



House Price Bubble Detection in Ukraine

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1. Introduction

The real estate market can be a major source of systemic risk and thus any imbalances can be a threat to the financial stability of a country. The most widely known evidence of real estate markets being a source of systemic risk is the Global Financial Crisis (GFC), a distinctive feature of which were price bubbles that appeared on numerous real estate markets all over the world. Excessive and uncontrolled house price growth was left without proper attention because of widespread misperception that housing was an asset class the price of which would grow forever. That perception made housing the most attractive investment, which in turn fueled demand even further and led to an amplification of the bubble. Another driver of the bubble build-up was affordable and easily accessible lending, thus creating for financial institutions exposure to future crisis consequences. The bursting of the bubble had negative consequences not only for property owners (such as resulting in having negative equity), but for the complete global financial system. Banks that were holding assets, collateralized by overpriced housing, had their balance sheets and solvency at risk because of asset price corrections, thus erasing a great part of bank equity. That was detrimental to solvency of financial institutions and led to widespread financial instability. Worsening positions of banks and even failures, in turn, resulted in impaired credit supply that had profound implications for the real economy and households across the globe (Aoki and Nikolov, 2012).

There are many other examples of massive overvaluation of house prices that was followed by a large downfall and in some cases by a prolonged financial and/or economic crises (Glaeser, 2013). One of them is the case of Japan’s real estate market, which experienced a massive surge in asset prices from the latter half of the 1980s to the early 1990s. Aggressive bank behavior, protracted monetary easing, taxation and regulations on land that led to higher land prices, a weak mechanism to impose discipline on economic agents and self-confidence are among the factors behind the bubble (Okina *et al.*, 2001).

An investigation of the causes of the GFC suggests that widespread moral hazard and prudential requirements that were not sufficient to deal with systemic externalities also induced the imbalances on financial markets (Nier and Merrouche, 2010). In Europe, one of the largest house price accelerations in the early-to-mid 2000s was experienced in the Baltic States. The bubble was determined by both supply and demand factors. The demand factors were primarily related to lending: favorable standards, absence of caps on macroprudential ratios, such as loan-to-value ratios, and low mortgage interest rates. The demand for housing was also fueled by low taxation, partial deductibility of mortgage interest payments, nominal convergence, and underdeveloped rental markets (Bukeviciute and Kosicki, 2013).

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Considering the lessons learnt from episodes of housing bubbles, the real estate market is now under much closer surveillance by central banks and other financial regulators globally. For instance, it is now common practice for central banks in many countries to regularly publish a financial stability report with a separate chapter dedicated to the analysis of systemic risks stemming from the real estate market. In addition, it became obvious that to interpret house price movements, one needs to think of house price fundamentals as factors that form and thus explain the behavior of asset prices. The most important indicator of stability of the real estate market is the level of house prices and the extent to which they are valued fairly. The overvaluation of housing, not supported by the growth of disposable income of households, can lead to lower affordability of housing and a higher debt burden of the population and thus is a threat to financial stability. In turn, high household indebtedness puts the economy at risk of big asset price movements and can cause more disruptive consequences in case of any crisis events via the collateral channel (Hviid and Kuchler, 2017).

To be classified as a bubble, asset price growth must have certain features. The signs of the bubble become obvious when the price movement is greater than can be substantiated by the dynamics of rents or other fundamental factors. The prices then show substantial momentum at high frequencies, while they revert to mean at lower frequencies (Glaeser and Nathanson, 2014). Asset price bubbles, overall, can be interpreted as the periods during which asset prices run well above the intrinsic value. Thus, to detect a bubble, it is essential to identify the intrinsic value of housing (Fama, 1965). In this paper, we build a framework for the assessment of the intrinsic value of house prices for Ukraine, as well as for the identification of thresholds, the breach of which would signal a bubble.

The National Bank of Ukraine is responsible for maintaining price and financial stability in the country with the goal of contributing to Ukraine's sustainable economic development. One of the biggest crises that the Ukrainian economy has gone through was the GFC, which started from the worldwide imbalances in the housing market, connected to the excessive risk-taking in a favorable macroeconomic environment. Thus, to maintain financial stability, it is necessary to monitor the risks stemming from the real estate market.

The research question was developed before Russia's full-scale war on Ukraine, at the time of an active initial recovery of mortgage lending in Ukraine. This determined the relevance and urgency of a tool for measuring the overvaluation and identification of bubbles on the residential real estate market, which can occur during the boom of mortgage lending. The full-scale war in Ukraine updated the relevance and motivation of this research. Currently, the Ukrainian real estate market is in a state of disequilibrium and experiences a huge structural break: price dynamics are chaotic and not driven by fundamentals, but rather by the irrational expectations of sellers, housing's distance from the frontline, and high uncertainty. The framework that is proposed in this research is expected to be of great importance for the after-war reconstruction and development of Ukraine. Indeed, it is expected that mortgages (as well as affordable housing loans, issued under the state-financed programs¹) will be the primary tool for financing the purchase, reconstruction, or renovation of housing for Ukrainian people, including those who lost their homes due to the military actions

¹ With a goal to help Ukrainian citizens to obtain (reobtain) housing, the Government of Ukraine launched in October 2022 the Affordable Mortgage program, initiated by President Volodymyr Zelenskyy, available at: <https://www.me.gov.ua/Documents/Detail?lang=en-GB&id=579381a5-f682-426b-a435-f02142327298&title=AffordableMortgage-GovernmentAssistanceInPurchasingHousing>.

of Russia. We expect mortgage lending to recover at a quick rate after the war; thus, a tool that can monitor house prices and the extent to which they are fairly valued must be in place.

Beyond its usefulness to Ukraine in the aftermath of the current war, this research contributes to the literature by showing how a framework for determining fundamental house prices and house price bubbles can be implemented for countries with emerging, small, and open economies, due to adjustments for high inflation and significant dependence on reserve currencies that are considered. This has important implications for mitigating the risks that originate from imbalances on housing markets. Our results suggest that the only pronounced and prolonged period of a house price bubble is the one that coincides in time with the GFC. The bubble signals produced by the methods that we use are, on average, simultaneous and in accordance with economic sense.

The remainder of the paper is organized as follows. Next, we provide a short review of the literature. We then provide an overview of the real estate market in Ukraine. The next section describes our data. The following two sections discuss our methods and results, respectively. The final section concludes.

2. Literature review

The intrinsic level of house prices can be measured on the basis of a wide variety of methods. Among the most popular are simple ratios that typically compare house prices to fundamental factors of house price growth, usually either rents or income. Among the most widely used ratios are price-to-income, price-to-rent, as well as imputed-to-actual-rent and imputed rent-to-income ratios. This method of identifying misvaluations of house prices is described in detail by Case and Shiller (2003) and Himmelberg *et al.* (2005). Bourassa *et al.* (2019) consider a large set of methods for measuring house price bubbles, based on housing data for six cities in Europe and the U.S. They find that the best method for identifying house price bubbles both ex-ante and ex-post is the price-to-rent ratio.

Another approach used to determine the fundamental level of house prices is regression analysis, which includes univariate and multivariate models of different sorts, which are based on supply and demand variables. Focusing on the Euro area, Annett (2005) introduces a framework for assessing the fundamental level of house prices using a panel regression model for eight countries. The author uses real disposable income per capita, real long-term interest rate, and real credit as determinants of fundamental house prices. Skaarup and Bødker (2010) estimate a demand-supply housing model to investigate housing price trends for Denmark. Their analysis suggests that house price growth is supported by fundamental factors, such as real disposable income and financial wealth, as well as real mortgage rates. The importance of demand factors is also highlighted for the Czech Republic by Hlaváček and Komárek (2011). Anundsen *et al.* (2016) investigate the role of house price dynamics and credit activity on the probability of crises. They find that measures of bubble-like behavior in both credit and housing markets are significant and are strongly correlated with each other. Additionally, when rising house prices coincide with high lending activity, it markedly amplifies the probability of a financial crisis. Maynou *et al.* (2021) analyze the data for twelve European countries and find that the main determinants of real house price dynamics were mainly fiscal factors and unemployment. Finally, Emenogu *et al.* (2021) focus on detecting periods of extrapolative expectations in house prices across Canadian cities. The research features a non-linear heterogeneous agent model (Bolt *et al.*, 2019) for the housing market in which agents

switch between different types of house price expectations. The authors estimate the levels of house prices using typical demand-side fundamentals, such as disposable income per capita, population, and the real effective mortgage rate. They conclude that the model of the fundamental level of house prices lacked supply-side variables, the better modeling of which remained an important avenue for future research provided that the necessary data are available.

Yet a different method for detecting house price bubbles is a regression approach that employs unit root tests (Taipalus, 2006; Phillips *et al.*, 2011; Yiu *et al.*, 2013; Asal, 2019; Hagemann and Wohlmann, 2019). The unit root method is built on the time series properties of house prices. Thus, under this method it is not possible to get an indication of the magnitude of a property price bubble. According to the evidence found by Engsted *et al.* (2016), another drawback of the unit root approach is that it can detect a bubble while it emerges, but it is not able to find any disequilibria beyond the highest point of the bubble. Finally, this approach is excessively sensitive to any deviations from the equilibrium level (Taipalus, 2006; Yiu *et al.*, 2013). Thus, the unit root approach is considered not suitable for this research.

Another method that has been used in prior research is the exponential growth rate, which implies that a faster than exponential rate of growth in house prices is unsustainable and thus becomes evidence of a bubble (Zhou and Sornette, 2006). However, this method is unappealing from a theoretical perspective since it does not relate house prices to fundamental factors and might produce incorrect bubble signals (Bourassa *et al.*, 2019). Finally, a present value approach suggests that the value of housing should correspond to the present value of all future earnings that it will generate, which is essentially the rental income stream (Campbell and Shiller, 1988). An application of the method to the housing market in the U.K. is provided by Black *et al.* (2006), and Klotz *et al.* (2016) use this approach to examine residential property dynamics in four European countries. While this approach is considered suitable for detecting any deviations from the fundamental house price levels, it is out of the scope of this research due to its complexity relative to other approaches.

Analysis of the advantages and disadvantages of the various methods that have been used in prior research led us to perform this research based on two methods: simple ratios of house prices to their fundamentals and multivariate regression analyses based on supply and demand variables. These methods were chosen because of their efficiency in detecting house price bubbles, as proven by the literature, and simplicity of calculations and thus, understanding, given the fact that the results will be presented to the public within the regular communications of the National Bank of Ukraine.

3. The Ukrainian real estate market

Since 2000, Ukraine has gone through four major crises: the GFC; the social-economic crisis of 2014-15 that was deepened by the aggression in the Eastern part of Ukraine and the annexation of Crimea by the Russian Federation; the coronavirus crisis of 2020, and the current crisis that was triggered by Russia's full-scale war on Ukraine. The first three crises² appear clearly in Figure 1, which highlights real GDP growth during the period.

² The fourth crisis is not covered by the observation period of this research.

[Insert Figure 1 here]

During the last decade, the level of inflation in Ukraine was high, reaching 31.1% in mid-2008 and 60.9% in April of 2015 (Figure 2)³. Considering the previous periods of high inflation and the fact that they undoubtedly affect house prices, this research is conducted with quantitative data entirely in real terms, as we aim to isolate and identify the imbalances specific to the real estate market. Another macroeconomic indicator that is of extreme importance for the analysis of the housing market is the exchange rate of the Ukrainian hryvnia (UAH) to the U.S. dollar (USD) (also see Figure 2). Almost all house prices, quoted in the advertisements by real estate agencies, are denominated in USD, with an exchange rate of hryvnia to the U.S. dollar being a key reference point for both sellers and buyers. Thus, large shifts in exchange rates have a substantial effect on the house price dynamics.

[Insert Figure 2 here]

Currently, mortgage lending has no significant effect on the real estate market, since the volume of loans for house purchases is unnaturally small. The mortgage-to-GDP ratio only amounted to 0.55% as of the end of Q3 2021 (National Bank of Ukraine, 2021). This ratio reached its maximum level in 2009, when the mortgage lending was more vigorous in months preceding the economic crisis (Figure 3). During the 2009-2020 period, the mortgage market was almost inactive. Mortgage lending started to recover slowly in mid-2020, primarily due to lower interest rates and the launch of a state-financed affordable mortgage program, which was offering substantially lower interest rates for borrowers, with subsequent compensation for lenders. Most housing purchases are financed from households' savings. As of the end of 2020, only 5% of transactions were paid with the help of mortgages (National Bank of Ukraine, 2020). Buyers also actively use free installments offered by developers to purchase newly built properties on the primary real estate market.

