended non-stationary time series, such as price indices in their levels.

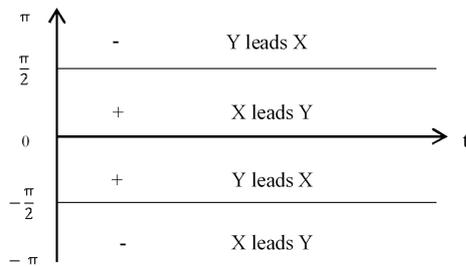


Fig. 1. Outline of a wavelet phase difference function and of analogical partial wavelet phase difference function, respectively, indicating time changes in a sign of co-movement between analysed pair of time series ( $X, Y$ ) and indicating which of them led the other in case of considered frequency band.

The wavelet phase difference function, whose outline is depicted in Fig. 1, gives an information on time changes in causality direction (phase lead of  $x(t)$  over  $y(t)$ ), as well as an information on time changes in sign of co-movement between two analysed time series and is defined as:

$$\varphi_{xy}(\tau, s) = \tan^{-1} \frac{J(W_{xy}(\tau, s))}{R(W_{xy}(\tau, s))},$$

$$\varphi_{xy}(\tau, s) \in \langle -\pi, \pi \rangle \quad (12)$$

or

$$\varphi_{xy}(\tau, s) = \varphi_x(\tau, s) - \varphi_y(\tau, s). \quad (13)$$

The partial squared wavelet coherency gives an information on a time and frequency localized co-movement (cross-correlation) between pair of analysed time series  $x(t)$  and  $y(t)$  after controlling for a time series  $z(t)$  and is defined as:

$$R_{xy|z}(\tau, s) = \frac{|R_{xy}(\tau, s) - R_{xz}(\tau, s)R_{yz}(\tau, s)|^2}{(1 - R_{xy}(\tau, s)^2) - (1 - R_{yz}(\tau, s)^2)}, \quad (14)$$

where  $R_{yz}(\tau, s), R_{xz}(\tau, s)$  denote wavelet coherency between  $y(t)$  and  $z(t), x(t)$  and  $z(t)$ , respectively, and

$$0 \leq R_{xy|z}(\tau, s) \leq 1, \quad (15)$$

where 0 indicates low cross-correlation and 1 indicates high cross-correlation [1, 8, 44–46].

The partial wavelet phase difference function, whose outline also is depicted in Fig. 1, gives an information on time changes in causality direction (phase lead of  $x(t)$  over  $y(t)$ ), as well as an information on time changes in sign of co-movement between two analysed time series after controlling for third time series  $z(t)$  and is defined as [1, 8, 44–46]:

$$\varphi_{xy|z}(\tau, s) = \tan^{-1} \frac{J(W_{xy|z}(\tau, s))}{R(W_{xy|z}(\tau, s))},$$

$$\varphi_{xy|z}(\tau, s) \in \langle -\pi, \pi \rangle. \quad (16)$$

According to Soares and Aguiar-Conraria phase difference and/or partial phase difference test results are significant only when wavelet coherency or partial wavelet coherency test results, respectively, are statistically significant in case of considered time and considered frequency band [1, 8].

### 5. Research scope

The research has encompassed price movements on the direct and indirect property markets within the Polish and Austrian national economies in the period starting on 31 December 2004 and finishing on 31 December 2014. Price movements have been represented by the selected price indices, enumerated in Sect. 6. In terms of the Polish indirect property market the scope of the presented research encompassed enterprises, whose stocks were included as of 31 December 2014 in the portfolio of the property enterprises stocks market sub-sector price index “WIG-Developers”, which was set by the Warsaw Stock Exchange. Indicated enterprises have been taken into the research scope starting since the beginning of the year in which the initial public offering of their stocks was performed at the Warsaw Stock Exchange and finishing with the end of the financial year finished 31 December 2014 or finishing with the end of the next financial year in the case of the enterprises with a shifted financial year. Financial years started before 1 January 2005 and enterprises which were insolvent as of 31 December 2014 have not been taken into the research scope.

