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An empirical investigation into regional housing market synchronisation in Poland

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A B S T R A C T

Objective: The article aims to investigate the synchronisation of metropolitan house prices from 2000 to 2020 based on novel empirical data. We applied several econometric procedures to address the cyclicity of housing markets.

Research Design & Methods: Using a unique dataset of over four million offers, we investigated the synchronisation of 18 regional housing markets in Poland from 2000 to 2020. The study used spectral analysis.

Findings: The study proved the strong synchronisation of housing cycles in Polish regional housing markets. Moreover, when the cycle amplitude was considered, the econometric analysis showed regional disparities in the cyclical behaviour of housing prices. According to the research, Lublin and Opole had the lowest housing cycle magnitude, and Gdańsk, Katowice, and Łódź had the largest magnitude.

Implications & Recommendations: The information about housing cycles has important policy implications. Housing wealth effects generated by cyclical house prices may be more persistent than financial wealth effects. Consequently, they may substantially affect consumption dynamics. Therefore, precisely identifying market cycles and differences in cycle synchronisation is vital when constructing an effective, selective, and well-timed monetary policy.

Contribution & Value Added: The research narrows the knowledge gap on the synchronisation of housing markets in an emerging economic environment. With their distinct institutional structures, Eastern European countries have little knowledge of this issue.

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INTRODUCTION

The recent two decades have brought empirical evidence on business cycle synchronisation and its determinants (Beck, 2019). Following mainstream economic interest, substantial but not entirely consistent research has been done on housing market fluctuations in the short and long run. Furthermore, the body of econometric evidence demonstrates that house prices exhibit cyclical behaviour as other major asset classes and are possibly synchronised due to various factors.

Housing market synchronisation is essential for several reasons. Firstly, housing market synchronisation suggests that positive and negative economic shocks will magnify across regions and countries. Secondly, it has some important policy implications for private and public stakeholders. Miles argues that knowledge about the co-movement of house prices is helpful for developers and institutional investors when building a diversified housing stock portfolio (Miles, 2020). Thus, housing cycles and their potential synchronisation are particularly interesting to policymakers responsible for financial stability and various interlinkages between housing markets, the construction industry, and the economy (Duca *et al.,* 2021). In the latter case, the synchronisation of housing cycles, or lack thereof, requires a different approach to devising regional housing policy instruments (Miles, 2020).

The synchronisation of house price cycles has been relatively understudied compared to related housing market convergence and spill-over effects. This particular observation is even more apparent in the case of emerging economies, where the relative research gap is substantial. The article narrows the research gap by examining the cyclical behaviour of 18 regional housing markets in Poland. The article investigates the synchronisation of metropolitan house prices from 2000 to 2020 based on novel empirical data. We applied several econometric procedures to address the cyclicity of housing markets.

This article proceeds as follows. The following section will describe the previous research on the synchronisation of house price cycles. In particular, we will focus on similarities and differences found in the regions and countries investigated. The third section will explain our data and methodology. The fourth section will describe the empirical results and discuss the significant implications. Finally, research conclusions, limitations, and directions for further investigation will be found in the last section.

LITERATURE REVIEW

Over the last two decades, mainstream economists have drawn growing attention to the dynamics of house markets, but it has been dramatically amplified since the global financial crisis. As a result, one of the recurrent themes in the economic literature is the housing market cycle. The economic literature in the field may be divided into two distinct categories. The first branch of empirical research addresses the question of the presence of housing market cycle synchronisation. The second branch of the study aims to identify various factors that explain housing market synchronisation. Moreover, several scholars addressed methodological issues in identifying and measuring housing market cycles.

The empirical research suggests that housing market synchronisation has increased substantially globally (Duca, 2020; Hirata *et al.,* 2012). Interestingly, empirical research indicates that the major cities in the world may exhibit different synchronicity patterns than other cities of their respective countries. This phenomenon can be explained by global capital flows (Alter *et al.,* 2019), a conclusion much in line with mainstream economic research. A recent econometric study reveals that capital mobility positively relates to business cycle synchronisation (Beck, 2021; Lazarevic *et al*., 2022; Lv, 2023). The important influencing factors can also be found in analysing the migration trends and their links with the business cycles and overall financial stability (Vučković & Škuflić, 2021), especially in the case of intellectual migration (Oliinyk *et al*., 2022). Furthermore, there is a substantial body of empirical evidence that indicates that housing markets dynamics are interconnected with mortgage markets, financial stability, and the broader economy and strongly influenced by investor expectations (Adarov, 2022; Cesa-Bianchi, 2013; Duca, 2020; Duca *et al.*, 2021; Hoesli, 2020; Mizero *et al*., 2018; Do & Park, 2018; Jorda *et al.,* 2019; Brychko *et al.,* 2021; Brychko *et al.,* 2021; Kuo *et al*., 2021; Tomal, 2021; Trojanek *et al.*, 2022). The mortgage markets, in their turn, are significantly affected by borrowers' financial ability (Kovacs & Pasztor, 2021). Furthermore, the synchronisation of housing cycles has often been associated with European integration (Alvarez *et al.,* 2010; van Ewijk & Arnold, 2015; Zelazowski, 2018). However, despite the increased synchronisation of housing markets worldwide, significant differences can be found when comparing selected economies.

Like many other research problems related to house price dynamics, the synchronisation of housing cycles has been extensively addressed based on US metropolitan data. In the early yet influential study based on 51 US cities, Ghent and Owyang address the cyclical behaviour of house prices and compare it to the business cycle (Ghent & Owyang, 2010). Other US studies suggest that household price cycle differences may be attributed to geography and the coastal housing market's distinct synchronisation patterns (Flor & Klarl, 2017). Another US study on the house price dynamics in 19 metropolitan areas from 1998 to 2013 reveals that the magnitude of cyclical swings (booms, busts) is negatively related to underlying fundamental growth rates. Therefore, it is more plausible that bigger booms or busts will appear in fast-growing markets with weaker economic bases (Peng *et al.,* 2014). The role of macroeconomic uncertainty in explaining the synchronisation of house price cycles was addressed using machine learning (Gupta *et al.,* n.d.). In contrast, Marfatia explains the role of time-varying macroeconomic variables in predicting house price variation (Marfatia, 2021).

Established long-run house price indices in the UK have facilitated several empirical studies on the synchronisation of regional house price cycles. For example, estimates based on a Markov switching VAR model demonstrate differences in the duration and magnitude of regional housing cycles (Chowdhury & Maclennan, 2014). Another economic study compares the house prices and affordability cycle to find a significant synchronisation between the two (Pitros & Arayici, 2017). However, recent empirical research suggests that the housing market cycle synchronisation in the UK is weaker than in the US (Miles, 2020).