[Insert Figure 3 here]

The homeownership rate in Ukraine is extremely high in international comparison. As of 1 January 2018, 95% of households were living in their own housing, 1% in state-owned units and 4% were renting (State Statistics Service of Ukraine, 2018). Individuals own most of the housing that is commissioned. Households also own the housing stock that forms the supply on the rental market. Composed of mostly person-to-person transactions, the rental market is mostly unregulated; rental agreements are rarely registered officially or notarized. Therefore, the rental market is very elastic because the transactions are usually very frequent.

The housing (mostly apartments) that is owned by developers and has not yet been sold to individuals (the transactions in which real estate developers sell housing to individuals) is the primary real estate market. Buyers can purchase apartments from the developers at different stages of the construction process; often that means buying a property that is not yet built. The risks of construction delays and even of purchasing an apartment that will never be finished due to, among other things, bankruptcy of the developer are borne by the buyer. That makes investing in real estate on the primary market a risky business, which led to almost inexistent mortgage lending on the primary real estate market. Only around 10% of new mortgages in 2021 were issued for the purchase of newly built housing (National Bank of Ukraine, 2021).

³ The numbers are from the corresponding month of the previous year (i.e., year-on-year).

The housing that is owned by individuals and is offered to another individual (individual-to-individual transactions) is considered the secondary real estate market. Prices on the secondary market are usually higher because housing for this segment of the market is usually fully equipped and has all the necessary refurbishments. Buyers can start living there immediately, without additional investments and any risks that the purchased unit will be unfinished.

4. Data

We gathered a long list of variables that have been used for the estimation of the fundamental level of house prices in the literature (Table 1). We use data for six Ukrainian cities: Kyiv, Lviv, Odesa, Kharkiv, Dnipro and Donetsk. For each city, we have house price data (dependent variable) and data for the demand-side fundamentals (independent variables). The data on the supply-side fundamentals, lending and macroeconomic factors are collected only at the country level.

[Insert Table 1 here]

House prices are measured for each city for the period 2003-2021 at a monthly frequency. We perform separate calculations for the primary and secondary real estate markets only for Kyiv, since for the other five cities only data on prices on the secondary market are available for a sufficiently long period. According to the type of urban development in the largest Ukrainian cities, transactions are mainly for units in high-rise multi-dwelling residences. The data on the average price of dwellings for each city in each month are from real estate agencies, which aggregate advertisements from housing developers and individuals. Ideally, some control for the quality of units should be undertaken (Duca *et al.*, 2021), but the data that would be needed for that purpose are currently not available. However, there is no reason to believe that this affects the results in any significant manner.

Given the peculiarities of the Ukrainian economy, when preparing the dependent variable, we need to account for inflation and changes in the UAH/USD exchange rate. The important role of the exchange rate in the Ukrainian residential real estate market is attributed to the fact that for much of the period the most popular stores of value for households were dollar cash savings and real estate. This happened after the large outflow of retail deposits due to the loss of trust in domestic banks after the crisis of 2014 (discussed above). According to the National Bank of Ukraine (2016), between 2014 and Q1 2016, the net outflow of deposits amounted to UAH 68 billion (hryvnia deposits) and to USD 14.9 billion (FX deposits), representing 27% and 64% of the total as of the beginning of 2014, respectively. Additionally, three large waves of hryvnia devaluation in 2009, 2014 and 2015 undermined the trust of households in the national currency as a mean of storing value. Thus, the lack of trust in domestic banks and the national currency shifted the investment patterns of households and were the reason why the real estate market became mostly USD-denominated: people were saving money to buy real estate while others were getting the proceeds from selling properties in US dollars.

While it is relatively easy to deal with inflation by considering real house prices, it is more difficult to account for the effect of foreign exchange rate dynamics. We adjust house prices and rental rates for the change in the exchange rate by subtracting from the year-on-year change of house prices and rental rates a portion of the change in the foreign exchange rate. Although house prices are believed to be closely linked to the exchange

1 rate dynamics, when the movements of the rates become too substantial, there will emerge other factors related
2 to housing demand that will partially offset these movements. Therefore, to account for the effects of exchange
3 rate dynamics on house prices, we must choose the proper percentage of adjustment between 0% and 100%.
4
5 For that purpose, we consider the following. First, the exchange rate adjustment should smooth out any price
6 jumps due to the hryvnia depreciation during and after large crisis episodes in Ukraine (2008 and 2014-2016).
7
8 Second, it should not affect the growth pattern of house prices to such an extent as to affect the effects of
9 fundamentals on house prices. According to Figure 4, Panel A, a 20% exchange rate adjustment is too small
10 to smooth the spikes from the hryvnia depreciation in 2008 and 2014-2016. The house price surges are still
11 present, and this appreciation is clearly not coming from any fundamentals or events on the real estate market.
12
13 On the other hand, a 60% exchange rate adjustment (Panel C) is too large, since it makes house price dynamics
14 inverse and cancels out some of the growth driven by fundamental factors or events on the market. Thus, the
15 optimal exchange rate adjustment for the purpose of our research is 40% (Panel B).
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22 [Insert Figure 4 here]

23
24 Figure 5 depicts the nominal, exchange rate adjusted and real house price indexes for Kyiv for both types of
25 markets, while Figure 6 contains the real house price indexes for other cities. The real exchange rate adjusted
26 house prices unveil the true bubble episodes that were taking place due to imbalances on the real estate market
27 or economy in general, not due to inflation or the hryvnia depreciation. House prices were rapidly growing
28 from late 2003 until mid-2007. The growth phase was followed by a subsequent correction: the decrease in
29 house prices was almost threefold in the regional cities, while for Kyiv the price halved. That resulted in real
30 house prices being close to the level of early 2003 for all cities in the scope of this research, except Kyiv. In
31 subsequent periods, house prices recovered slightly. Except for the turbulent period from mid-2014 to mid-
32 2015, due to a series of massive hryvnia depreciation and the social-economic crisis of 2014-15, real house
33 prices were relatively stable and never showed any signs of a possible bubble formation. The data on house
34 prices in Donetsk after the start of the war in the eastern part of Ukraine in 2014 is of limited reliability, since
35 the city was occupied until the end of the observation period, but the data are still published by real estate
36 agencies.
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44 [Insert Figures 5 and 6 here]

45
46 The independent variables are divided into four groups: supply-side, demand-side, lending, and
47 macroeconomic factors. Supply-side fundamentals are associated with the housing stock and construction
48 process. We select the data on the area of commissioned dwellings in Ukraine and Kyiv and the construction
49 cost index for Ukraine as supply factors. The list of demand-side variables is longer, since it can include every
50 variable that explains households' living conditions. We consider the rental rate of housing, the average
51 monthly income of a person, disposable income as a share of the aggregate income of the population, the
52 capital investment of households for buying or building housing, the unemployment rate, and the population
53 number as potential demand-side independent variables.
54
55 Lending conditions essentially contribute to house price dynamics as a demand factor since they describe the
56 easiness of access to funding for house purchases by households. We isolate the variables that describe lending
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conditions and activity in a separate group as such variables do not explain the intrinsic value of housing, but the bubble build-up itself (Bourassa *et al.*, 2019). Interest rates are mean reverting and thus an irrelevant variable for explaining long-run house price dynamics. In the results section, we briefly discuss the model that includes lending conditions variables among the independent factors. Macroeconomic factors are represented in this research by the current account balance to GDP.

The available literature and economic intuition suggest that to generate the intrinsic level of house prices, one needs to build a model that is underspecified, thus one must select a short list of variables that are truly fundamental. The process of determining a short list of variables is essentially one of model specification selection. Thus, we performed several iterations (described in more details in Appendix A) to construct a model, checking their summary metrics and building a fitted value. The aim was to check whether the model coefficients and fitted values conform to economic sense. Our basic principles for model selection were:

- statistical significance of coefficients for the independent variables;
- higher R^2 and adjusted R^2 , logically correct (or interpretable) signs of the coefficients for the independent variables;
- no significant correlation (over 0.8) between variables to avoid multicollinearity.

Due to high seasonality, disposable real aggregate income (only the average monthly income of a person as a component of it) and the unemployment rate were seasonally adjusted with the help of the R-interface of X-13-ARIMA-SEATS, the seasonal adjustment software by the U.S. Census Bureau. Table 2 lists the variables that were retained.

[Insert Table 2 here]

Aggregate household income is a key factor that affects house prices, since higher income allows for buying more real estate, as well as borrowing more money for this purchase (Geng, 2018). We construct an income variable that most fully explains the possibility of households buying an apartment or taking out a loan for it. For this purpose, we merge the monthly real average salary, population number and disposable income as a share of aggregate income of the population into one indicator⁴:

$$\text{Disposable real aggregated income}_{t,i} = \text{Average salary per month}_{t,i} * \text{Number of population}_{t,i} * \text{share of disposable income in aggregate income}_{t,i}, \quad (1)$$

where indices “ t,i ” stand for the given point of time and a particular city: Kyiv, Lviv, Odesa, Kharkiv, Dnipro, or Donetsk (all are oblast⁵ central cities). The State Statistics Service of Ukraine publishes the data on the average salary per month only at the oblast level, except for Kyiv. However, to examine if oblast-level data are a good proxy for city-level data, we compared salaries (quarterly averages for 2017-2020) for the oblasts and cities. According to the results of this analysis, the prices in the cities are on average 2% higher than at the

⁴ We are aware that when multiplying the average monthly salary per worker by the population number, we are overestimating the measure of aggregate income, since there is a share of the population that is outside the working age range or is unemployed. However, this should not lead to a systematic bias.

⁵ In Ukraine, the oblast is the first-level administrative division of the country. The territory of Ukraine is divided into 24 oblasts, each of which has administrative centers that are usually the largest and most developed cities of the oblast.

level of the oblast. For Dnipropetrovsk oblast (the central city is Dnipro), the average salary is even 3% higher in the oblast than in the city. Thus, we conclude that the oblast-level salary is a good proxy for city-level data. Apart from two episodes of crises (2008-2009 and 2014-2015), the aggregate disposable income of households was growing even in real terms (Figure 7). The most rapid growth took place during the last half of the period. The only short episode of income reduction occurred in early 2020, due to the Coronavirus pandemic. Still, the growth recovered fast and continued up to the end of 2021.

[Insert Figure 7 here]

The rate of unemployment is available at the city-level only for Kyiv, while for other regions it is published only at the level of the oblast. Unemployment is related to both the current ability of households to buy housing and the level of economic activity. Given that our measure of real aggregate disposable income refers to data on the average salary and a count of the whole population, it does not have a high correlation with the rate of unemployment, thus we do not face the problem of multicollinearity. Figure 8 shows that there were two massive jumps in the level of unemployment – both coincide in time with the biggest crises. It is worth mentioning that the most massive increase in the level of unemployment occurred in the Donetsk oblast after 2014. This dynamic is explained by the military aggression of the Russian Federation and the start of the war on the East of Ukraine, with the part of Donetsk oblast being occupied from mid-2014 to the end of the observation period.

[Insert Figure 8 here]

Another variable of interest is the ratio of current account balance to GDP, which has been shown to have a strong negative correlation with house prices in a large set of countries. According to Bernanke (2005), the explanation for this relationship resides in the “global saving glut” hypothesis. More recent papers (Ferrero, 2015) argue that a progressive relaxation of lending conditions can produce a strong negative correlation between house prices and the current account balance. This point of view makes this variable suitable for the detection of price bubbles, which are often accompanied by the easing of borrowing constraints. In this research, this variable also enriches the model with the macrofinancial perspective.