## 6. Data used

In order to perform the research, the four time series of the standardized (to exhibit the zero mean and standard deviation of one) quarterly logarithmic rates of return on the price indices on the Polish and Austrian real estate markets, previously deflated as of 31 December 2004 using the Consumer Price Index estimated by the Polish Central Statistical Office or the Austrian Harmonized Index of Consumer Prices estimated by the Eurostat, respectively, and normalized to the level of 1000 points as of 31 December 2004, encompassing the period Q4 2004–Q4 2014, have been taken into consideration. The sequence of the indicated data transformations has been performed in line with the methodology used by Miller et al. [1]. Additionally, the Austrian price indices have been previously converted into the PLN using the real EUR/PLN foreign exchange rates, estimated using the average foreign exchange rates presented by the National Bank of Poland and using the above mentioned consumer price indices. It should be noticed that wavelet analysis also enables to perform analogical research on the price indices in their levels, due to its ability to examine stationary, as well as only locally stationary time series [1].

List of the considered market price indices:

1. Price index of the property enterprises stocks being in the scope of the research (the Polish indirect property market price index), retraced using own estimations in accordance with the Warsaw Stock Exchange indices rules, due to the fact that the “WIG-Developers” index, presented by the Warsaw Stock Exchange, was not set till the 2Q 2007;
2. Investment property fair value index (the latent Polish direct property market price index based on the sector level appraisal data, available only since 2005, covering especially commercial real estate markets), according to the own estimations based on the cyclical revaluations of the aggregated investment portfolios of the enterprises taken into the scope of the research done in the accordance with the International Accounting Standard no 40 “Investment property” and disclosed in their quarterly financial statements, available since 2005, when the IAS no 40 came into force, enabling using appraisal based valuations approach instead of historical cost approach, mirroring to the some extent the stock market price indices estimation rules, including not taking into account any disposal gains (indicated index, however being based on appraisals, fulfills the gap caused by the Polish property market informational inefficiency and is extensively explained in [9, 10]);
3. IATX index (the Austrian indirect property market price index), according to the Vienna Stock Exchange data;
4. Index of the residential property prices on the direct market in Vienna (the Austrian direct housing

property market price index), according to the National Bank of Austria data.

“WIG-Developers” index retraced since the 4Q 2004 and IATX index are fully comparable, encompassing market price movements of the stocks of the property enterprises operating in the CEE region, both on the primary and on the secondary housing and commercial real estate markets. Despite the existence of the set by the Vienna Stock Exchange CERX index (CEE Real Estate Index in EUR), made up of the most liquid stocks of property enterprises in the region of Eastern-South and Central Europe, only the indicated indices have been used, due to the fact that the total capitalization of the CERX index as of 31 December 2014 consisted in *ca.* 75% of the stocks of the property enterprises covered in the “WIG-Developers” index portfolio and in *ca.* 50% of the stocks of the property enterprises covered in the IATX index portfolio. It reflects the fact of significant coincidence between the portfolios of the indicated three indices, which certainly influences the strength of the co-integration relationships between these indices. On the considered date the IATX portfolio capitalization consisted in *ca.* 10% of the enterprises also listed in the “WIG-Developers” index portfolio and conversely the capitalization of the “WIG-Developers” index portfolio consisted in *ca.* 60% of the enterprises also listed in the IATX index portfolio.

Analogical research could be performed using the retraced mirrored investment property fair value index in the scope of the Austrian economy.

Despite the fact that due to the lack of data connected with the direct real estate markets of higher frequency,

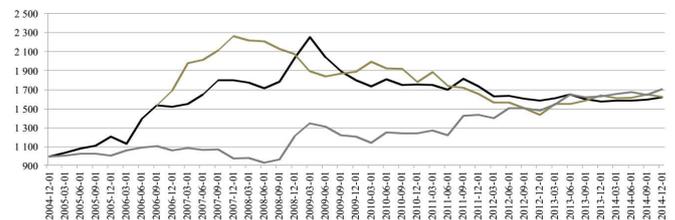


Fig. 2. Comparison of the direct commercial real estate and direct housing market price indices in Poland with the direct housing market price indices in Austria. Appraisal based fair value index of the aggregated portfolio of investment property of enterprises being in the scope of the research deflated as of 31 December 2004 using the CSO CPI, according to the own estimations, normalized on 31 December 2004 is depicted by the black curve. Index of the average transactional prices of a square meter on the primary housing real estate market in Warsaw, according to the NBP data at constant prices 2004, normalized to the level of the above mentioned fair value index as of the 3Q 2006 is depicted by the brown curve. Normalized index of residential property prices on the direct market in Vienna deflated as of 31 December 2004 using the Eurostat HICP, according to the National Bank of Austria data, converted into the PLN using real EUR/PLN exchange rates is depicted by the grey curve. Source: own estimations.