Scarce evidence on regional housing cycles comes from other European countries. The long-run cyclical behaviour of housing markets in Italy shows that house price cycles in the 1970s and early 1980s were similar to other European countries, not necessarily revealed in official public statistics (Gabrielli *et al.,* 2018). The research on the interlinkages between business and housing price cycles in Spain indicates that house price cycles are more sensitive to shocks than business cycles (Sala-Rios *et al.,* 2018).

Using data from eight Australian metropolitan areas, Akimov *et al*. (2015) identify the cyclical fluctuation of house prices and conclude that despite overall similarities, there are significant differences in the synchronisation of the housing market in Melbourne and Sydney and other provincial cities (Akimov, *et al.,* 2015). The spill-overs between monetary policy, the housing market, and business cycles were investigated using Chinese empirical data from 1998 to 2018 (Li *et al.,* 2021).

The scoping analysis of the prior research in the field suggests that house price cycle synchronisation is still understudied and requires more empirical attention, especially considering the possible multifaced consequences of the Covid-19 pandemic or war in Ukraine that caused asymmetric economic and financial disturbances.

RESEARCH METHODOLOGY

Methods

Determining turning points and cycle phases is complex due to the many approaches for extracting fluctuations in economics time series based on different theoretical premises and using other procedures. As a result, the exterior image of the cycle, the position of turning points, and the duration of phases will vary depending on the process used. In the case of housing cycle analyses, approaches taken from business cycle analyses dominate level cycles (Alqaralleh & Canepa, 2020; André *et al.,* 2019; Bracke, 2013; Girouard *et al.,* 2005), growth cycles (Agnello *et al.,* 2020), and deviation cycles (Akimov *et al.,* 2015; Fan *et al.,* 2019; Gray, 2018; Zelazowski, 2017).

The pioneering work of Nelson and Plosser (1982) showed that the hypothesis that the formation of real GDP (and other variables describing the real sphere of the economy) is a process of a random walk with drift could not be rejected. Hence, such a course can be written as:

$$y_t = \mu + y_{t-1} + \varepsilon_t \tag{1}$$

in which:

μ - ind drift component; $\mu > 0$;

ε **-** random component.

Considering the above relationship, it can be seen that a one-time disturbance of the previous growth path will result in its permanent deformation with no possibility of returning to the previous course. The analysis of business cycle fluctuations is more complicated because random straying causes the trend to be subject to deviation. Hence, distinguishing the development trend from cyclical changes is more complicated. However, the authors of the real business cycle theory propose statistical methods to overcome such challenges. They are still based on the assumption that the cyclical component of a variable y is the difference between its current value and a measure showing the value of the trend but that the latter component is a weighted average of past, present, and future observations. The estimation of the thus defined trend component (g_t) is realised by the function of the:

The most widely used cyclic component extraction techniques in econometric analysis are Hodrick – Prescott (1997), Baxter–King (1999) and Christiano–Fitzgerald (2003) filters. The first of these (HP) is a high-pass filter, so the interference of use (parameter selection) is only concerned with defining the eliminated lower band of oscillations. Baxter–King (BK) and Christiano–Fitzgerald (CF) filters are examples of band-pass filter techniques, so the choice of smoothing parameters determines the lower and upper bands of the oscillation frequencies cut off. However, in the case of the BK filter, the initial and final observations are lost, and in the case of the CF filter, it is possible to obtain an apparent phase shift as long as the input series is stationary (Canova & Ferroni, 2011). Realising the advantages and disadvantages of the indicated techniques, it is worth using each of them to capture the common features of the fluctuations of the variables under study, independent of the applied stochastic elimination filter.

$$min[\sum_{t=1}^{T}(y_t - g_t)^2 + \lambda \sum_{t=3}^{T}(\Delta^2 g_t)^2 \quad (2)$$

in which:

λ - the non-negative parameter of smoothing, *i.e.* filtering (cutting off) selected harmonics of the time series.

The next stages of econometric work consisted of conducting a spectral analysis, because the actual course of the economic process, as a stochastic process, can be represented in the form of a trigonometric polynomial:

$$y_t = \sum_{i=1}^{T/2}(a_i \cos 2\pi\omega_i\, t + b_i \sin 2\pi\omega_i t) \quad (3)$$

in which:

$\omega_i = \frac{i}{T}$ - frequency of individual component harmonics, $i = 1,2,\dots,\frac{T}{2}$.

Identifying the frequency of the dominant fluctuations makes it possible to determine the number of cycles per unit of time, while the period indicates how long one cycle lasts. Since the study of the synchronisation of economic fluctuations used a series describing more than a dozen Polish cities, an opportunity arose to capture the relationship between the oscillations of these quantities. Mutual spectral analysis of two stochastic processes makes it possible to calculate the coherence coefficient and the phase angle (Granger, 1969; Priestley, 1981). The former indicates which frequency components are correlated with each other. The latter measures the difference in phase between the corresponding harmonic components of the processes under study. Its representation in degrees makes it possible to determine the temporal relationships (advance or lag) between the variables under study. Warner (1998) shows that this is possible after applying the formula:

$$L(\omega) = L_1(\omega) * \frac{1}{\omega} \quad (4)$$

in which:

$L_1(\omega) = \frac{\varphi(\omega)}{360}$, if $0 \le \varphi(\omega) \le 180$ or $L_1(\omega) = \frac{\varphi(\omega)-360}{360}$, if $180 \le \varphi(\omega) \le 360$;

$\varphi(\omega)$ - phase angle for frequency ω;

$\frac{1}{\omega}$ - fluctuation period expressed in months.

In general, the methodology – widely used in the literature – allows us to identify frequency patterns in market volatility and leading and lagging relationships, and to quantify the strength of market synchronization. We will also investigate the dynamics and interdependencies between markets.

Data

In Poland, the National Bank of Poland (NBP) and Statistics Poland (SP) provide apartment price indices for provincial cities. In 2010, the NBP was the first to publish hedonic indices for Poland's largest cities (data from Q3 2006). Since 2013, the NBP has been surveying residential and commercial real estate prices as part of the statistical survey program of official. Previously published data on the average transaction and offer prices revealed some discrepancies compared to data from local valuers' databases (Gluszak *et al.,* 2018; Hill & Trojanek, 2022; Konawalczuk, 2014). Since 2015, SP has published average prices for residential units in provincial cities. Noteworthy, these indicators are premise-based; the cooperative ownership right is not included.