For the calculation of price-to-rent ratios, we need data on rents in addition to those on house prices. Average rental rates are also collected from real estate agencies. Rental rates for apartments in Kyiv were relatively stable during the period of observation with a short spike in 2015, due to hryvnia depreciation (Figure 9). This spike was corrected with the help of the exchange rate adjustment. The adjustment factor for rental rates is 20%, while it was 40% for house prices. The difference in the adjustment factor is supported by the fact that the rates on the rental market of Kyiv are usually expressed in hryvnia, with only a small share of high-class residences denominated in USD. Furthermore, for an individual, the proceeds from selling an apartment are usually perceived as savings or capital investment, while those from renting more often as operational day-to-day use or short-goal savings. Thus, the proceeds from selling should be more heavily denominated in the currency that has a higher ability to store value.

[Insert Figure 9 here]

5. Method

As mentioned, we rely upon two methods: simple ratios of house prices to their fundamental values and regression analyses based on supply and demand variables.

5.1. Calculation of ratios

The most widely used ratios due to their simplicity of calculation and ease of understanding are the price-to-income and price-to-rent ratios. They provide a measure of relative over- or undervaluation of housing by relating house prices to their fundamentals – income and rents. Price-to-income and price-to-rent ratios have been found to be useful in identifying bubble and non-bubble periods (Bourassa *et al.*, 2019). In this research, the price-to-income ratio is the square meter price of an apartment, multiplied by the standardized area of an apartment (70 square meters) and divided by the average annual after-tax wage earned by the household⁶. The price-to-rent ratio is the purchase price per square meter of an apartment, divided by the annual rental per square meter.

$$\text{Price to Income Ratio}_{t,i} = \frac{\text{Price per sq.m}_{t,i} * \text{standardized area of an apartment}}{\text{Average annual wage earned by the household after tax}_{t,i}} \quad (2)$$

$$\text{Price to Rent Ratio}_{t,i} = \frac{\text{Purchase price of an apartment per sq.m}_{t,i}}{\text{Annual rental per square meter}_{t,i}} \quad (3)$$

where indices “ t,i ” stand for the given point of time and a particular city: Kyiv, Lviv, Odesa, Kharkiv, Dnipro or Donetsk.

Based on the research by Dreger and Kholodilin (2011), if the price-to-income or price-to-rent ratio exceeds one standard deviation of the long-term average of the time series, the probability of a house price bubble exceeds 50%. Bourassa *et al.* (2019) refer to a bubble when the ratio is more than 20% above its long-term average. In addition, according to Czerniak and Kawalec (2020), the relationship between house prices and rental rates over a long-term period is almost constant, apart from periods during which there is a structural break on the market. Thus, we estimate the long-term average of the price-to-income and price-to-rent ratios and compare the current values to the long-term average plus one standard deviation of the ratio values over the observation period.

5.2. Regression analysis

The regression analyses are performed with ordinary least squares (OLS) models for each city:

$$y_{t,i} = \beta_0 + \beta_1 X_{t,i,1} + \beta_2 X_{t,i,2} + \beta_3 X_{t,i,3} + \dots + \beta_p X_{t,i,p} + \varepsilon_{t,i}, \quad (4)$$

where $y_{t,i}$ is a dependent variable in time “ t ” and city “ i ” and $X_{t,i,p}$ are the determinants of house price dynamics of p parameters in time “ t ” and city “ i ”.

After establishing the baseline model, we estimate the fitted values, which are then interpreted as fundamental house prices. Then, we compare these fitted values of fundamental house prices with the actual values of house

⁶ The after-tax wage earned by the household is calculated based on the number of working individuals in the household, according to the State Statistics Service of Ukraine (SSSU).

prices for the same periods. We then formulate a threshold, the breach of which identifies the presence of a bubble. A threshold of one to two standard deviations outside the time series (depending on the asset class and the historical volatility of prices) can be considered a proper one for bubble detection (Fleckenstein and Sheehan, 2008; Gao and Martin, 2021). In this paper, we use a threshold of one standard deviation outside the time series. We compare the results of the ratio and regression analyses to assess whether the methods yield similar results.

Next, to reaffirm the results of the regression analysis based on multivariate models for each city separately, we apply a within regression model with one-way (individual) effects on panel data. The equation is:

$$\tilde{Y}_i = \alpha + \tilde{X}_{i,p}\beta_{fe} + \tilde{u}_i \tag{5}$$

where $\tilde{Y}_i$ is a dependent variable in city “ i ” and $\tilde{X}_{i,p}$ are the determinants of house price dynamics of p parameters in city “ i ”. The intercept α is the same for all cities.

6. Results

6.1. Ratio analysis

We begin with the analysis of the price-to-rent ratios for Kyiv. This ratio is assessed for the capital only since data on rental data for apartments is unavailable for other cities of Ukraine. Figure 10 suggests that there was a period of a house price bubble towards the end of the GFC, namely in late 2009 – early 2010. In addition, there were residual signs of housing mispricing throughout 2011. There were also some imbalances on the real estate market during the crisis of 2014-2015, which were mainly explained by a sharp depreciation of the hryvnia.

[Insert Figure 10 here]

According to Czerniak and Kawalec (2020), over a long-term horizon, the relationship between house prices and rental rates is relatively constant, unless there is a structural break on the market. Thus, assuming no structural change, any large deviations in this ratio are a signal of house prices diverging from fundamental values. This is the case with the real estate market of Kyiv, since the ratio was relatively stable within the investigated period with a coefficient of variation of only 9.85%. That also means that during the last decade house prices were priced relatively fairly.

In contrast to the house price or rental rates data series, there is no need to do the exchange rate adjustment for income, since salaries in Ukraine are predominantly denominated in hryvnias, except for the IT-industry (and some rare occasions in other sectors). However, unlike other inputs used for the ratio analysis, income demonstrates high seasonality. To obtain the average annual after-tax household wage, we multiply the average after-tax monthly deseasoned income of a person in a given city by the number of working people per household (at the national level) and by 12 (number of months in a year).

A house price bubble on the real estate market of Kyiv is again detected for the period of the GFC, from early 2006 to late 2008 (Figure 11). In addition, and in alignment to the results for the price-to-rent ratio, some signs of disequilibrium were also present during a short period in early 2010. The spike in the ratio in early 2015

and 2016 is primarily explained by the sharp hryvnia depreciation. As the real estate market is closely linked to exchange rate dynamics, it needed some time to adapt to this large change in macroeconomic conditions. Since 2016, the price-to-income ratio has been declining, leading to greater affordability of housing for households in Kyiv. Although bubble signals are concomitant, the price-to-income ratio is more volatile than the price-to-rent ratio.

[Insert Figure 11 here]

Income, despite being one of the key drivers of house prices, is not the single explanatory variable. Its contribution to house price growth can change depending on other macroeconomic conditions, such as mortgage lending, unemployment, etc. The absence of or an unnaturally low level of mortgage lending weakens the transmission mechanism from income to house prices. For instance, before mid-2021, real estate developers could not pass their increased construction costs to consumers, since the demand was weak (this being primarily explained by almost absent mortgage lending). Thus, developers were forced to operate with low margins (National Bank of Ukraine, 2021). Therefore, despite rising household income, real estate prices remained stable. This is explored further in the regression analyses.

For the regional cities of Ukraine, the bubble episodes are more prominent. The price-to-income ratios for Donetsk, Dnipro, Lviv, Odesa and Kharkiv were extremely high during the period 2005-2008, clearly suggesting a bubble (Figure 12). The level of the ratio was much higher than the average over the observation period, increased by one standard deviation, thus this period can be identified as a bubble. The ratio analysis allows us to conclude that in the six cities of Ukraine under scrutiny there was only one period of house price bubble, which coincided in time with the GFC.

[Insert Figure 12 here]

To investigate whether the price-to-income ratio approach can be improved to make it more suitable for the detection of future house price bubbles, moreover when the history of house prices is limited, we formulated a two-step approach. Such an approach may be useful as part of the toolkit of a central bank. The first step consists of detecting periods of bubbles that occurred previously, as just described. This allows us to identify two types of periods: periods of bubble inflation and bursting and periods during which neither pronounced nor prolonged bubbles were detected. The second step is to use as threshold a long-term average calculated only over periods for which no bubble was detected. The rationale for this is that periods of bubbles are phases of abnormal behavior of house prices, which should be excluded of the long-term average if we want to detect house price bubbles in the periods to come. Since there is only one period of bubble on residential real estate markets in Ukraine, we select the trough (lowest point in the house price series – September 2009) in the real estate cycle as the starting point for the calculation of the long-term average.

Using this approach, we still do not observe any periods of large price overvaluation for the Ukrainian cities from late 2009 to the end of 2021 (Figure 13). This is because, except for some spikes in 2014-2016 caused by large hryvnia devaluations, the price-to-income ratio was generally trending down, indicating higher housing affordability.

[Insert Figure 13 here]

6.2. Regression analysis

The regression analysis for each city (for Kyiv for primary and secondary markets individually) is implemented using Equation (4). While calculations for the ratio approach were performed on a monthly basis, regression analyses are undertaken with quarterly data. This is because the unemployment rate, which is considered essential data for this research, is only available since 2013 on a monthly basis. Given that the variables used for the regression analysis are nearly always non-stationary and exhibit a trend, we perform cointegration tests for our individual models. The tests are based on checking whether the model residuals are stationary (i.e., whether the model variables are cointegrated) by means of Augmented Dickey-Fuller Test Unit Root tests, the results of which are presented in Table 3. The residuals of the models are stationary at the 5% significance level.

[Insert Table 3 here]

In general, the models have high explanatory power and economically meaningful coefficients (Table 4) and accordingly should provide for a proper assessment of fundamental house prices and hence of bubbles. Additional tests suggest that we have problems of heteroscedasticity and autocorrelated error terms; however, we wanted to retain the model since it is derived from both literature and practice and has a solid theoretical background. The other reason is that heteroscedasticity and autocorrelated error terms mainly affect the standard errors and thus do not interfere with the primary objective of our research, which is the fitting of fundamental values for house prices. However, we calculate the heteroscedasticity and autocorrelation (HAC) robust standard errors, which correct the falsely small standard errors estimated in the previous step. The results are provided in Table 5.

[Insert Tables 4 and 5 here]

The results of individual regressions for the primary and secondary markets of Kyiv suggest that aggregate disposable income and unemployment are more important for the latter market type than for the former. This is intuitive as transactions on the secondary market occur between individuals and, thus, the prices are more affected by the changes in household welfare than is the case on the primary market. The coefficients for the unemployment rate and the ratio of current account balance to GDP have the correct sign and are highly significant for all cities. Regression results further indicate that the coefficient signs for aggregate disposable income is counter-intuitive for Odesa and Kharkiv⁷. House prices were relatively stable despite rising incomes, given the almost absent mortgage lending due to both high mortgage interest rates and low mortgage supply from banks because of low levels of creditor rights protection. The growth in income had a limited impact on housing affordability given that households were unable to move up the property ladder by borrowing. This is consistent with the statement that the sensitivity of house prices to its drivers largely depends on the structural

⁷ The counter-intuitive negative signs disappear when the models are estimated in growth rates rather than levels or when either house prices or income is expressed in nominal rather than real terms. Such specifications, however, are not suited for bubble analysis.

characteristics of each economy (Bank for International Settlements, 2020), with the mortgage market and its peculiarities being one of the most important elements of the structure.

The strongest explanatory power is recorded for Dnipro, Odesa, and Donetsk cities. As mentioned above, for the purpose of this research we can allow slightly underspecified models, since we want the model to explain any fundamental behavior only and not any bubble component⁸. The fitted values from the regressions constitute the fundamental house prices, which are then increased by one standard deviation to determine the bubble threshold. For almost all cities, the bubble on the housing market is detected only for the GFC period (Figure 14). Afterwards, there are no signs of massive price overvaluations.

[Insert Figure 14 here]

To reinforce the results of the individual regressions, we also perform our analysis based on panel data as presented in Equation (5). According to the results of the within regression model with one-way (individual) effects on panel data, population, unemployment, and the ratio of current account balance to GDP appear with the right sign and are significant (Table 6). Using the fitted values produced by the panel data model produces similar bubble periods to those that were identified previously in this section, i.e., a bubble is identified only during the GFC (Figure 15). However, the within regression model with one-way (individual) effects on panel data produced the fitted values of another shape, which may be due to the model accounting for the steep change in the macroeconomic conditions before and during the socio-economic crisis of the mid-2010s in Ukraine, which sharply influenced both the rate of unemployment and current account balance.