quarterly data, depicted in Figs. 2 and 3, have been used,

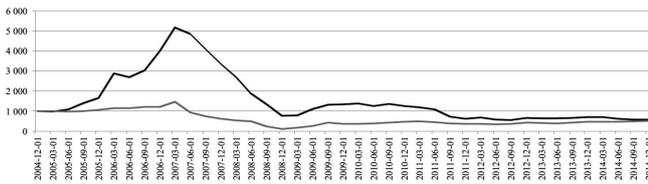


Fig. 3. Comparison of the indirect real estate market price indices in Poland and in Austria. Price index of the property enterprises stocks being in the scope of the research deflated as of 31 December 2004 using the CSO CPI, retraced according to the own estimations and normalized to the level of 1000 points as of 31 December 2004 is depicted by the black curve. IATX index, according to the Vienna Stock Exchange data, deflated as of 31 December 2004 using the Eurostat Austrian HICP converted into the PLN using real EUR/PLN exchange rates and normalized to the level of 1000 points as of 31 December 2004 is depicted by the grey curve. Source: own estimations.

the wavelet analyses, which are often conducted to analyse high frequency data sets, have been subsequently performed in the aim to detect any structural changes dates that potentially influenced the considered spillover effects directions. The extremities of short data sets have been supplemented with zeros, causing the existence of the edge effects [8].

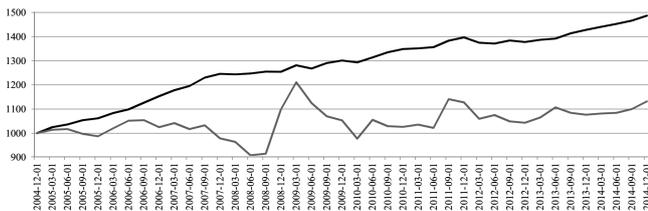


Fig. 4. Comparison of the GDP indices in Poland and in Austria. Index of the Polish seasonally adjusted GDP at constant prices [Q4 2004] is depicted by the black curve. Index of the Austrian seasonally adjusted GDP at constant prices [Q4 2004] converted into the PLN using the real EUR/PLN exchange rates is depicted by the grey curve. Source: own estimations based on the Eurostat, the Polish CSO and NBP data.

Apart from any structural changes, relationships between two or more markets might be influenced, inter alia, by some macroeconomic fluctuations [47]. Consequently, wavelet partial phase difference analyses have been simultaneously performed, using as the control variables, the three quarterly time series of the standardized (to exhibit the zero mean and standard deviation of one) first differences of the natural logarithms of the indicated EUR/PLN real exchange rates, as well as of the seasonally adjusted, using the “BV4.1 Procedure” developed by the Federal Statistical Office of Germany, Gross Domestic Product (GDP) indices in Poland and in Austria, estimated using data presented by the Polish Central Statistical Office and by the Eurostat, respectively, and previously deflated as of 31 December 2004 using

the Consumer Price Index estimated by the Polish CSO and Austrian Harmonized Index of Consumer Prices estimated by the Eurostat, respectively, and normalized to the level of 1000 points as of 31 December 2004, encompassing the period Q4 2004–Q4 2014. Additionally, the Austrian GDP index has been previously converted into the PLN using the indicated real EUR/PLN foreign exchange rates. These time series have been depicted in Fig. 4.

### 7. Results and discussion

Table I depicts the results of the augmented Dickey–Fuller tests on nonstationarity of the considered time

TABLE I

Test statistics (1), *p*-values (2) of the augmented Dickey–Fuller tests on nonstationarity of the considered time series in levels (normalized to the level of 1000 points as of 31 December 2004 price indices or seasonally adjusted, using the “BV4.1 Procedure” developed by the Federal Statistical Office of Germany, macroeconomic variables previously deflated as of 31 December 2004 using the appropriate consumer price indices and converted into the PLN using the real exchange rates, as well as the indicated exchange rates) in the sample period Q4 2004–Q4 2014 and in the first differences of their natural logarithms (logarithmic rates of return) in the sample period Q1 2005–Q4 2014, using quarterly data, and lags numbers chosen automatically using AIC (3). #1 — Property enterprises stocks price index. #2 — Investment property fair value index. #3 — IATX price index. #4 — Index of the prices on the direct property market in Vienna. #5 — GDP of Poland. #6 — GDP of Austria. #7 — EUR/PLN average real exchange rate. Results of the tests with a constant are indicated by A; results of the tests with a constant and a linear trend are indicated by B; results of the tests with a constant and a linear and quadratic trends are indicated by C. Source: own estimations.