Considering some limitations of NBP and SP information, we decided to use a dataset on asking house prices. According to some studies, offer prices can aid in monitoring the current housing market

(Diewert & Shimizu, 2016; Li *et al.,* 2019; Wang *et al.,* 2020). However, they are inconclusive in determining whether offer prices can be used to replace transaction prices in index construction (Anenberg & Laufer, 2017; Ardila *et al.,* 2021; Kolbe *et al.,* 2021; Wang *et al*., 2020). Nonetheless, they agree that using offer prices in forecasting models improves accuracy. Moreover, in the case of new builds listings can provide more reliable information on the housing market than transactions (Hill *et al*., 2023).

Considering the above information, the study employed a one-of-a-kind database of over 4.5 million housing offers in 18 provincial capital cities in Poland from 2000 to 2020. Earlier data were obtained from archival advertisements in photocopies, photographs, or actual periodicals, which were then digitally reproduced and organised in a database. Furthermore, data from 2008 were collected several times a quarter from advertising portals (gratka.pl / otodom.pl). Initially, more than 5.5 million offers were collected in the database (after preliminary cleaning to remove offers that did not include a price, surface area, or a specified general or specific location) by both ownership and cooperative ownership of the premises. Furthermore, as a result of the repeated offers, the following had to be removed: offering the same apartment in subsequent months (*e.g.*, January, February, March), offered by different intermediaries (the same apartment was offered more than once), and offering the same apartment in a given quarter at different prices (the lowest price offer was left in the database). Finally, the database contains 4 509 144 apartment offers in 18 Polish provincial cities from 2000 to 2020. Using the data gathered, geometric average prices for 1 m2 of usable floor area in apartments were calculated (Figure 1). Price indices were calculated using the above-mentioned methodology.

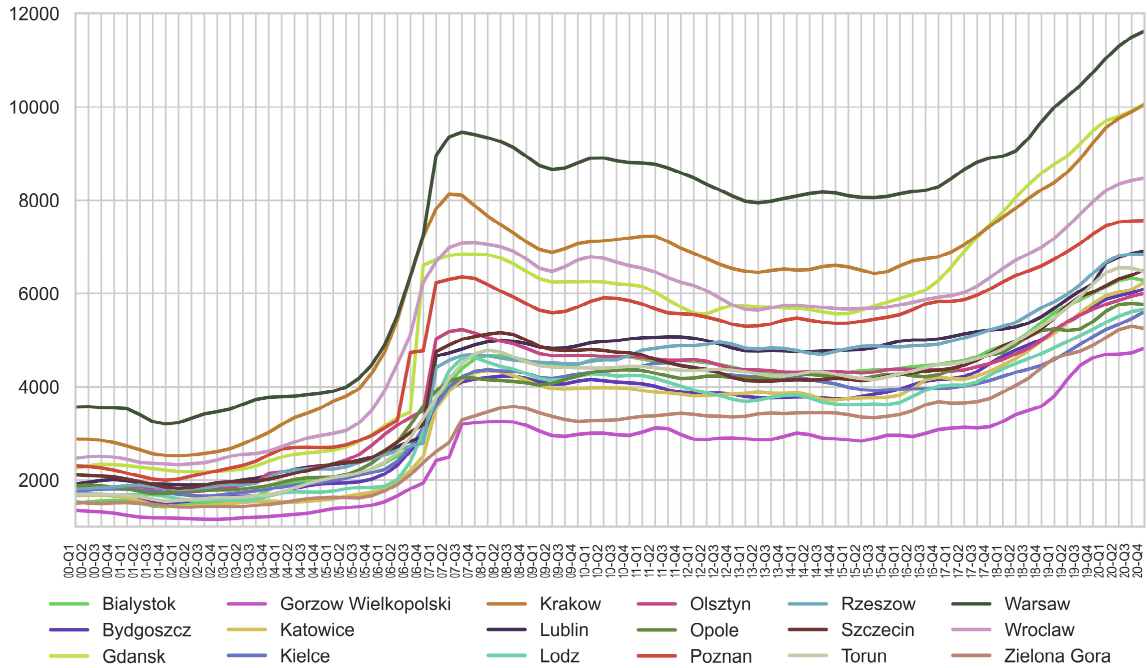

Figure 1. Geometric average prices for 1 square metre in provincial capital cities in Poland in 2000-2020
Source: Trojanek, 2021.

Statistical analysis was conducted on time series determining an apartment's average price per square metre from 2000 to 2020. Each time, these prices were determined quarterly, which satisfies the prerequisites of using quantitative instruments for studying the economic situation in further stages of the work. The spatial scope of the source data was determined by the set of cities constituting the seat of the authorities of the given voivodeship. A summary list of cities for which average prices per square metre of apartments were analysed is presented in Table 1.

Formally, the 18 cities have the same status, except Warsaw, which, apart from being the capital of a voivodeship, is also the country's capital. However, as demonstrated by the data in Table 1, the individual locations differ significantly in their demographic potential. For this reason, it was decided to conduct a grouping based on population. The first grouping included cities with less than 200 000 inhabitants, *i.e.* Gorzów Wielkopolski, Kielce, Olsztyn, Opole, Rzeszów, and Zielona Góra. Group no. 2 consists of cities with a population between 200 000 and 500 000. These are Białystok, Bydgoszcz, Gdańsk, Katowice, Lublin, Toruń, and Szczecin. Finally, the third group includes Poland's most populous cities, *i.e.* Kraków, Łódź, Poznań, Wrocław and, above all, Warsaw.

Table 1. Main information about the cities included in the study

No.	City	Voivodship	Population in thousands (2020)	Annual growth rate of housing prices 2000-2020	Housing stock
1.	Białystok	podlaskie	298	12.88%	134359
2.	Bydgoszcz	kujawsko-pomorskie	347	11.46%	152586
3.	Gdańsk	pomorskie	472	14.29%	236119
4.	Gorzów Wielkopolski	lubuskie	123	11.99%	53588
5.	Katowice	śląskie	292	12.76%	146387
6.	Kielce	świętokrzyskie	194	9.16%	86491
7.	Kraków	małopolskie	781	11.16%	402538
8	Lublin	lubelskie	340	12.52%	157147
9.	Łódź	łódzkie	677	10.88%	360921
10.	Olsztyn	warmińsko-mazurskie	172	10.38%	79461
11.	Opole	opolskie	128	8.69%	54830
12.	Poznań	wielkopolskie	534	11.09%	266686
13.	Rzeszów	podkarpackie	197	11.79%	85592
14.	Szczecin	zachodniopomorskie	401	10.13%	183237
15.	Toruń	kujawsko-pomorskie	201	11.86%	92168
16.	Warszawa	mazowieckie	1 794	9.08%	997054
17.	Wrocław	dolnośląskie	644	11.96%	340384
18.	Zielona Góra	lubuskie	141	10.70%	55922

Source: Statistics Poland (2022).