[Insert Table 6 here]

[Insert Figure 15 here]

Given that the variables (in levels) used for the estimation of fundamental house prices (income and population) are non-stationary, it must be checked whether the residuals produced by the model are stationary. We conduct two different types of unit root tests on the residuals of the panel-data model. According to Croissant and Millo (2008), the Levin-Lin-Chu unit root test is a first-generation panel unit root test as it assumes no cross-sectional correlation; it is based on the estimation of Augmented Dickey-Fuller (ADF) regressions for each time series. The second is the Pesaran cross-sectionally augmented version of the Im-Pesaran-Shin panel unit root test which is a so-called second-generation panel unit root test. Both tests suggest stationarity of the residuals of the panel-data model. The results are presented in Table 7.

[Insert Table 7 here]

Due to the reasons mentioned previously, we also provide (Table 8) the heteroscedasticity and autocorrelation (HAC) robust standard errors for the model on panel data.

[Insert Table 8 here]

⁸ To check if the addition of mortgage lending variables makes our model fully specified, we tested the models with a *New mortgages issued during the quarter to GDP* variable. This variable has a very high correlation with the dependent variable, has positive and significant coefficients and provides high R^2 for the models. The R^2 for the models with *New mortgages issued during the quarter to GDP* variable is in the range from 82.1% to 91.7%.

1 The various methods used (price-to-income ratios, individual regressions, and panel regressions) indicate that
2 since 2003 the largest Ukrainian cities experienced only one true house price bubble that occurred during the
3 GFC (Figure 16). The panel regressions detect a bubble concurrently with the price-to-income approach. The
4 individual regressions were the last to capture the overvaluation. Some signs of a bubble were detected by the
5 panel approach in the 2010s, when house prices bounced back after the bubble burst, while the fundamentals
6 were still low after the crisis. Since it lasted only for one quarter and only prevailed for two cities, Kyiv and
7 Kharkiv, there are no grounds to call this episode a bubble.

11 [Insert Figure 16 here]

14 To shed additional light on the degree of synchronicity of bubble signals, Table 9 compares the signals
15 produced by both regression methods with the results of the price-to-income ratio analysis, since the latter
16 produces, in our view, the results that are most consistent with economic intuition. The percentage of quarters
17 in which bubble signals were simultaneous with the ones that were produced by ratio analysis was slightly
18 higher for the panel regressions. In sum, all three methods provide reasonable and concurrent results that
19 collectively form a reliable framework for detecting price bubbles on residential real estate markets in Ukraine.

24 [Insert Table 9 here]

28 **7. Conclusions**

31 This paper presents a framework for the assessment of the fundamental values of house prices and
32 identification of bubbles on residential real estate markets in Ukraine. Two general approaches are used, i.e.,
33 ratio calculations and regression analysis, with two variants for each method. We additionally consider the
34 opportunity of considering a bubble threshold for the ratio analysis that would only consider non-bubble
35 periods rather than an average calculated over the entire observation period. The results across methods are
36 consistent and indicate that the period of the GFC was the only time during which a bubble occurred on housing
37 markets in Ukraine.

42 The Ukrainian economy and real estate market have several peculiarities, such as episodes of high inflation,
43 high dollarization of the housing market, and an inactive mortgage market. Thus, although this research draws
44 upon many comparable studies, we had to make several corrections to incorporate those features. For instance,
45 since in Ukraine there is a pronounced division into primary and secondary real estate markets, we applied the
46 framework to the two types of markets for the city of Kyiv. Another characteristic of the market is that
47 transactions are often denominated in U.S. dollars rather than in local currency. The paper thus contributes to
48 a better understanding of how the general framework for assessing house price bubbles can be adapted to better
49 suit the needs of central banks in emerging economies.

56 The almost non-existent mortgage market does not constitute a permanent feature of the Ukrainian economy;
57 on the contrary, before the start of the war in February 2022, we had been expecting the market to reach
58 normality in the course of time. Our expectations had been driven by the weak but steady recovery of mortgage
59 lending from mid-2020 to January 2022 and the results of banking surveys (National Bank of Ukraine, 2021)
60 that were asserting that the market would be several times more active in the years to come. Thus, we had been

1 expecting that with the gradual recovery of the mortgage market, household income would more clearly
2 emerge as a driver of house prices. Hence, looking forward, we expect this framework to become increasingly
3 valuable with the recovery of the mortgage market which is likely to occur once the war is over.
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Table 1. Comprehensive list of variables that can be used for estimation of the fundamental level of house prices

Dependent variable	Independent variables			
House prices (for each city)	Supply-side fundamentals (at the aggregate level)	Demand-side fundamentals (for each city)	Lending factors (at the aggregate level)	Macroeconomic factors (at the aggregate level)
Nominal house prices on primary and secondary real estate market (REM), UAH per sq.m.	Commissioned dwellings in Ukraine, sq.m.	Rental rate of housing, UAH per sq.m.	Mortgage portfolio (credit stock) in local currency, as of the end of period, UAH	Current Account Balance to GDP, %
Real house prices on primary and secondary REM, UAH per sq.m.	Construction costs index for Ukraine, points	Exchange rate corrected rental rate of housing, UAH per sq.m.	Mortgage portfolio in foreign currency, UAH	
Exchange rate corrected nominal house prices on primary and secondary REM, UAH per sq.m.		Average monthly income of a person/per household, UAH	Exchange rate adjusted mortgage portfolio, all currencies, UAH	
Exchange rate corrected real house prices on primary and secondary REM, UAH per sq.m.		Capital investment of households for buying or building housing, UAH	Interest rate on UAH mortgage, weighted average on the flow of credit, %	
		Unemployment rate, %	New mortgage lending (flow of credit) in all currencies, over a period, UAH	
		Population number, persons	NBU policy rate, %	
		Share of disposable income in aggregate income of the population, %	Google trend rate of “credit” search	

Table 2. Short list of variables that can be used for estimation of the fundamental level of house prices

Dependent variable	Independent variables
House prices (for each city)	Demand-side fundamentals (for each city)
Exchange rate corrected real house prices on primary and secondary real estate markets, UAH per sq.m. <i>Monthly, from Jan 2003</i> <i>Source: real estate agencies, NBU.</i>	Exchange rate corrected real rental rate of housing, UAH per sq.m. (For Price-to-Rent Ratio only) <i>Monthly, from Dec 2009</i> <i>Sources: real estate agencies, NBU.</i>
	Disposable real aggregate income (synthetic variable), UAH <i>Monthly, from Jan 2003</i> <i>Sources: State Statistics Service of Ukraine, NBU.</i>
	Unemployment rate (according to the methodology of the International Labor Organization), % <i>Monthly, from Jan 2013</i> <i>Quarterly, from Q1 2003</i> <i>Source: State Statistics Service of Ukraine.</i>
	Current Account Balance to GDP, % <i>Quarterly, from Q1 2003</i> <i>Source: NBU</i>

Table 3. Results of the Augmented Dickey-Fuller Test Unit Root Test on the model residuals

Value of test-statistic	Donetsk	Dnipro	Lviv	Odesa	Kharkiv	Kyiv, primary market	Kyiv, secondary market
	-3.1505	-2.6937	-2.7341	-3.9195	-2.6912	-3.1489	-3.0447
Critical values for test statistics							
1%	-2.60						
5%	-1.95						
10%	-1.61						

Table 5. Heteroscedasticity and autocorrelation-consistent robust standard errors and coefficients’ significance for individual models

Robust model summary statistics	Kyiv primary	Kyiv secondary	Donetsk	Dnipro	Lviv	Odesa	Kharkiv
Intercept	1.3586/***	1.2609/***	1.4794/***	18.5863	254.9743/*	1.1649/***	2.8080/***
Independent variable 1	0.1981	0.1791	0.3119	1.3323	19.0998/*	0.1154/*	0.2558/***
Independent variable 2	0.1725/**	0.1571/***	0.3125/*	0.2016/***	1.4396	0.3535/**	0.5800
Current account balance to GDP	0.8755/**	0.9437/*	0.9611	0.3712/***	0.9751	0.6242/***	0.7256/***

*, ** and *** denote significance at the 10%, 5% and 1% level, respectively.

Table 6. Results of the within model with one-way (individual) effect on panel data

Oneway (individual) effect Within Model				
Call:				
plm(formula = log(rer) ~ log(dunemp) + log(pop) + ca, data = panel, effect = "individual", model = "within", index = c("city", "Date"))				
Balanced Panel: n = 7, T = 76, N = 532				
Residuals:				
Min.	1st Qu.	Median	3rd Qu.	Max.
-0.558813	-0.148977	-0.021568	0.123385	0.689944
Overall intercept for within model and its accompanying standard error				
Intercept:	-20.53682	Std. Error	5.490619	
Coefficients:				
	Estimate	Std. Error	t-value	Pr(> t)
Log(dunemp)	-0.663479	0.044967	-14.7547	<2.2e-16
Log(pop)	2.132748	0.389558	5.4748	6.815e-08
CA	-1.506141	0.202199	-7.4488	3.926e-13
Total Sum of Squares: 44.755				
Residual Sum of Squares: 28.127				
R-Squared: 0.37153				
Adj. R-Squared: 0.3607				
F-statistic: 102.864 on 3 and 522 DF, p-value: < 2.22e-16				

Table 7. Results of Im-Pesaran-Shin and Levin-Lin-Chu unit-root tests for the residuals of the panel data regression

	Levin-Lin-Chu Unit-Root Test	Im-Pesaran-Shin Unit-Root Test
p-value (Alternative hypothesis: stationarity)	< 2.2e-16	0.02248

Table 8. Heteroscedasticity and autocorrelation-consistent robust standard errors and coefficients' significance for model on panel data

	Estimate	Std. Error	t value	Pr(> t)
Log(dunemp)	-0.66348	0.10182	-6.5161	1.702e-10
Log(pop)	2.13275	0.84539	2.5228	0.01194
CA	-1.50614	0.27421	-5.4927	6.194e-08

Table 9. Comparison of bubble signals across different approaches

	Type of regression analysis compared to ratio analysis	Donetsk	Dnipro	Lviv	Odesa	Kharkiv	Kyiv primary REM	Kyiv sec-ry REM
Number of quarters in which bubble signals were different	Individual regressions	7	5	4	4	4	7	4
	Pooled OLS panel data regression	3	2	2	3	4	8	7
% of quarters in which bubble signals were different	Individual regressions	9%	7%	5%	5%	5%	9%	5%
	Pooled OLS panel data regression	4%	3%	3%	4%	5%	11%	9%