	A		B		C		(3)
	(1)	(2)	(1)	(2)	(1)	(2)	
Time series in their levels							
#1	-1.06	0.73*	-2.11	0.54*	-3.42	0.14*	7
#2	-2.52	0.11*	-2.08	0.56*	-2.37	0.64*	1
#3	-1.45	0.55*	-1.28	0.88*	-3.38	0.15*	9
#4	-0.35	0.91*	-2.81	0.19*	-3.79	0.06*	0
#5	-2.09	0.25*	-2.11	0.52*	-1.23	0.97*	0
#6	-2.66	0.08*	-2.83	0.18*	-3.85	0.05*	1
#7	-2.42	0.14*	-3.25	0.07*	-3.32	0.17*	1
First differences of the natural logarithms of the time series.							
#1	-4.45	0.00	-3.48	0.04	-4.06	0.04	8
#2	-5.27	0.00	-5.89	0.00	-5.31	0.00	0
#3	-4.31	0.00	-4.33	0.00	-4.30	0.01	1
#4	-5.74	0.00	-5.69	0.00	-5.39	0.00	0
#5	-5.40	0.00	-5.85	0.00	-4.52	0.01	0
#6	-4.30	0.00	-4.27	0.00	-4.28	0.01	8
#7	-4.92	0.00	-4.89	0.00	-4.80	0.00	3

\* indicates that the 5% significance level of confirmation of the null hypothesis on nonstationarity of the analysed times series was exceeded.

TABLE II

Results of the estimation of the F-statistics (1) and P-values (2) of the Granger causality tests between the pairs of the first differences of the natural logarithms of the time series presented in Table I in the sample period Q1 2005–Q4 2014 (assuming 4 lags).  $H_0$  = time series X does not cause time series Y. Time series are presented in the following way: series from the set of time series X in the vertical dimension, series from the set of time series Y, i.e. replicated series X, in the horizontal dimension. Property enterprises stocks price index is denoted by A, investment property fair value index is denoted by B, IATX price index is denoted by C, index of the residential prices on the direct property market in Vienna is denoted by D. Source: own estimations.

		A	B	C	D
A	(1)	–	0.95	0.33	1.87
	(2)	–	0.45	0.86	0.15
B	(1)	4.84	–	3.09	1.05
	(2)	0.00*	–	0.03*	0.40
C	(1)	2.31	2.87	–	1.34
	(2)	0.08	0.04*	–	0.28
D	(1)	5.16	2.22	5.03	–
	(2)	0.00*	0.09	0.00*	–

\* indicates that the 5% significance level of confirmation of the null hypothesis of no causal relationship between the analysed times series was not exceeded, i.e. the Granger causality relationship between them was not rejected, however its confirmation requires additional corroboration with economic theory.

series. The results indicate that all of the considered time series have been integrated of order 1, which legitimize the use of the Granger causality tests in the scope of the first differences of the natural logarithms of these time series. The results were also confirmed by the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test results.

The results of the Granger causality tests, presented in Table II, in the scope of the international spillover relationships, have confirmed, using the quarterly data time interval, the lack of the international causality within both of the considered groups of the rates of return, i.e. between the direct and between the indirect property market price indices in Poland and in Austria in the period 2005–2014. Nevertheless, the results have confirmed, inter alia, the existence of the mutual causality between the changes in the levels of the rates of return on the Austrian indirect and changes in the levels of the rates of return on the Polish direct real estate market, as well as the unidirectional causality direction from the changes in the levels of the rates of return on the Austrian direct to the changes in the levels of the rates of return on the Polish indirect property market. Despite the indicated results, the wavelet analyses have been performed in the scope of all of the considered hypotheses in order to check the existence of the statistically significant co-movement between the considered time series and to verify the stability of their causal directions.

Table II, additionally, depicts the results of the tests on the domestic causal relationships between the direct and indirect property price levels [48].