Figure 2 presents the development of residential property prices, broken down into the above groups. As the subject of quantitative analysis in this article is cyclical changes in the series under study, the data were previously subjected to seasonal adjustment, which was conducted under the assumption of the typical pattern of occurrence of trends, cyclical, and seasonal fluctuations in financial time series (Tsay, 2010). Removing seasonal fluctuations was done using the Census X-13 procedure (Sax & Eddelbuettel, 2018). Given the size of the individual groups, it was considered that they would only be represented by the cities with the lowest and highest levels of observed prices as of the end of 2020.

The presented waveforms indicate the co-existence of an upward trend in the observed prices accompanied by cyclical changes. At the same time, there is a nominal price disparity between individual cities, which is not related to their size measured by their population size. Clear evidence is provided by the average prices per square metre of an apartment in Łódź, Gdańsk, and Rzeszów, *i.e.* representatives of the three groups of cities distinguished earlier. Łódź is a more populous city and closer to the capital than Gdańsk. Still, nevertheless, apartments in Łódź are cheaper than in the capital of the Pomeranian Voivodeship. Although based on smaller nominal differences, a similar conclusion applies to residential property prices in Rzeszów, one of the smallest voivodeship cities.

Analysing the data in Figure 1, it should be noted that, generally, a relationship persists, indicating that more populated cities have higher prices per square metre of residential property. However, the universality of the above conclusion applies only to the price leaders of particular population groups. In particular, it should be noted that in Łódź – belonging to the group of cities with the largest population – the price of a unit area of an apartment is not only lower than in Gdańsk (the most expensive of the cities in group 2) but also for many years has not been equal to the prices from Bydgoszcz, which is the cheapest city in the same group.

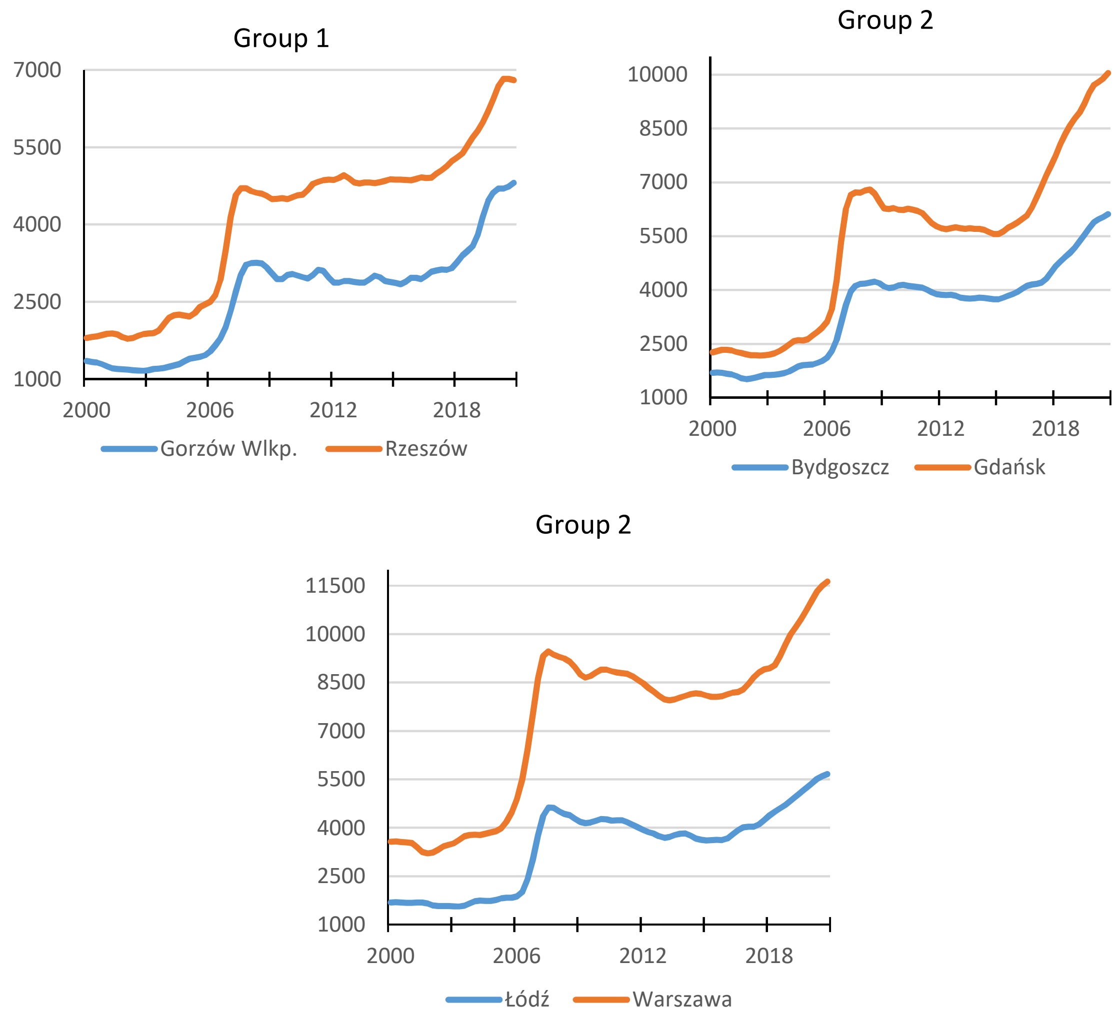

Figure 2. Average prices (in PLN) per square metre of an apartment in selected voivodship cities in Poland between 2000 and 2020

Note: Group 1 – cities with a population below 200 000; Group 2 – cities with a population above 200 000 and below 500 000; Group 3 – cities with a population above 500 000.

Source: own elaboration.

RESULTS AND DISCUSSION

Coinciding Phases of Housing Price Fluctuations

In the further parts of this study, the focus is on examining the cyclical changes occurring in the surveyed residential property price series. As has already been pointed out, it was assumed that there is an upward trend in the structure of the observed quantities, as well as fluctuations of seasonal nature and periods longer than four quarters. Therefore, a seasonal adjustment was made, and the occurrence of a multi-year increase was proved using a graphical analysis (Figure 2).