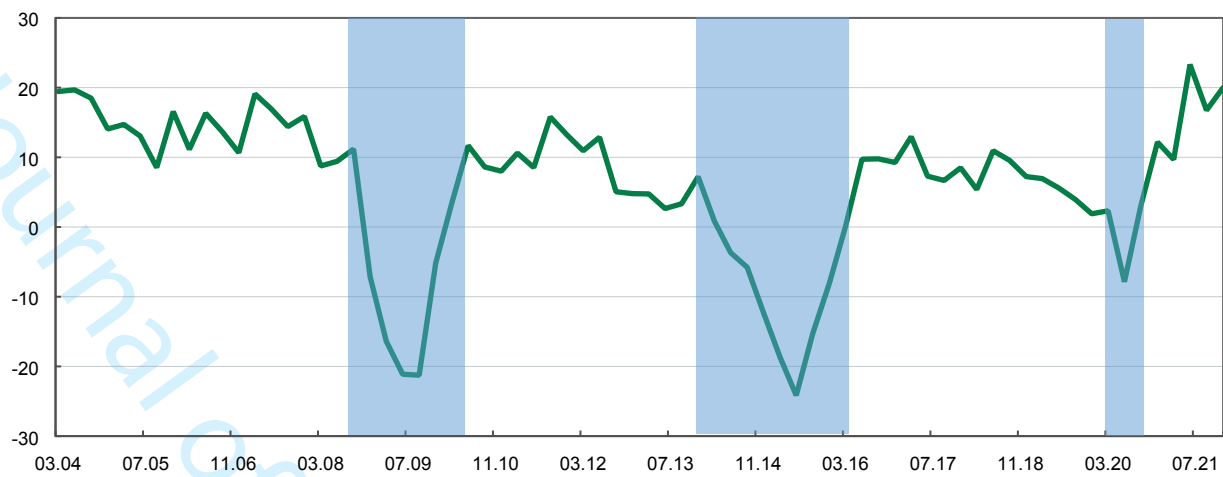


Figure 1. Real GDP growth, % y-o-y

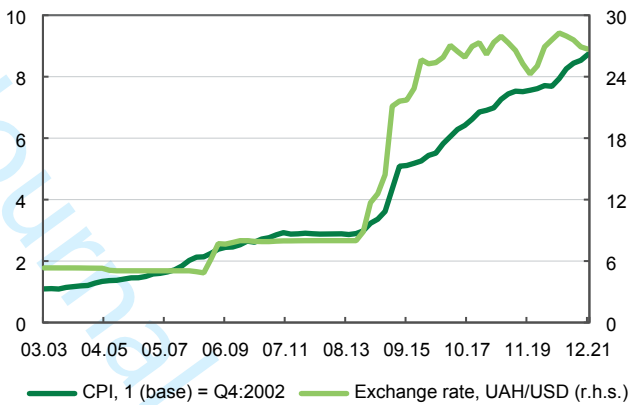


Figure 2. Consumer price index and exchange rate

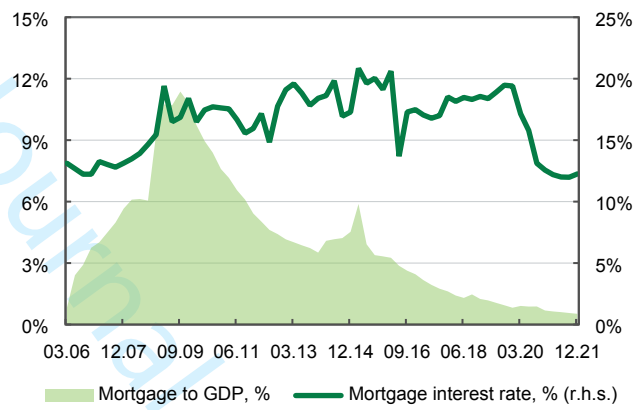
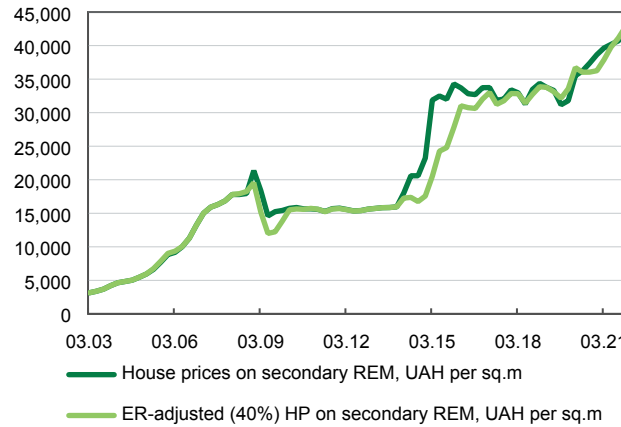
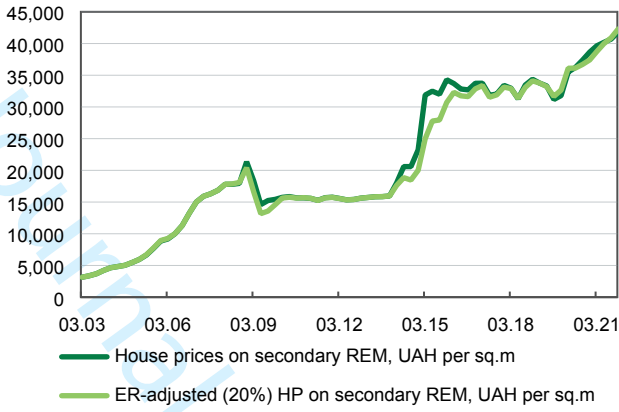
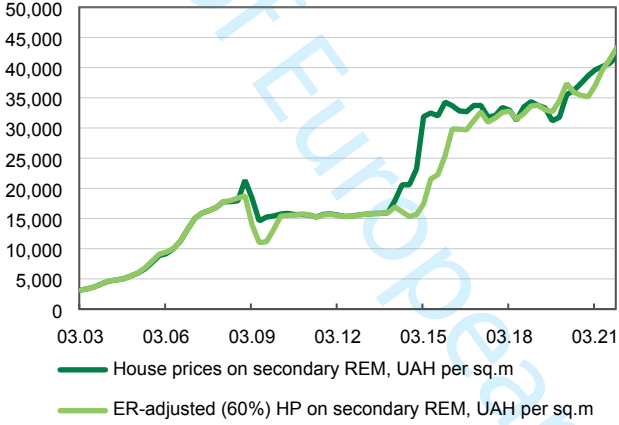


Figure 3. Mortgage to GDP and UAH interest rates



Panel A

Panel B



Panel C

Figure 4, Panels A-C. Actual house prices and alternative ER adjustments

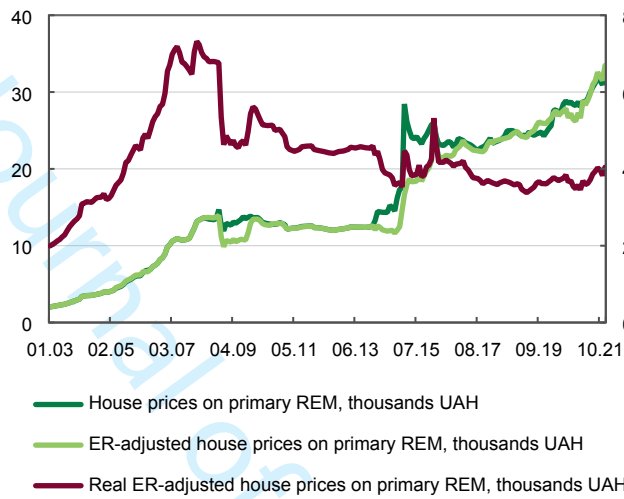


Figure 5, Panel A. House price metrics for the primary real estate market of Kyiv (monthly data)

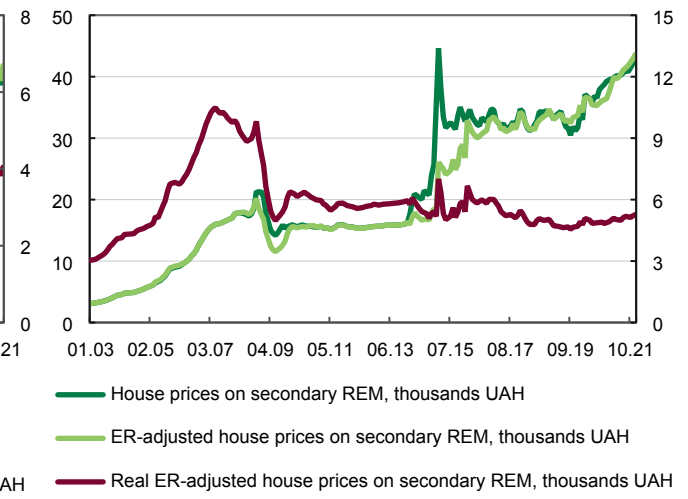


Figure 5, Panel B. House price metrics for the secondary real estate market of Kyiv (monthly data)

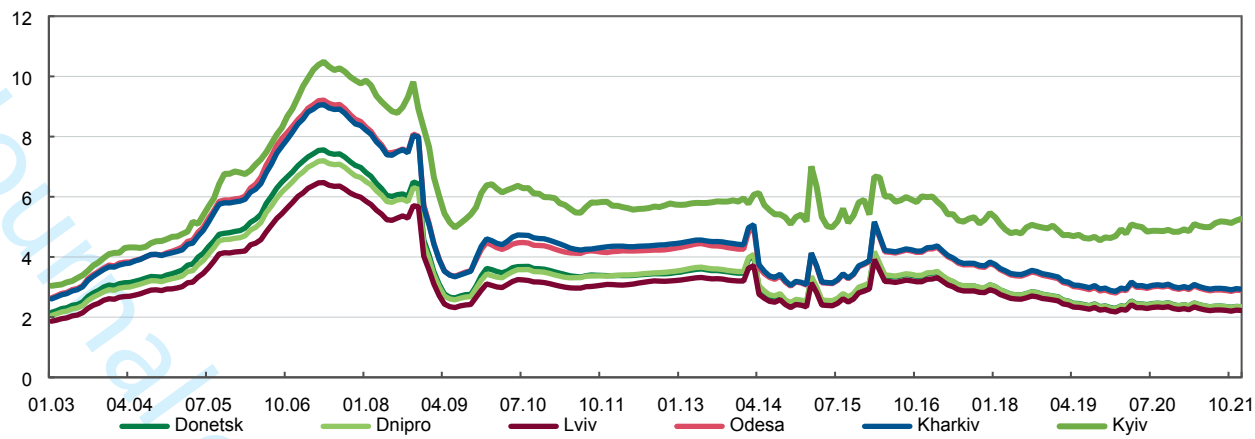


Figure 6. Real exchange rate adjusted house prices on the secondary real estate markets of Ukrainian cities (monthly data), thousand UAH per sq. m

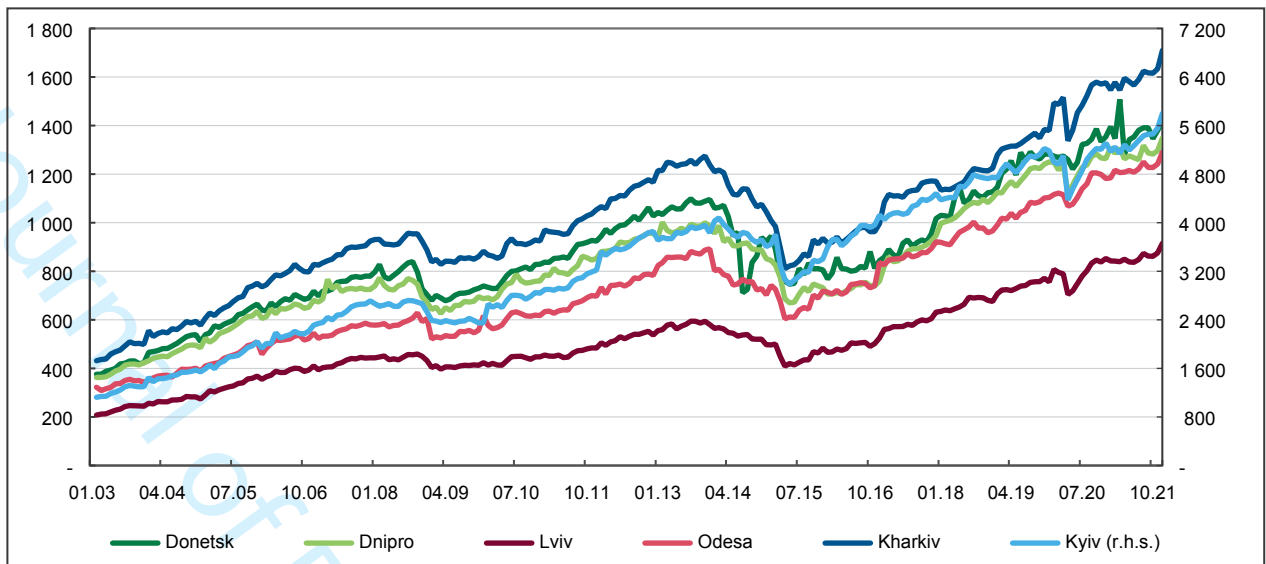


Figure 7. Real aggregate disposable income in Ukrainian cities, million UAH

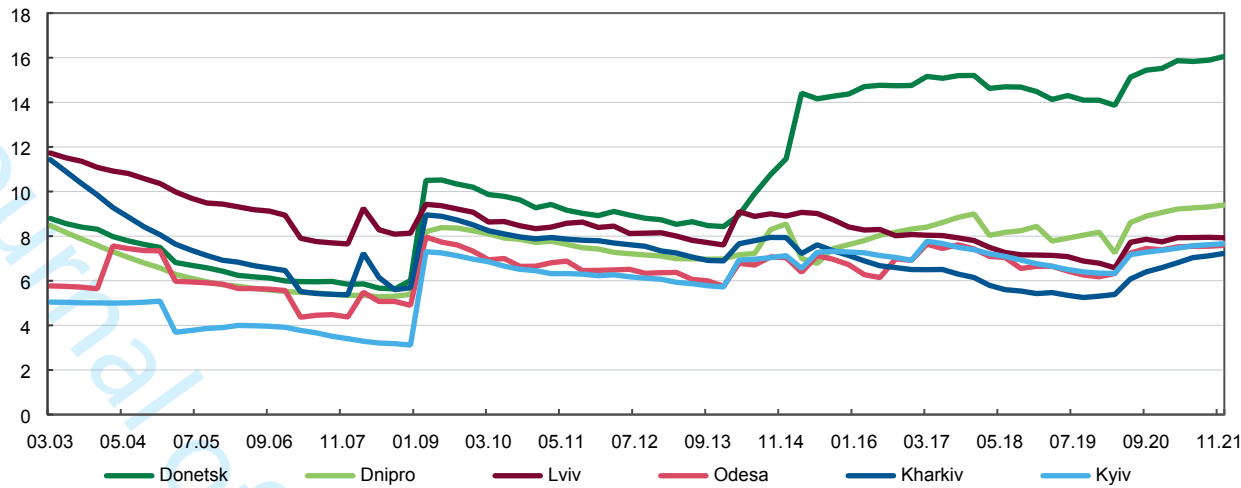


Figure 8. Deseasoned quarterly rate of unemployment (to working age population) in Ukrainian cities, %