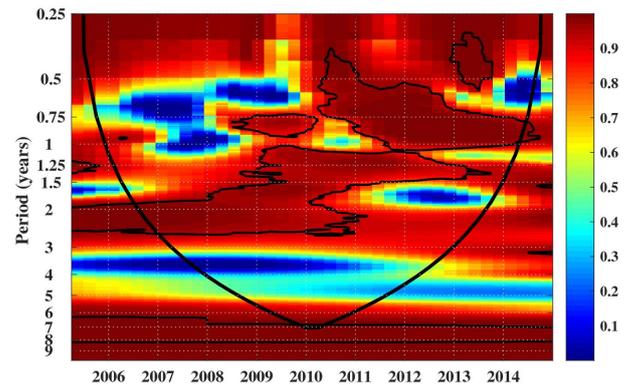


Fig. 5. Wavelet squared coherency between the logarithmic rates of return on the price indices on the direct real estate markets in Austria and in Poland in the period Q4 2004–Q4 2014. Source: own estimations.

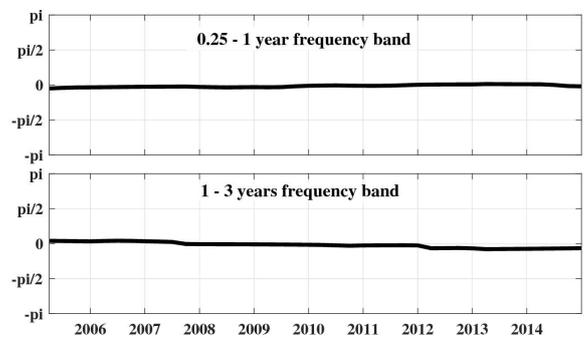


Fig. 6. As in Fig. 5, but for wavelet phase-difference. Source: own estimations.

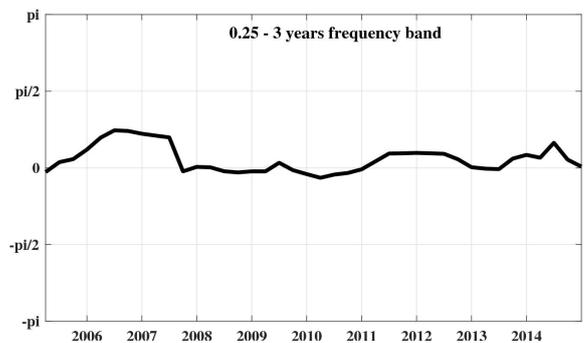


Fig. 7. Partial wavelet phase-difference between the logarithmic rates of return on the price indices on the direct real estate markets in Austria and in Poland in the period Q4 2004–Q4 2014, controlling for the real GDP growth rates in the indicated national economies and for the EUR/PLN real exchange rates fluctuations. Source: own estimations.

Figures 5–16 depict the results of the wavelet analyses performed in order to verify the research hypotheses, using squared wavelet coherency, wavelet phase-difference, as well as partial wavelet phase-difference methods.

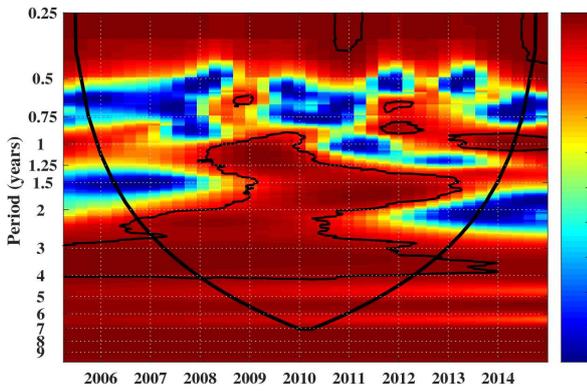


Fig. 8. Wavelet squared coherency between the logarithmic rates of return on the price indices on the indirect real estate markets in Austria and in Poland in the period Q4 2004–Q4 2014. Source: own estimations.

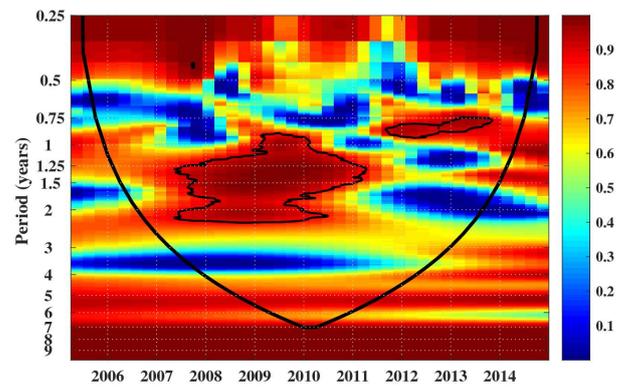


Fig. 11. Wavelet squared coherency between the logarithmic rates of return on the price indices on the indirect RE market in Austria and on the direct RE market in Poland. Source: own estimations.