Concerning cyclical (non-seasonal) changes, the classical approach to analysing business cycle fluctuations can be used, which assumes the examination of the absolute level of a given economic quantity. It is an approach based on the assumption that the business cycle has only two phases: upward and downward. The former lasts from a lower turning point (bottom) to an upper turning point (peak) and the latter in the opposite sequence. Furthermore, this cycle structure allows for relatively stable dating of turning points, which is particularly important when extending the observed time series. Due to the scarcity of statistical data describing the prices of residential real estate on a regional basis in Poland, it is understandable that researchers wishing to explore this market of tangible assets systematically expand their collections of information. Therefore, it is worth basing the first stage of quantitative analyses on the classic cycle definition, as subsequent observations may influence the estimated form of the trend function.

In the property market, it is possible to adopt an analytical algorithm, described in more detail in the work of Harding and Pagan (2002). At the same time, it should be noted that phases and cycles of different lengths are possible in individual economic sectors. For the real estate market – due to investment processes (land acquisition with construction period), which are much more time-consuming than an industrial activity – longer periods should be assumed. Therefore, as suggested by Bracke (2013) and Girouard *et al*. (2005), it can be considered that a phase (the period between two adjacent differential turning points) cannot be shorter than six quarters and that a complete cycle is at least 12 quarters. Supplying the t-indices identifying the above-defined turning points with calendar dates makes it possible to assign individual quarters and years to the distinguished phases. As a result, it is possible to determine whether there was a phase of price expansion or recession in the property market during a given period.

The results of an analysis assuming the above analytical approach and focusing on selected Polish cities were presented by Trojanek (2021). The Warsaw property market is the largest in Poland, because it is the capital city, which means it is also the centre of economic, scientific, cultural, and political life. Therefore, the price turning points in Warsaw should be particularly distinguished. The summary presented in Trojanek's (2021) work suggests that the price expansion of a square metre of an apartment in Warsaw took place between mid-2002 and Q3 2007 and again from Q3 2013 to the end of the analysed period. Noteworthy, the identical movements accompanied the expansion in the value of residential assets in the Polish capital in at least half of the other examined cities. From the end of 2003 to mid-2007 and the first quarter of 2016, one can even notice a complete synchronisation of the phases. The complete congruence of the dating of the decline phase can also be attributed to significant periods. These are the years 2000-2002 (up to Q2) and 2009-2013 (again up to Q2) and two quarters at the end of 2008 and the beginning of 2009. Importantly, the price changes in Warsaw are a leading indicator for some cities.

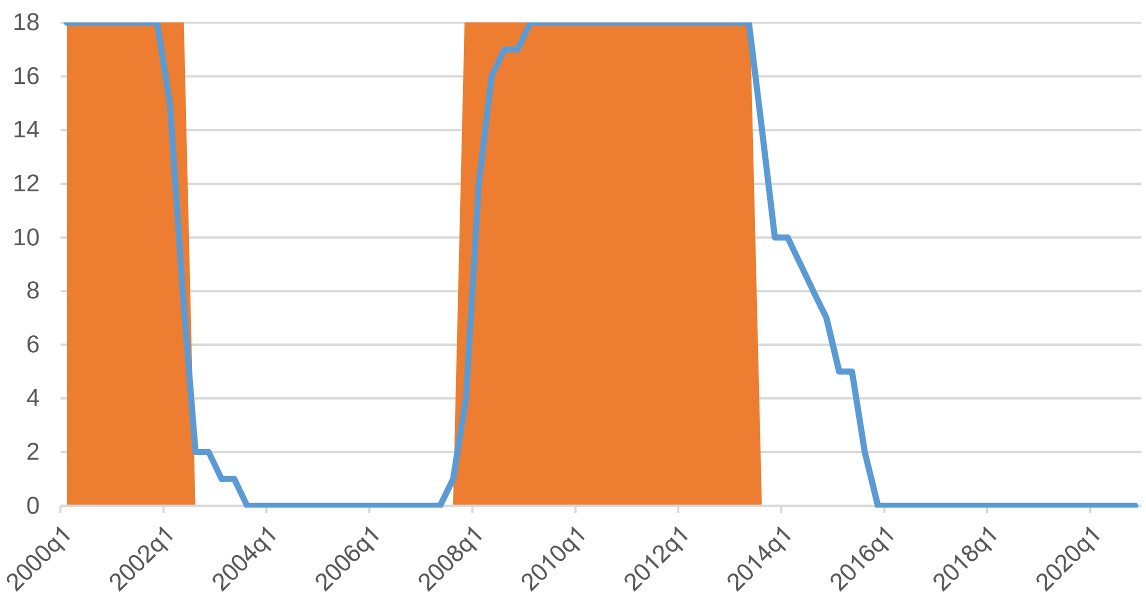

Figure 3. The number of cities with a downward phase in the prices per square metre (in PLN) of an apartment in the years 2000-2020

Note: The shaded area identifies the time range of the price recession in Warsaw.

Source: own elaboration

Residential Property Price Decomposition

Figure 4 presents the obtained cyclical components for selected cities identifying groups distinguished based on population size, see Figure 2. As can be seen, all filtering techniques show far-reaching correspondence during the upward cycle treated as relative deviations from the trend. Moreover, the high ability of econometric filters to identify phases of the classically defined cycle of price changes. An inverse deviation from the isolated development trend can be discerned in each observed price recession. This is not a perfect regularity, but it is understandable given the inevitable shift in the dating of turning points in the classical and growth cycles.

However, differences in the intensity of price changes cannot be overlooked if one identifies them with the cyclical component determined using the filtering technique. For this reason, recourse has been made to the instrumentation used in business cycle surveys since estimating oscillations in relative form makes it possible to calculate the standard deviation of the observed changes. Furthermore, this makes it possible to examine the dispersion of the series around the trend line, which is an expression of the variability of the oscillation. The results obtained are presented in Table 3.

Table 3. Standard deviation (in %) of the cyclical component of the average level of the price per square metre of a dwelling in voivodship cities in Poland from 2000 to 2020

City	Standard deviation (%)			City	Standard deviation (%)		
	BK	CF	HP		BK	CF	HP
Białystok	8.22	6.17	8.27	Olsztyn	8.71	7.28	8.80
Bydgoszcz	8.26	6.55	8.39	Opole	7.50	5.64	7.29
Gdańsk	11.13	8.79	10.81	Poznań	9.90	7.91	9.54
Gorzów Wielkopolski	9.38	7.64	9.15	Rzeszów	8.20	6.80	7.67
Katowice	11.59	9.49	10.87	Szczecin	9.20	7.10	8.99
Kielce	8.24	6.35	7.79	Toruń	8.79	6.90	8.72
Kraków	9.55	7.60	9.91	Warszawa	9.89	8.01	9.43
Lublin	7.79	6.15	7.43	Wrocław	9.87	7.76	9.71
Łódź	11.87	9.50	10.97	Zielona Góra	8.37	6.67	7.78

Note: BK – Baxter–King filter; CF – Christiano–Fitzgerald filter; HP – Hodrick–Prescott filter.
Source: own study.