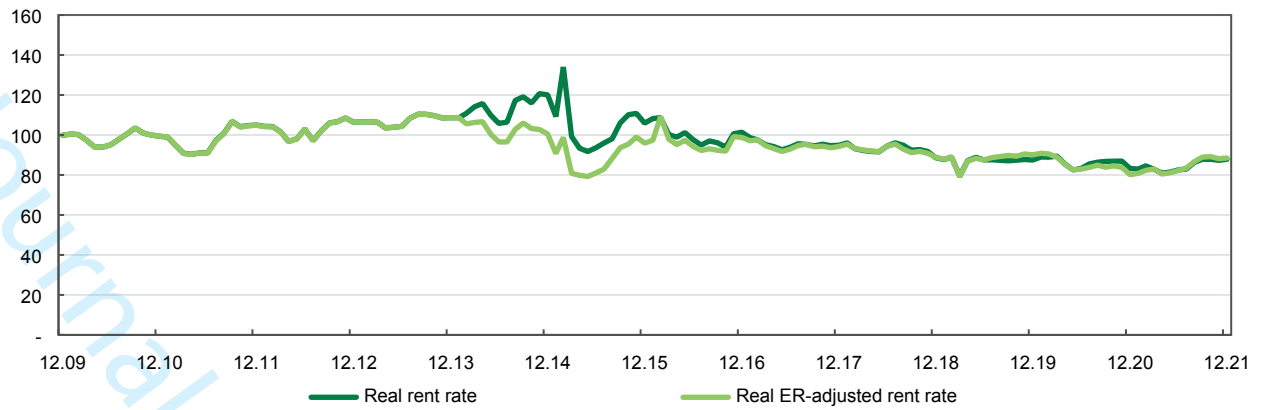


Figure 9. Rental rates in Kyiv, UAH per sq.m

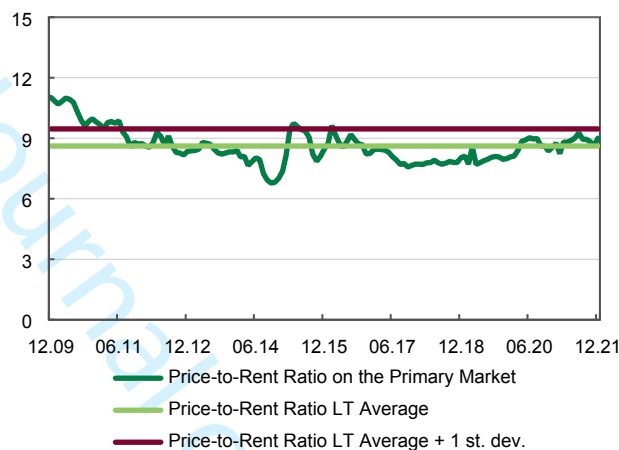


Figure 10, Panel A. Price-to-rent ratio on the primary housing market of Kyiv

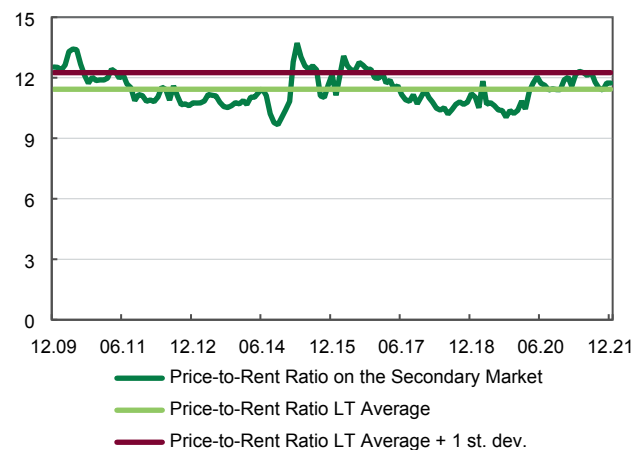


Figure 10, Panel B. Price-to-rent ratio on the secondary housing market of Kyiv

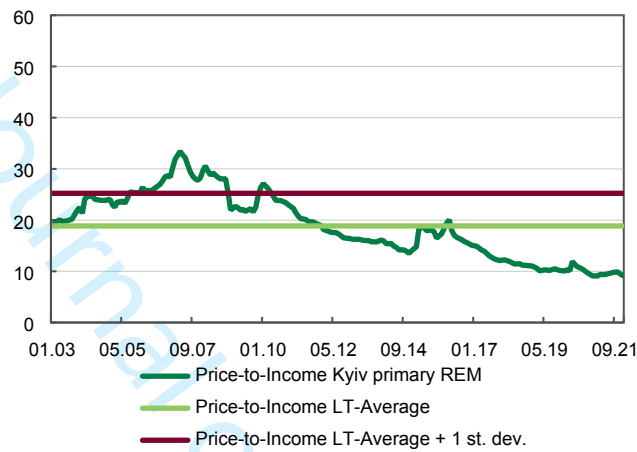


Figure 11, Panel A. Price-to-income ratio on the primary housing market of Kyiv

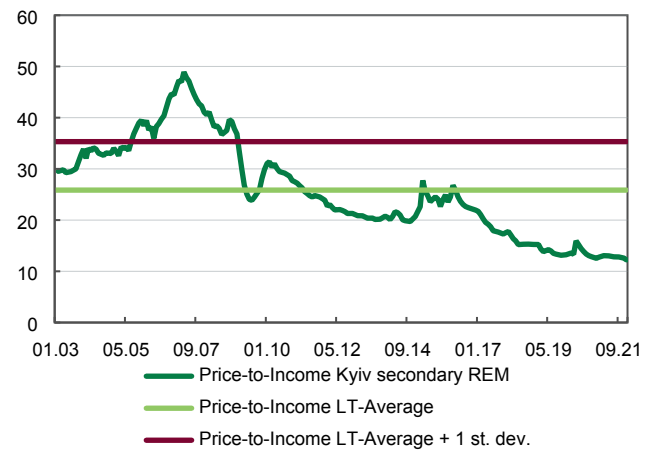


Figure 11, Panel B. Price-to-income ratio on the secondary housing market of Kyiv

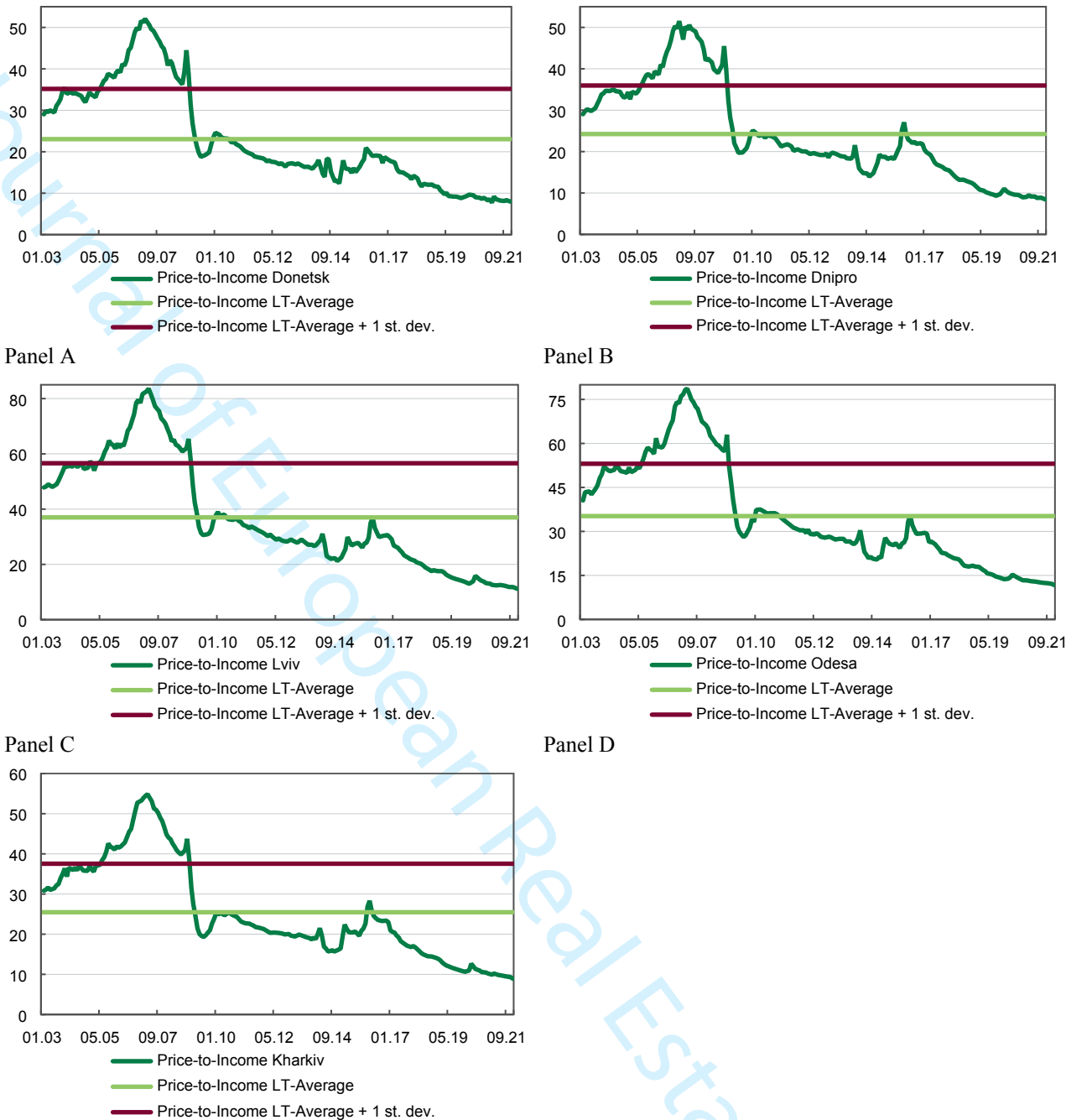
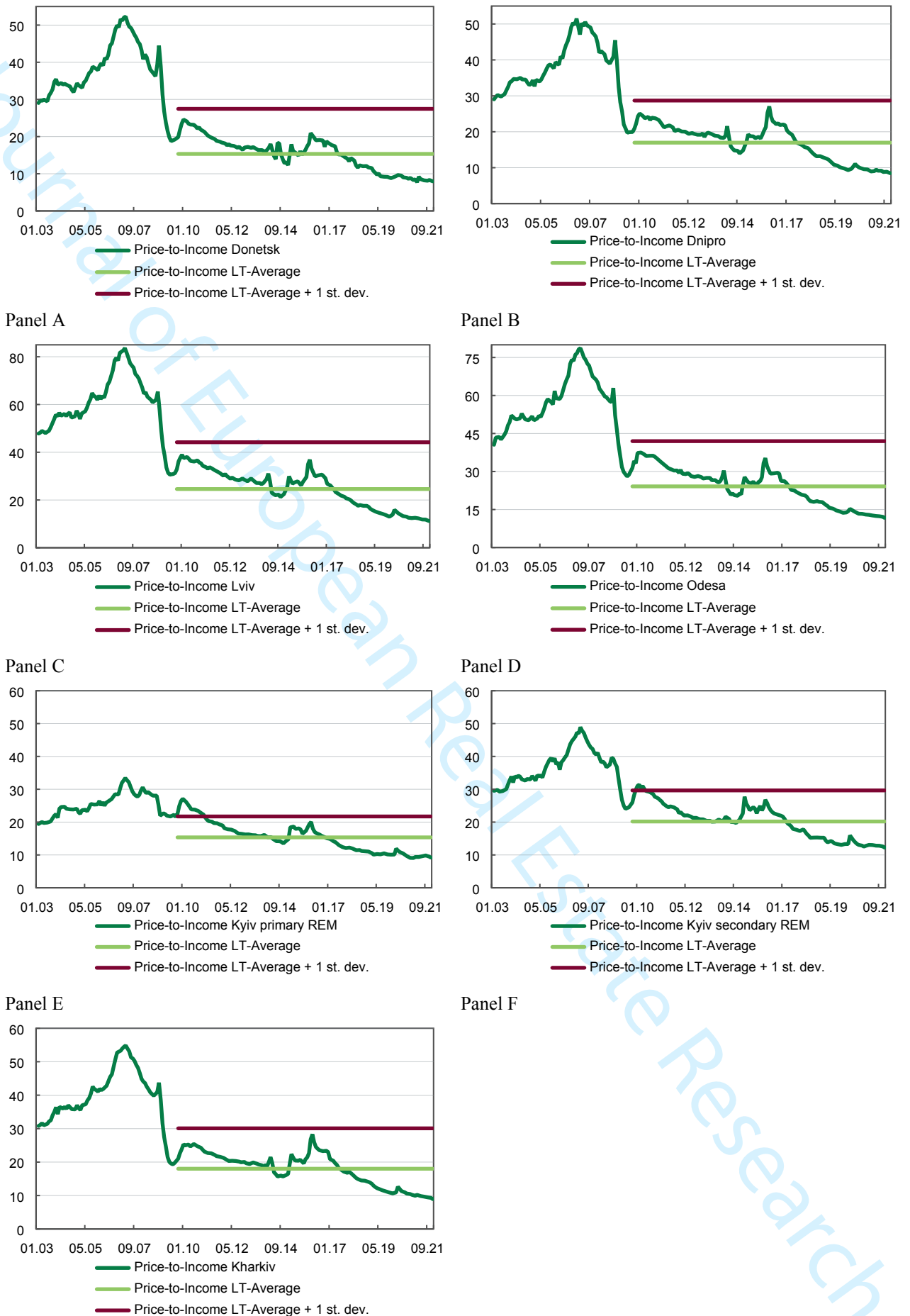