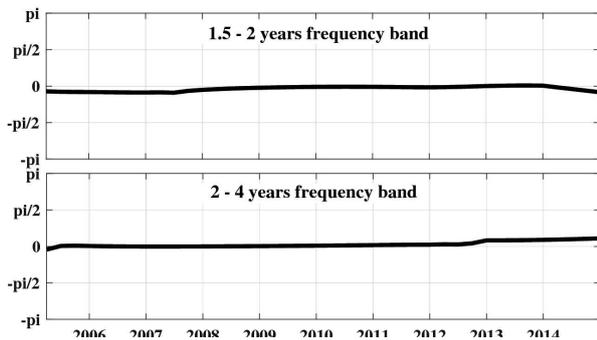


Fig. 9. As in Fig. 8, but for wavelet phase-difference. Source: own estimations.

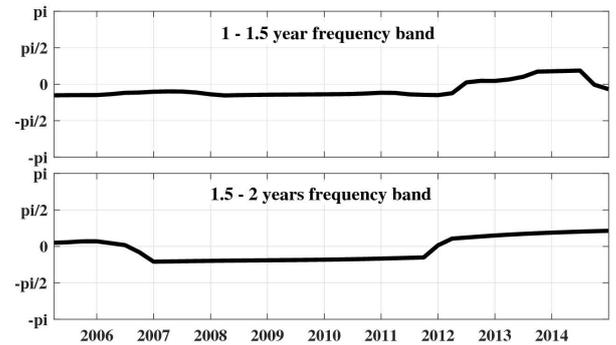


Fig. 12. As in Fig. 11, but for wavelet phase-difference. Source: own estimations.

The black thick lines in Figs. 5, 8, 11, and 14 cut the regions in which exist the edge effects connected with supplementing short data sets with zeros. The black thin lines in these figures designate the 5% level of significance, estimated using the Monte Carlo simulations. These lines also indicate the time periods when the phase

difference functions depicted in Figs. 6–7, 9–10, 12–13, 15–16 were statistically significant within the frequency bands, which were previously designated in line with the indicated significance lines [8].

The color bars in Figs. 5, 8, 11, and 14 depict that the bright and dark colors designate low and high squared

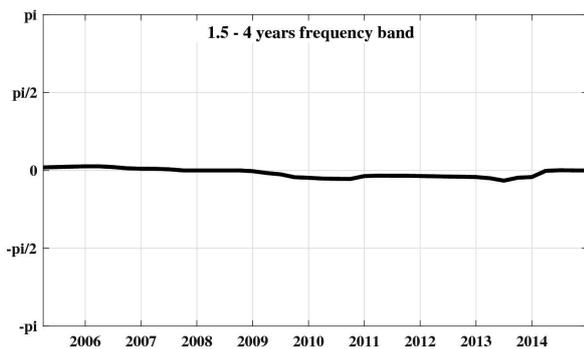


Fig. 10. Partial wavelet phase-difference between the logarithmic rates of return on the price indices on the indirect real estate markets in Austria and in Poland in the period Q4 2004–Q4 2014, controlling for the real GDP growth rates in the indicated national economies and for the EUR/PLN real exchange rates fluctuations. Source: own estimations.

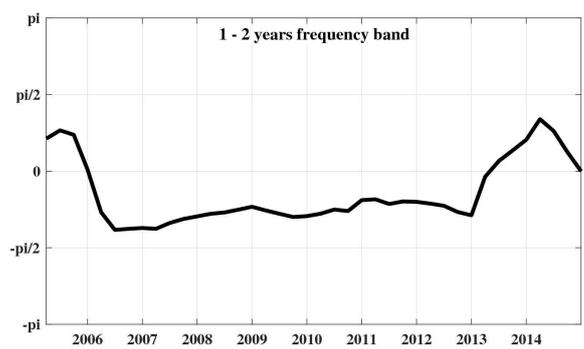


Fig. 13. Partial wavelet phase-difference between the logarithmic rates of return on the price indices on the indirect RE market in Austria and on the direct RE market in Poland in the period Q4 2004–Q4 2014, controlling for the real GDP growth rates in the indicated national economies and for the EUR/PLN real exchange rates fluctuations. Source: own estimations.