The results show that using the HP and BK filter results in very similar waveforms of the non-cyclic component, so the relative fluctuations are characterised by comparable dispersion around such a development trend. The use of the CF filter means less smoothing of the stochastic trend, so the cyclical fluctuations are less intense, as some of the harmonic components have been filtered out. The cities with the highest variability of the component responsible for cyclical fluctuations in property prices are Gdańsk, Katowice, and Łódź. The lowest variability of this characteristic is shown by Lublin and Opole.

Spectral Analysis of Cyclical Fluctuations

The following stages of the econometric work consisted of conducting a spectral analysis. However, it must be remembered that a spectral study requires stationary time series. If the variables have a unit root, the spectrum becomes so overwhelmed by low oscillation frequencies that it is almost impossible to isolate the conjunctural components. Therefore, the spectral analysis was preceded by stationarity testing, which used the methods proposed by Dickey and Fuller (1981) and Kwiatkowski, Phillips, Schmidt, and Shin (1992). In the augmented Dickey–Fuller (ADF) test, the null hypothesis assumes the presence of a unit root (non-stationarity).

In contrast, the Kwiatkowski–Phillips–Schmidt–Shin (KPSS) test posits the null hypothesis that the variables analysed are stationary. The significance level was assumed to be 5%, and the test equations included a free expression. The resulting empirical ADF and KPSS statistics are included in Tables 4 and 5.

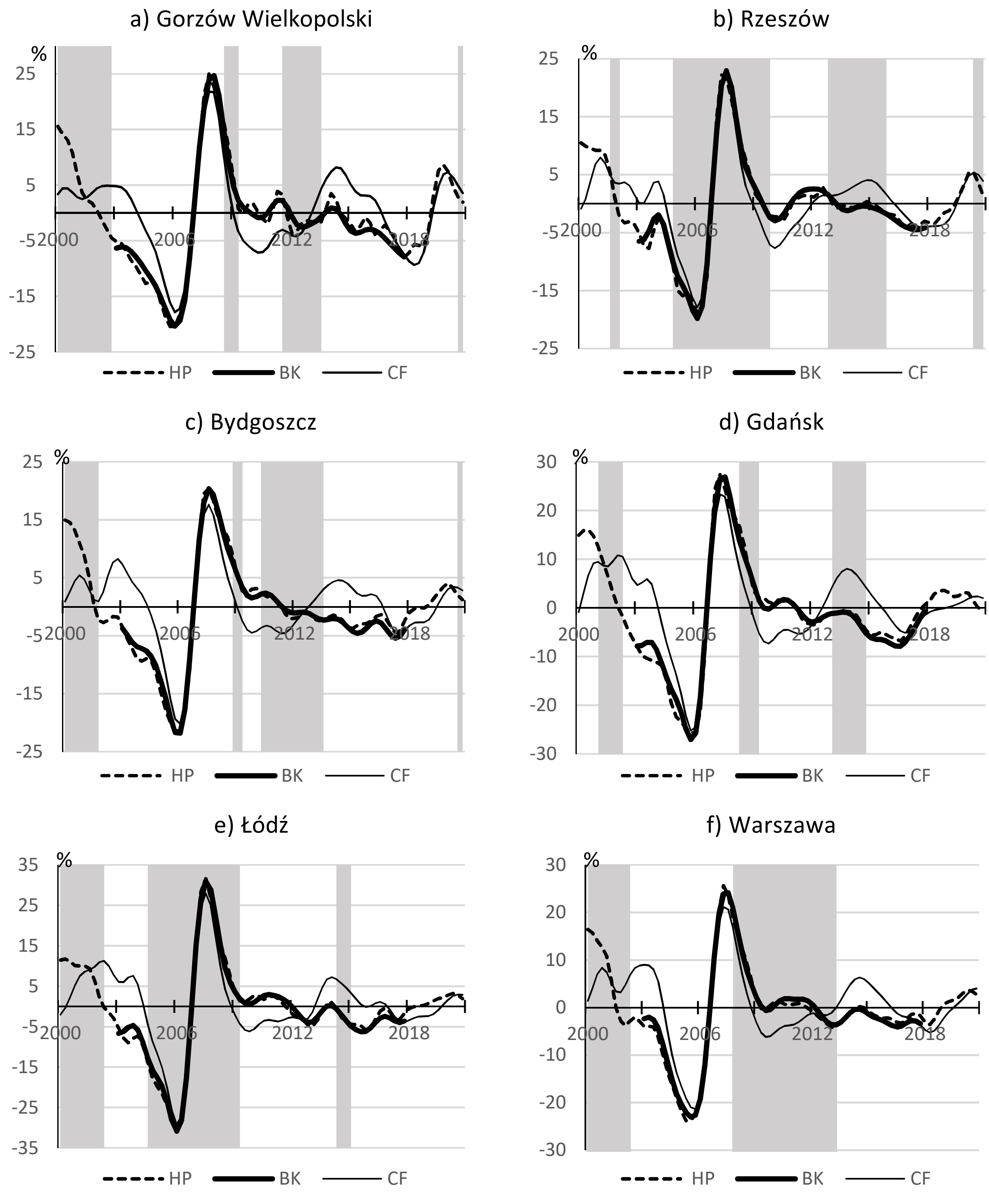

Figure 4. Cyclical component of the average price level of a square metre of an apartment in selected voivodship cities in Poland in the years 2000-2020

Note: BK – Baxter–King filter; CF – Christiano–Fitzgerald filter; HP – Hodrick–Prescott filter.
The shaded area identifies the time range of the price recession in a given city.
Source: own elaboration.