Figure 12, Panels A-E. Price-to-income ratios on the secondary real estate markets of Ukrainian cities



Panel G
Figure 13, Panels A-G. Price-to-income ratios with alternative thresholds for the Ukrainian cities

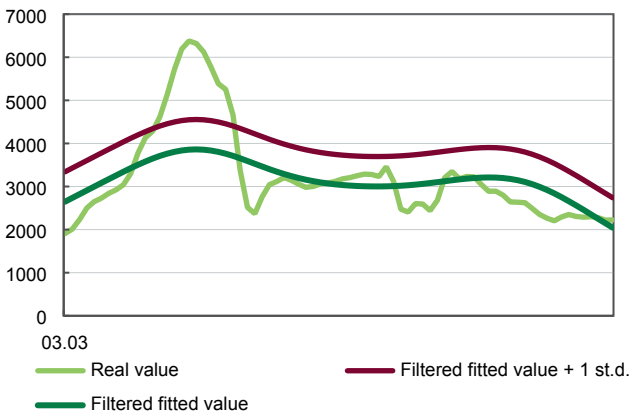
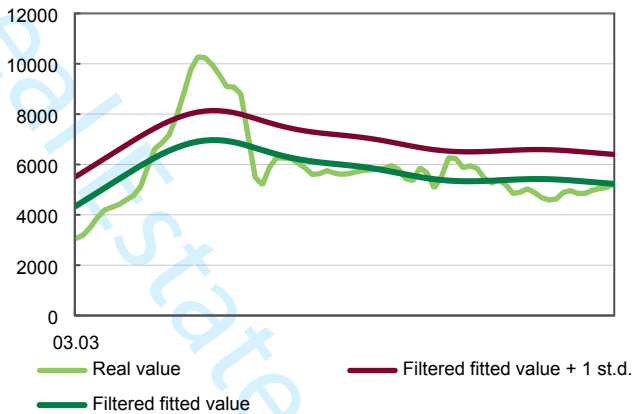
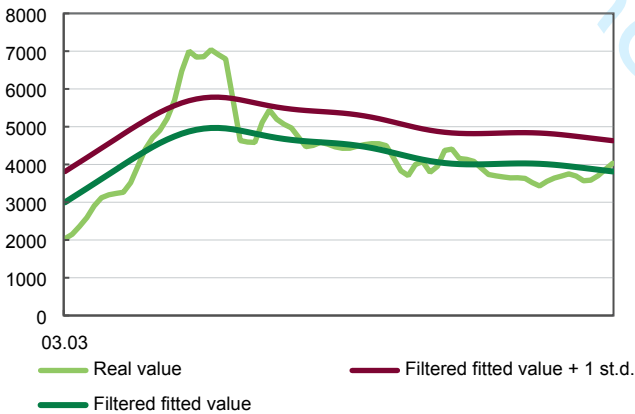
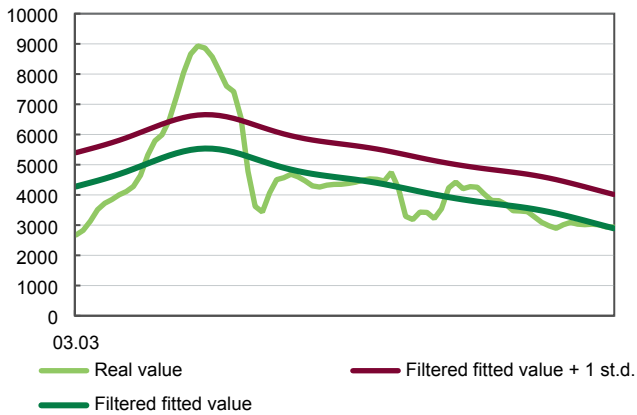
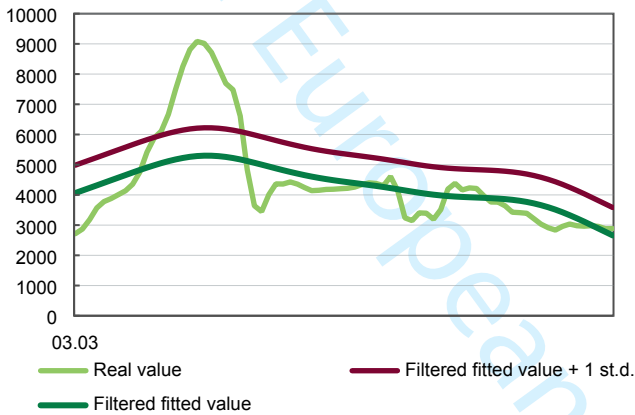
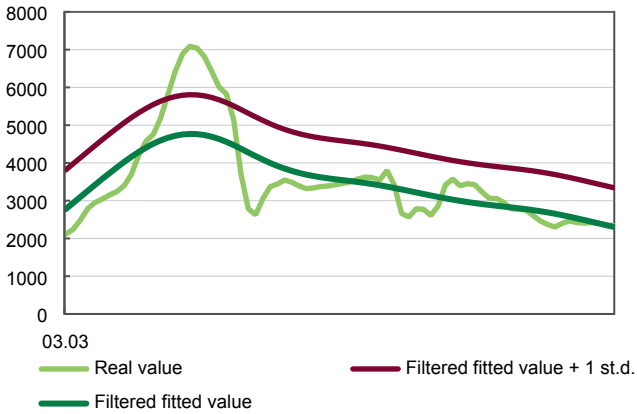
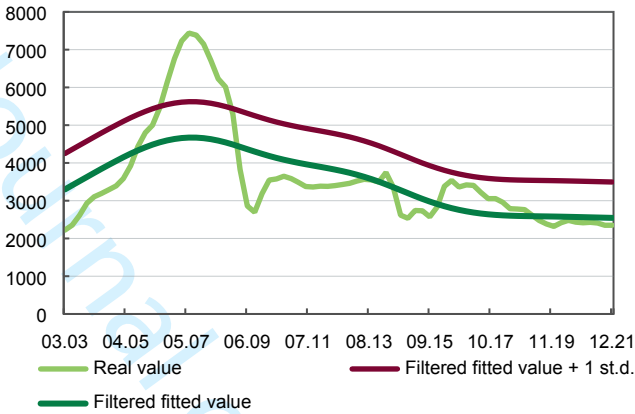


Figure 14, Panels A-G. Comparison of fundamental values, bubble thresholds and actual values of house prices in Ukrainian cities

Fundamental values – fitted values of individual regressions for each city separately. Bubble thresholds – fundamental values, increased by 1 standard deviation for fitted values (as stated on graph). Actual values – real exchange rate adjusted house prices (dependent variables) for each city. Fitted values are filtered with HP-filter with lambda 1600.