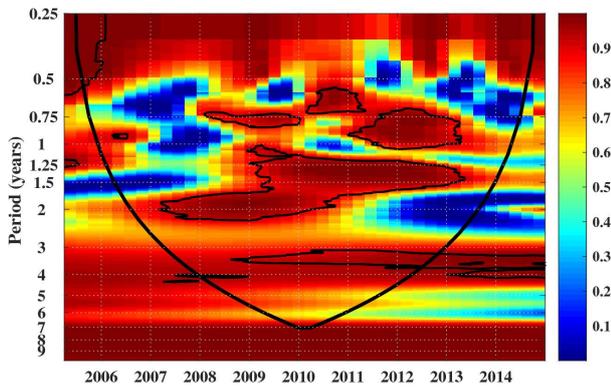


Fig. 14. Wavelet squared coherency between the logarithmic rates of return on the price indices on the direct RE market in Austria and on the indirect RE market in Poland. Source: own estimations.

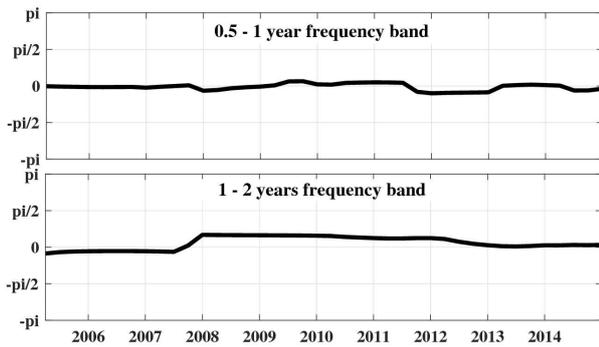


Fig. 15. As in Fig. 14, but for wavelet phase-difference. Source: own estimations.

coherency (cross-correlation) between the analysed time series, respectively. Indicated figures do not allow to distinguish between negative and positive cross-correlations.

Figures 5–7 verify the first research hypothesis on the stable existence of the international spillover direction between the rates of return on the price indices on the

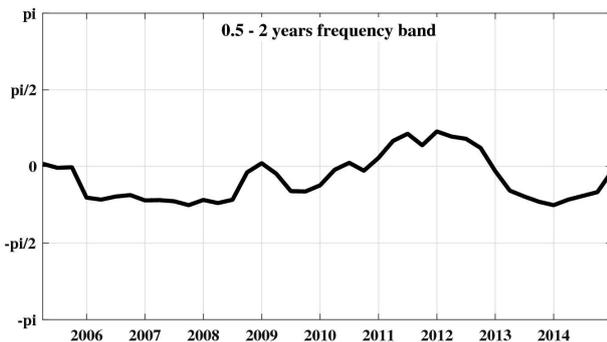


Fig. 16. Partial wavelet phase-difference between the logarithmic rates of return on the price indices on the direct RE market in Austria and on the indirect RE market in Poland in the period Q4 2004–Q4 2014, controlling for the real GDP growth rates in the indicated national economies and for the EUR/PLN real exchange rates fluctuations. Source: own estimations.

direct real estate markets [49] in Austria and in Poland in the period Q4 2004–Q4 2014. Indicated rates of return displayed high co-movement (cross-correlations) in the frequency bands between half a year and one year and between one year and 3 years. Consequently, the phase differences in the frequency bands 0.25–1 and 1–3 years have been checked. Figure 6 depicts the relatively high stability of the considered causality direction in the entire sample period 2005–2014. Nevertheless, after controlling for the economic growth rates and for the EUR/PLN exchange rates fluctuations, the wavelet partial phase difference analyses results have indicated that the causality sign between the considered time series changed multiple times. As a result, the first research hypothesis has been empirically rejected.

Figures 8–10 verify the second research hypothesis on the stable existence of the international spillover direction between the rates of return on the price indices on the indirect real estate markets in Austria and in Poland in the period Q4 2004–Q4 2014. Indicated rates of return displayed high co-movement (cross-correlations) in the frequency bands between 1 year and 2 years in the period 2008–2013 and between 2 and 4 years in the entire sample period, as well as between 0.75 and 1 year in the period since 2012. Consequently, for these periods the phase differences in the frequency bands 1.5–2 and 2–4 years have been checked. Figure 9 depicts the relatively high stability of the considered causality direction in the entire sample period 2005–2014. Nevertheless, after controlling for the economic growth rates and for the EUR/PLN exchange rates fluctuations, the wavelet partial phase difference analyses results have confirmed that the causality sign between the considered time series changed in 2008 and in 2013, indicating that after the global real estate and global financial crises the price fluctuations on the Polish indirect property market led the Austrian ones in the period 2008–2013. As a result, the second research hypothesis also has been empirically rejected. Nevertheless, Figs. 5, 7, 8, and 10 have confirmed that the international spillover effects between pairs of the direct and indirect property market price indices existed in the considered period, which is in the opposition to the above mentioned Granger causality tests results.