Table 4. ADF test statistics

City	ADF test			City	ADF test		
	BK	CF	HP		BK	CF	HP
Białystok	-3.05	-9.93	-3.56	Olsztyn	-2.53	-9.81	-2.38
Bydgoszcz	-3.16	-9.05	-3.48	Opole	-2.44	-10.17	-2.47
Gdańsk	-3.38	-9.27	-3.33	Poznań	-0.15	-9.39	-4.47
Gorzów Wielkopolski	-2.37	-9.38	-1.82	Rzeszów	-2.68	-9.48	-3.91
Katowice	-3.34	-8.91	-3.72	Szczecin	-2.09	-9.51	-2.19
Kielce	-4.96	-8.80	-3.33	Toruń	-3.53	-9.11	-3.25
Kraków	-3.11	-9.30	-4.13	Warszawa	-2.54	-10.11	-3.49
Lublin	-2.62	-8.60	-3.83	Wrocław	-2.04	-9.21	-3.61
Łódź	-2.72	-9.13	-2.76	Zielona Góra	-3.49	-8.39	-3.18

Note: the critical value of the ADF test statistic was -2.90, with a significance level of 5%. BK – Baxter–King filter; CF – Christiano–Fitzgerald filter; HP – Hodrick–Prescott filter.
Source: own study.

Table 5. KPSS test statistics

City	KPSS test			City	KPSS test		
	BK	CF	HP		BK	CF	HP
Białystok	0.13	0.04	0.06	Olsztyn	0.11	0.06	0.06
Bydgoszcz	0.13	0.04	0.07	Opole	0.14	0.04	0.07
Gdańsk	0.11	0.04	0.06	Poznań	0.09	0.04	0.06
Gorzów Wielkopolski	0.11	0.05	0.07	Rzeszów	0.11	0.05	0.05
Katowice	0.10	0.04	0.06	Szczecin	0.12	0.05	0.07
Kielce	0.15	0.06	0.06	Toruń	0.13	0.04	0.06
Kraków	0.11	0.05	0.06	Warszawa	0.11	0.04	0.06
Lublin	0.13	0.04	0.06	Wrocław	0.13	0.04	0.07
Łódź	0.11	0.04	0.06	Zielona Góra	0.10	0.04	0.05

Note: the critical value of the ADF test statistic was -2.90, with a significance level of 5%. BK – Baxter–King filter; CF – Christiano–Fitzgerald filter; HP – Hodrick–Prescott filter.
Source: own study.

Because all the empirical values of the ADF test for the fluctuations obtained with the CF filter were smaller than the critical one, the hypothesis of non-stationarity of the analysed series had to be rejected. Such a conclusion cannot be drawn concerning the fluctuations obtained from the HP filter, especially the BK filter. In the latter case, it is related to the truncated time series. As Caner and Kilian (2001) demonstrated, the ADF test's power decreases for samples with limited observations. Such an effect is not observed when using the KPSS test. None of the empirical values of the KPSS test exceeded the critical one. Therefore, there were no grounds to reject the null hypothesis of stationarity of the cyclical components of the variables under study. This meant that proceeding to the power spectral analysis was possible without fear of very low frequencies dominating the spectrum.

The graphical representation of the harmonic structure is the periodogram. In the present work, it was smoothed with a five-element Parzen spectral window. Due to the voluminous nature of the underlying statistical material, the basic information elements are presented in Tables 6a-b and are limited to the three components with the highest spectral density values.[1]

Considering the fluctuation spectra of prices per square metre of apartments sold on the secondary market, one notices that harmonics with a periodicity equal to 28 quarters prevail in them. Therefore, on average, in the analysed series (consisting of 84 observations), at least two complete cycles should occur, consisting of two complete phases. The information in Figure 3 and the significant concordance of price oscillations shown earlier support this conclusion. However, Figure 3 shows that the concordance

[1] In the case of the BK filter, the size is reduced, so the periodicity of the harmonic factors (calculated as T/2) is different to that of the CF and HP filters. For this reason, the periodogram for the BK filter is omitted.

of returns was not complete. The reason for these differences was the slightly different distribution of the harmonics dominating the housing price spectra in the different cities, as highlighted in Table 6.

Table 6. The most important harmonic components of cyclical fluctuations of the average price level of a square metre of an apartment in voivodship cities in Poland in the years 2000-2020

CF filter							
City	**Fluctuation period (quarters)**			**City**	**Fluctuation period (quarters)**		
Białystok	28.00	16.80	6.46	Olsztyn	28.00	16.80	12.00
Bydgoszcz	28.00	16.80	12.00	Opole	28.00	16.80	10.50
Gdańsk	21.00	14.00	8.40	Poznań	28.00	16.80	7.00
Gorzów Wielkopolski	28.00	16.80	12.00	Rzeszów	28.00	16.80	8.40
Katowice	28.00	16.80	12.00	Szczecin	28.00	16.80	n.a.
Kielce	28.00	16.80	8.40	Toruń	28.00	16.80	12.00
Kraków	28.00	16.80	7.63	Warszawa	28.00	16.80	7.00
Lublin	28.00	16.80	12.00	Wrocław	28.00	16.80	7.63
Łódź	28.00	12.00	8.40	Zielona Góra	28.00	12.00	7.63
HP filter							
City	**Fluctuation period (quarters)**			**City**	**Fluctuation period (quarters)**		
Białystok	28.00	16.80	9.33	Olsztyn	28.00	16.80	9.33
Bydgoszcz	28.00	16.80	6.00	Opole	28.00	14.00	7.63
Gdańsk	21.00	14.00	7.00	Poznań	28.00	16.80	9.33
Gorzów Wielkopolski	28.00	16.80	12.00	Rzeszów	28.00	16.80	8.40
Katowice	28.00	12.00	9.33	Szczecin	28.00	16.80	9.33
Kielce	28.00	16.80	8.40	Toruń	28.00	16.80	12.00
Kraków	28.00	14.00	6.46	Warszawa	28.00	16.80	9.33
Lublin	28.00	16.80	12.00	Wrocław	28.00	16.80	6.46
Łódź	28.00	14.00	9.33	Zielona Góra	28.00	12.00	9.33

Note: The critical value of the KPSS test statistic was 0.46, with a significance level of 5%. BK – Baxter–King filter; CF – Christiano–Fitzgerald filter; HP – Hodrick–Prescott filter.
Source: own study.

In the study of the reciprocal spectrum, the values of coherence coefficients were estimated, which are the equivalents of correlation coefficients, but concerning the harmonic space for which the arguments of the function under study are the periodicities of fluctuations (expressed in quarters). As already indicated, it was decided that the reference system in each case would be Warsaw, which results from the fact that it is the leading real estate market in Poland and the centre of political and economic activity. Still bearing in mind the division of the 18 analysed cities into three groups distinguished based on population (Figure 1), they were again illustrated with the help of a representative in which, at the end of 2020, the prices of apartments were the lowest or the highest, respectively. In this case, Warsaw was replaced by Wrocław in the last group, as a relational study of price fluctuations in the same city is pointless. The graphical representation of the selected characteristics of the reciprocal spectrum is presented in Figure 5. The abscissa axis is described by the periodicity of the highlighted fluctuations, each time described in quarters. The right axis of ordinates identifies the angle given in phase months and, as relation (7) states, it is shown in months.