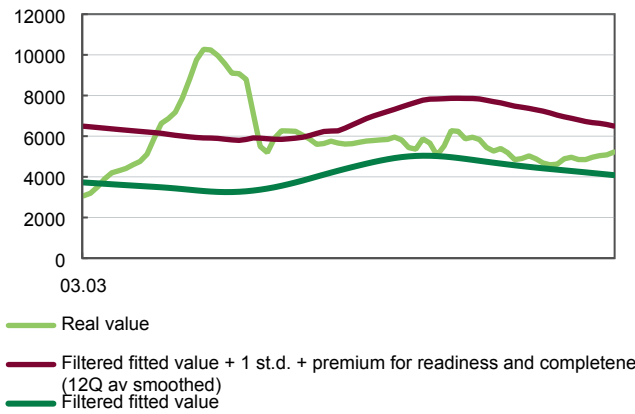
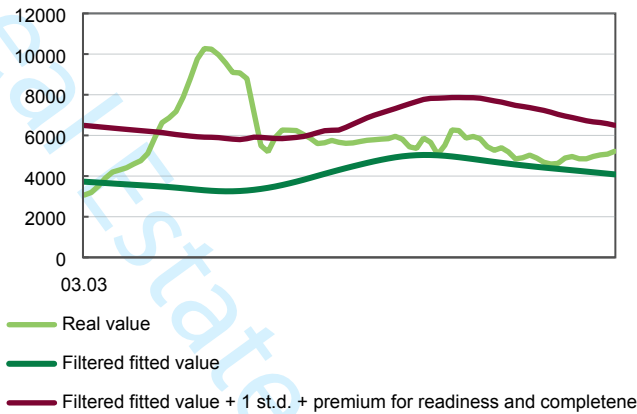
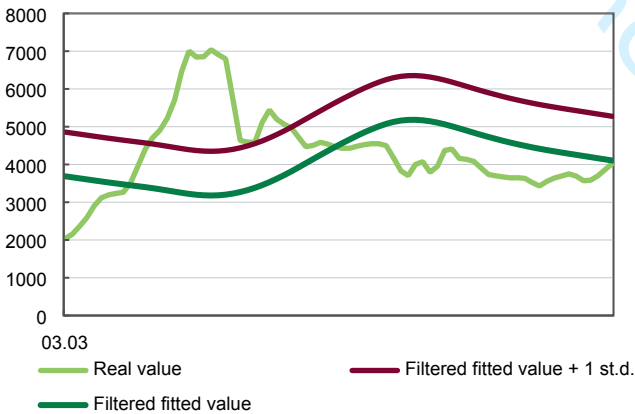
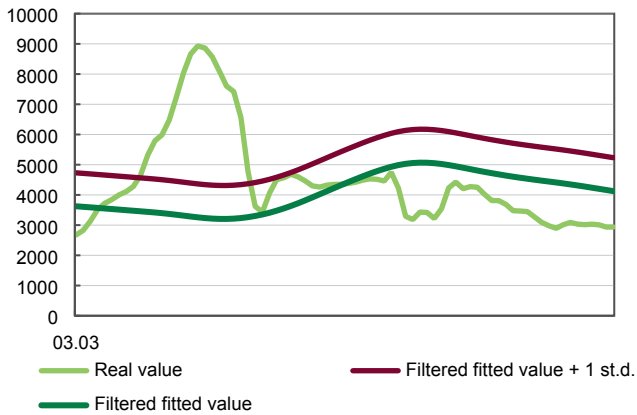
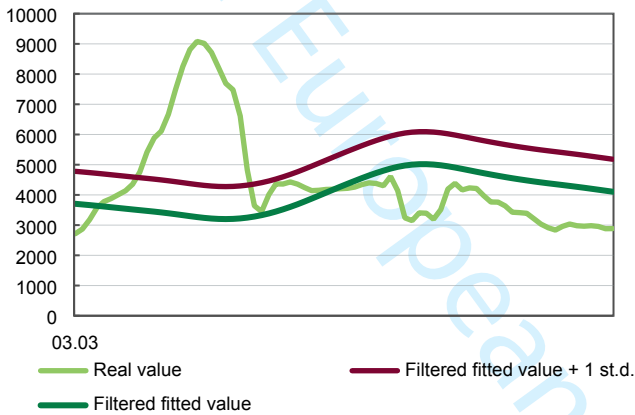
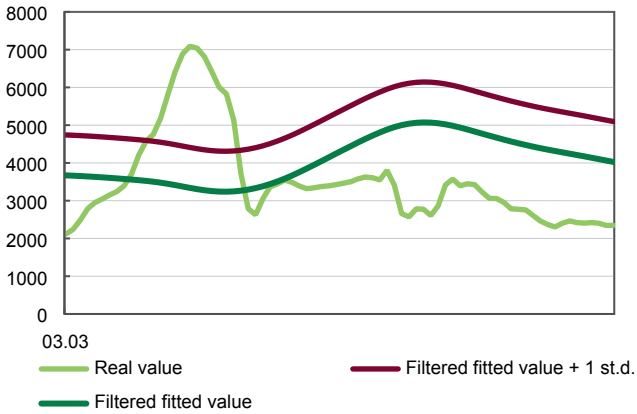
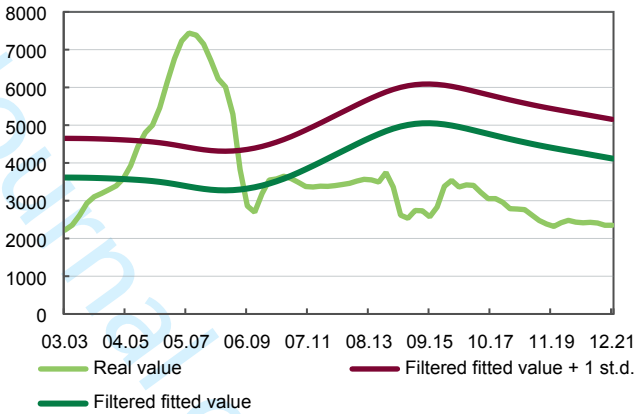


Figure 15, Panels A-G. Comparison of fundamental values, bubble thresholds and actual values of house prices Ukrainian cities

Fundamental values – fitted values of the within regression model with one-way (individual) effect for panel data. Bubble thresholds – fundamental values, increased by one standard deviation for fitted values except for the Kyiv secondary market for which we use one standard deviation plus the value of a premium for readiness and completeness of the market. The premium is a ratio of house prices on the secondary market to house prices on the primary market that is then smoothed by taking the 12-quarter average. This is to account for the fact that fundamental house prices for Kyiv are produced jointly for the primary and secondary markets, since the explanatory variables were the same for both. Hence, it produces rather low house prices for the secondary market, while the dynamics are overall correct and dictated by fundamentals. Actual values – real exchange rate adjusted house prices (dependent variables) for each city. Fitted values are filtered with HP-filter with lambda 1600.

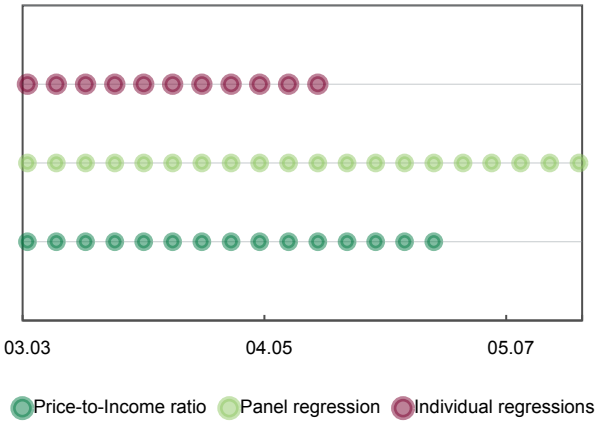


Figure 16. Bubble signals with different approaches with signals of a bubble that appear for at least two cities simultaneously.

Appendix

Appendix A

To construct an optimally specified model, needed to generate the intrinsic level of house prices, we have performed several iterations with different combinations of both dependent and independent variables.

1. Selecting the dependent variable.

Before we concluded that the model specification with real exchange rate adjusted house prices is the best fit as the left-hand side variable for our model, we considered four alternatives of the dependent variable:

- Nominal house prices;
- Nominal exchange rate-corrected house prices;
- Real house prices;
- Real exchange rate-corrected house prices.

We needed to adjust the dependent variable for exchange-rate fluctuations because, as it is mentioned in Section 3, the house price dynamics for the largest Ukrainian cities are extremely dependent on the exchange rate movements. Thus, large shifts in exchange rates have a substantial effect on the house price dynamics and cause movements that are not generated by the fundamental factors. Therefore, we had to correct the data in order to remove unwanted exchange rate dynamics.

We proceeded with real instead of nominal exchange rate-adjusted house prices because the model that incorporates the variables in nominal terms proved not suitable for bubble detection. First, when both left-hand side and right-hand side data are in nominal terms, the model works well (high R^2 and correct signs of coefficients) only due to the inflation that is inherent to both dependent and independent variables. Thus, we fail to explain the real house price movements, but mainly explain the dynamics due to inflation. Second, when we have nominal variables on either side, the independent variables fail to account for the impact of inflation and, therefore, the fitted values cannot be used to detect house price bubbles.

2. Selecting independent variables.

The comprehensive list of variables that can be used for estimation of the fundamental level of house prices is presented in Table 1. At first, we tried to construct a model that would contain the variables from all four groups on the right-hand side.

a) *Supply side drivers*

After testing this specification, we discovered that the volume of commissioned dwellings in Kyiv or in Ukraine as a whole is not significant for house price growth.

The construction costs index for Ukraine suited the model well in terms of significance of coefficients and contribution to the predictive power of model. However, this indicator is not usually considered a fundamental driver of house prices, since it appears to represent a trend that is mostly superficial (due to current price conditions) and not intrinsic.

b) ***The lending factors*** were not used in this research, as suggested by the literature.

c) Therefore, we proceeded with the ***demand factors***.

We did not use the rental rates in the regression analysis due to the short data series that does not cover the period of the GFC and thus the imbalances on the residential real estate market at that time.

Further, we proceeded with a model that featured the *average monthly income of a person/per household, unemployment rate, population number, share of disposable income in aggregate income of the population and capital investment of households for buying or building housing* on the right-hand side. Here we faced the problem of high multicollinearity (significant correlation, over 0.8, between some variables) that made us choose between income or capital investments of household. The literature suggests that income is the most suitable fundamental factor for modelling house price growth, which was also supported by the simple univariate regression results, where income and demographic variables had high R^2 s.

Thus, we had to choose between the *average monthly income of a person/per household, unemployment rate, population number* and *share of disposable income in aggregate income of the population*, since we still had a problem of multicollinearity with this combination of variables.

For most cities, we decided to deal with this dilemma by constructing a variable that most fully explains the possibility for households of buying an apartment or taking out a loan for it, i.e., the *disposable real aggregated income* that combined all the aforementioned variables, except unemployment. However, for some cities the intrinsic trend of house prices was better described by *population*.

Unemployment, because it was not highly correlated either with the aggregated income variable, or with population, became a separate demand-side variable that entered the individual regression equations for every city and panel data as well.

- d) Among macroeconomic variables, we selected the ratio of **current account balance to GDP** was used in all regressions since it is not highly correlated with other independent variables and contributes to the predictive power of the regression. This variable adds the macrofinancial perspective to the model.

Reviewer 1.

1. In several places it is said that the author is developing a framework for studying bubbles. As I see it this is not correct as there is nothing original on a general level in their approach. The article is a very good applications of rather established approached and is not developing a new framework. At least they should explain what they mean with framework!	<i>Thank you. We fully agree. We changed the wording from “developing a framework” to “presenting a framework”/ “show how to implement an instrument for detecting house price bubbles”.</i>
2. I like the simple equation used in the regression analysis as it makes the study easier to understand and therefore more credible. But they say on page 7 that they used several iterations to arrive at this equation. I would have liked a short appendix where they gave more information about the early versions and what variables were deleted in the process.	<i>The process of selecting a model specification is now described in Appendix A. Thank you for the suggestion.</i>

Reviewer 2.

I think that the role of the exchange rate could be explained better. The authors refer to “the proper percentage of adjustment” but I am not clear what this means.	<i>We have provided a better explanation of the role of the exchange rate on the real estate market in Ukraine in Section 4 “Data”. The optimal level of adjustment is described in detail in Section 4 and relies mostly on expert judgement. The process of choosing the proper adjustment is depicted in Figure 4.</i>
Also, this makes me think about how is the price variable entered in the regression and are all nominal variables in the same currency?	<i>All nominal variables are in the same currency, namely in UAH hryvnia. This information is provided in Tables 1 and 2.</i>
In relation to the regression analysis the authors state that “after establishing the baseline model, we estimate the fitted values, which are then interpreted as fundamental house prices.” However, when examining the results, the adjusted r-squared values are often quite low, also no DW statistic is reported. Therefore, the estimated fundamental values may be inaccurate. Similarly for the pooled model in table 5, the adjusted r-squared seems quite low especially for pooled data. Also, from the coefficients here are in table 4, I was not sure if the equations were estimated in logs.	<i>We updated the models with all variables in logs. Additionally, we added the current account balance to GDP variable to the right-hand side of all regression equations. This improved the R^2 as well as adjusted R^2 of both individual and panel-data models. We recognize the problem of heteroscedasticity and potential autocorrelation (since we have quarterly time series) that we face in some models and calculated the heteroscedasticity and autocorrelation-consistent (HAC) robust standard errors that are provided in Tables 5 and 8.</i>
Furthermore, for the panel model, there is an assumption of a common intercept, but the authors could check and show if this is appropriate.	<i>Thank you for this comment. We calculated the common intercept for the panel-data model using the “plm” package in R. The value of the intercept and its accompanying standard error are provided in Table 6.</i>
Also, they could conduct panel unit root and cointegration tests.	<i>Thank you for this important suggestion. Given that the variables (in levels) used for the estimation of fundamental house prices (income and population) are non-stationary, it must be checked whether the residuals produced by the model are stationary. We conduct two different types of unit root tests on the residuals of the panel-data model. The Levin-Lin-Chu unit root test is a first-generation panel unit</i>

	<i>root test as it assumes no cross-sectional correlation; it is based on the estimation of Augmented Dickey-Fuller (ADF) regressions for each time series. The second is the Pesaran cross-sectionally augmented version of the Im-Pesaran-Shin panel unit root test which is a so-called second-generation panel unit root test. Both tests suggest stationarity of the residuals of the panel-data model. The results are presented in Table 7.</i>
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