Figures 11–13 verify the last research hypothesis in the scope of the existence of the international spillover direction between the rates of return on the price indices on the indirect real estate market in Austria and on the direct real estate market in Poland in the period Q4 2004–Q4 2014. Indicated rates of return displayed high co-movement (cross-correlations) in the frequency bands between 1 year and 2 years only in the period 2007–2011 and between 0.75 and 1 year in the period 2011–2013. Consequently, for these periods the phase differences in the frequency bands 1–1.5 and 1.5–2 years have been checked, respectively. Figure 12 depicts the relatively high stability of the considered causality direction in the first of the considered periods (2007–2011) and depicts the lack of such stability in the second of

the considered periods (2011–2013). Nevertheless, after controlling for the economic growth rates and for the EUR/PLN exchange rates fluctuations, the wavelet partial phase difference analyses results have confirmed that the causality sign between considered time series did not change in the period 2007–2013, which is the only period when the considered co-movement were statistically significant, indicating that in this period the price fluctuations on the Polish direct property market led the price fluctuations on the Austrian indirect property market. However, taking into the consideration lack of the stability in terms of the mutual co-movement strength between the considered variables, the last research hypothesis has been conditionally discredited.

Figures 14–16 verify the last research hypothesis in the scope of the existence of the international spillover direction between the rates of return on the price indices on the direct real estate market in Austria and on the indirect real estate market in Poland in the period Q4 2004–Q4 2014. Indicated rates of return displayed high co-movement (cross-correlations), inter alia, in the frequency bands between 1.5 years and 2 years in the period 2007–2010 and between 1 and 2 years in the period 2009–2013, as well as between 0.75 and 1 year in the period 2011–2013. Consequently, for these periods the phase differences in the frequency bands 0.5–1 and 1–2 years have been checked, respectively. Figure 15 depicts the lack of the stability of the considered causality direction in the period 2007–2013. The wavelet partial phase difference analyses, used in order to control for the economic growth rates and for the EUR/PLN exchange rates fluctuations, have supported the above indicated results. Consequently, the last research hypothesis has been finally rejected.

## 8. Conclusions

Rejection of the research hypotheses on the existence of the stable international spillover effects directions between the levels of the rates of return on the price indices on the direct and on the indirect real estate markets between the national economies of Poland and Austria indicates that the knowledge of the current direction of such causalities within the considered complex system would not be permanently viable. Consequently, it invalidates its use in terms of making assumptions in the context of long term investment policies, the long term domestic housing policies and in the scope of the internal macroprudential policy [50] in case of the considered economies. Furthermore, it discredits its use in the scope of predicting overall sectorial economic growth rates or crises diffusion directions. Rejection of the research hypotheses also indicates that there is no time stability in terms of the informational efficiency domination of the one over the other national property markets, which unveils that in the long term there is no possibility to anticipate price changes on these markets using constantly one of the national property market price indices as a predictor.

Considered instabilities may have been caused by the some structural changes in the scope of the direct and indirect property markets, as well as in the scope of the real estate financing systems [50, 51] in both of the considered national economies. Especially, such structural changes might have been caused by the transition processes in the scope of the outward foreign direct investments in the CEE region [52, 53].

Phase-difference analyses between all of the considered pairs of time series have confirmed constant presence of the positive signs of the co-movement between them, which is in line with economic theory and influences investment decision processes [54, 55]. Squared wavelet coherency analyses have revealed that the statistically significant co-movement between the indicated pairs proceeded mainly in the mid and in the long term.

The results of the phase-difference tests have also confirmed that the direction of any of the considered economic spillover effects would depend on a frequency or on a period assumed during estimation of examined rates of return. The results of the partial phase-difference tests have shown that the above indicated phenomena are influenced, inter alia, by economic growth rates characterizing the considered national economies and by real foreign exchange EUR/PLN rate fluctuations.

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