The obtained estimates[2] indicated a very high coherence of harmonics with long and medium periods of oscillations determined for Warsaw and a given repeater of the group distinguished based on population. The degree of coherence decreases only with fluctuations of an average period equal to eight quarters. Looking at the values of the phase shift, especially where there is a high degree of

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[2] In this case, only the results obtained for the series smoothed with the CF filter are presented due to the limited possibility of presenting all results. Nevertheless, the main conclusions in terms of co-spectrum remained valid also against the other frequency filtering techniques.

coherence, it is small, as it never exceeds one quarter. Therefore, this is further evidence of the high synchronisation of price fluctuations in local housing markets in Poland.

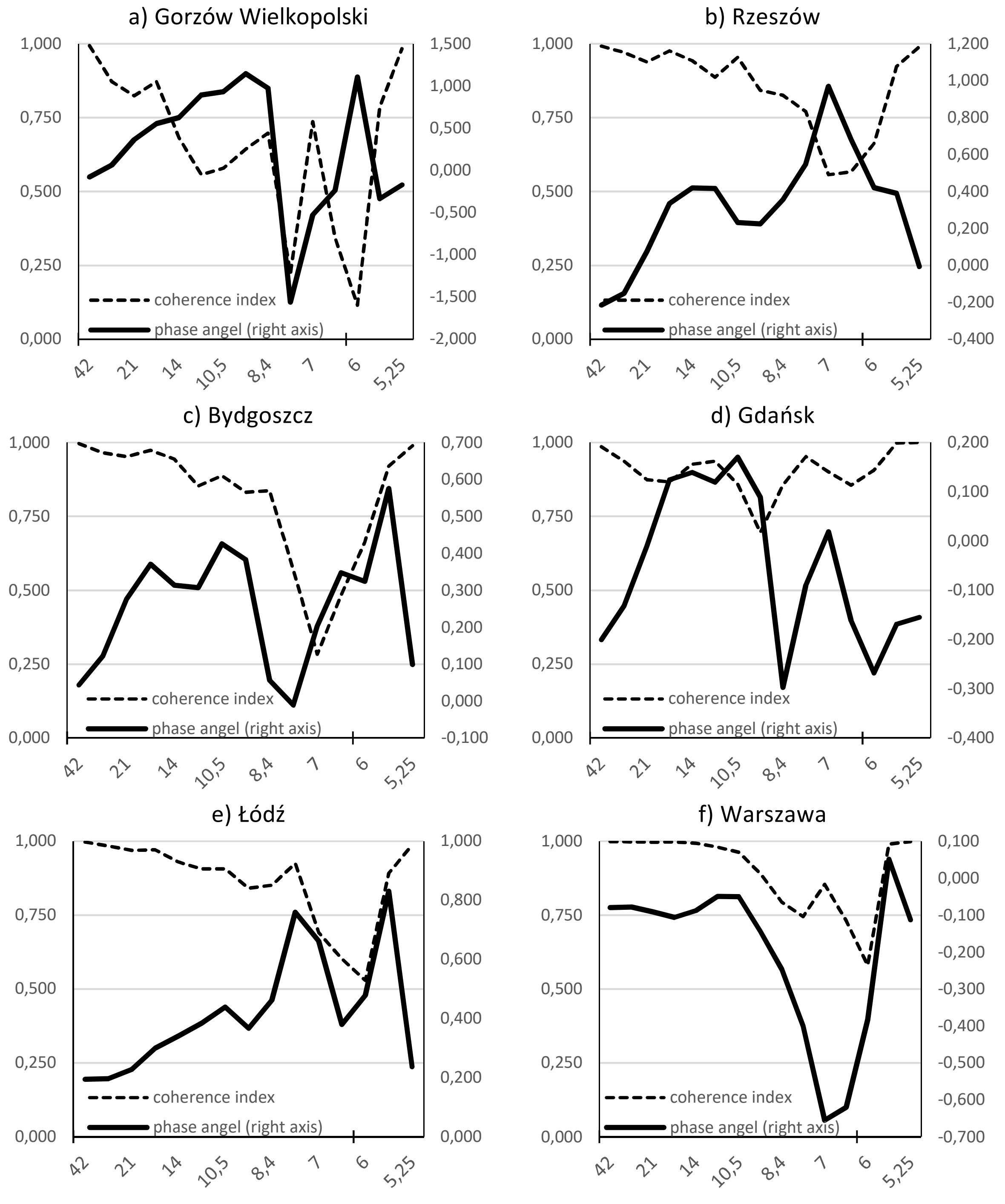

Figure 5. Selected characteristics of the spectrum of mutual cyclical fluctuations of the average price level of a square metre of an apartment in selected voivodship cities in Poland in the years 2000-2020

Source: own elaboration.

CONCLUSIONS

This study contributes to the ongoing economic discourse on housing market synchronization by addressing a notable gap in knowledge pertaining to regional housing markets in emerging economies. While considerable evidence exists for the US and EU, limited research has been conducted within the

Central and Eastern European (CEE) context. Therefore, this study bridges this knowledge gap and sheds light on housing market synchronization in Poland.

We traced the housing market's cyclical behaviour in 18 provincial capital cities in Poland from 2000 to 2020. The article provides empirical evidence of the high synchronisation of house cycles in regional housing markets in Poland. Moreover, econometric investigation demonstrates spatial differences in the cyclical behaviour of house prices when considering the cycle magnitude. The findings suggest that the housing cycle magnitude was the highest in Gdańsk, Katowice, and Łódź and the lowest in Lublin and Opole.

The information about housing cycles has important policy implications. Housing wealth effects generated by cyclical house prices may be more persistent than financial wealth effects (Sousa, 2010). Consequently, they may substantially affect consumption dynamics. Therefore, precisely identifying market cycles and differences in cycle synchronisation is vital when constructing an effective, selective, and well-timed monetary policy (Huang, 2020).

The study has some limitations. The spectral analysis is sensitive to data quality issues and time series length. Additionally, while spectral analysis can identify correlations and patterns in market synchronization, it does not provide direct causal relationships. We have not covered the house price dynamics during the Covid-19 pandemic and after the Russian aggression in Ukraine (Trojanek *et al.*, 2021; Trojanek & Gluszak, 2022). Both exogenous events have likely caused disturbances significantly affecting housing market synchronisation. It remains an interesting area for further research. Future studies could also include smaller cities, where synchronization patterns likely differ from those exhibited in major cities in Poland.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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