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Visegrad Region Dependency on Mining Industries: Impact of Raw Material Prices on Housing Prices and Investments

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Abstract
This study examines the impact of the mining industry and raw material prices on housing prices and real estate investment in the Visegrad region (Poland, the Czech Republic, Slovakia, and Hungary) from 2014 to 2023. Given the historical and economic links of this region with the development of the mining sector, the study aims to assess how fluctuations in raw material prices (e.g., coal, copper, steel) affect housing price dynamics and real estate investment decisions. The analysis uses Eurostat and World Bank data on key raw material prices, house price indices, and real estate investment flows. Panel regression analysis was used to identify the relationship between raw material price changes and housing prices, and the ARIMA model was used to forecast the impact of raw material prices on housing market trends. The study results show that the mining sector remains important for the real estate market of the Visegrad countries, and raw material price fluctuations have a significant impact on both residential real estate prices and investment flows to the housing sector in this region. In countries where mining remains the primary industry, property prices tend to be more cyclical. This highlights the importance of the mining industry to the housing market and the need to enhance risk management in the property sector in response to economic fluctuations.

Keywords
Real Estate, Visegrad region, mining industry, investments.

Introduction

The Visegrad countries are heavily dependent on old industrial sectors, in this case, mining (Éltető, Sass & Götz, 2022). It is therefore normal that changes in commodity prices can affect the economy, since the majority of exports to these countries are commodities (Vakhal, 2023). Although the dependence of raw material prices and the real estate market in these countries is indisputable, very little research has been done so far (Montvydaitė, 2024).

The European Union is focusing on green policies, aiming to reduce the region's dependence on fossil and polluting fuels (Pariso, Picariello, & Marino, 2023; Samašonok & Išoraitė, 2023; Soto & Martinez-Cobas, 2024; Ruginė & Žilienė, 2024; Miszczak, Kriviņš, & Kaze, 2024; Churikanova et al., 2025; Richert & Łebkowski, 2025).

The policy aims to attract investors to invest in green and sustainable industries instead of old and conservative ones (Zecca, Pronti & Chioatto, 2023; Pouresmaieli et al., 2024). Given that the real estate market is closely correlated with political and geopolitical factors and price fluctuations, it is essential to examine the impact of the new EU policy on this market (Zhao & Liu, 2023).

This article examines how changes in commodity prices in the Visegrad countries have affected housing values and real estate investment. The study aims to determine whether changes in commodity prices have a direct impact on the real estate market in the countries under study.

The study assumes that housing prices increase when raw material prices increase, as economic activity in mining regions stimulates both rising wages and housing demand (Hromada et al., 2021). However, falling raw material prices may have the opposite effect, reducing industrial profitability and negatively affecting the real estate market, such as decreased demand and reduced investment(Rešetar, Rešetar & Lukić, 2023). Considering these assumptions, several research hypotheses are raised:

RQ1: How have commodity price fluctuations affected house prices and real estate market activity in the mining regions of the Visegrad region over the past decade?

RQ2: Is there a statistically significant relationship between commodity price developments and real estate investment in these countries?

RQ3: What long-term predictions about real estate market developments can be made based on commodity prices and EU policies?

This study is relevant not only because it helps to understand how mineral extraction affects real estate prices, but it can also help to understand how to manage these changes and stabilize the market without disrupting the state economy. The results of the study are intended for investors, policymakers, and, of course, people who want to understand how green policies affect different markets. It is essential to note that, as the European Union strives to transition to a climate-neutral economy by 2050, this study holds significant value in predicting long-term changes in commodity prices and their impact on the regional real estate market.

Literature review

The mining sector has played a significant role in the economies of the Visegrad countries since very ancient times (Kochanek, 2021). Although the economies of these countries have grown and changed fundamentally in recent years, fossil fuels have remained significantly important for the economies of these countries (Rabbi & bdullah, 2024). The mining sector operates in these countries not only as a separate industry but also as a factor directly affecting the economy (Gavurová et al., 2017). The mining sector in the Visegrad countries – particularly in Poland and the Czech Republic – continues to have a significant impact on the housing market, although this connection may seem indirect at first glance(Marszowski & Iwaszenko, 2021).

The main factor linking these two areas is the dynamics of raw material prices, which directly affect both the income of residents and the demand for residential housing in mining regions (Liu, 2025).

During the rise in raw material prices, a trend can be observed that investment in mining infrastructure is also growing at the same time (Bragagni & Xhaferraj, 2021). In Poland, in 2021, as coal prices on world markets rose by more than 40 percent, investment in the mining sector increased by about 18 percent compared to the previous year (Bórawski, Bełdycka-Bórawska, Holden, 2023). This, of course, created additional jobs for people in the Upper Silesia region, which is completely dependent on coal mining (Frankowski, Mazurkiewicz & Sokołowski, 2023). High employment and growing incomes have stimulated housing demand, resulting in a 12 percent price increase in 2022 for this region, compared to an average of just 8 percent (Ryś & Ryś, 2025).

A similar situation occurred in the Czech Republic, where rising copper and coal prices in 2021-2022 in the Moravian-Silesian region, which is also heavily dependent on mining, led to housing prices increasing by more than 10 percent, compared to an average of just 7 percent (OECD, 2025).

As raw material prices fall, the mining sector is directly affected, which has very wide economic consequences in these countries (Arendt, Bach & Finkbeiner, 2022; Chilunjika, 2024). For example, in 2015–2016, when global coal prices fell by more than 50%, around 12,000 miners in Upper Silesia, Poland, lost their jobs. This led to population migration to other regions and a decline in house prices, with property prices in some

cities falling by up to 5 - 7% in one year. Similarly, in the Czech Republic, the same Moravian-Silesian region has experienced a decline in its population of more than 6% over the past five years, following the last commodity price crisis (Trembaczowski, 2021).

Also, increasing tax revenues allow municipalities to invest in public infrastructure and quality of life (Víghová, 2023; García-Estévez, Vargas-Prieto & Ariza, 2024; Okunevičiūtė Neverauskienė & Kleponė, 2024; Víghová, Košovská & Hudáková, 2024).

For example, in the Hungarian Borsod-Abaúj-Zemplén region, where coal mining is still thriving, local authorities invested revenues from the mining sector in the development of new residential areas and infrastructure improvements, as raw material prices increased, which resulted in a more than 15 percent rise in housing prices in this region(Bujdosó et al., 2022).

The economy of the Visegrad region, closely correlated with the mining industry, is characterized by increased sensitivity to fluctuations in raw material prices on global markets (Bórawski, Bełdycka-Bórawska, Holden, 2023). Coal, copper, iron ore, and steel are the primary raw materials, the price fluctuations of which directly or indirectly impact both the national economy and the state of local real estate (RE) markets (Laing & Pinto, 2023; Apanovych & Prágr, 2023). Changes in raw material prices determine the profitability of the mining sector, investment, employment in the region, and the income of the population (Calzada & Iizuka, 2024). These factors shape housing demand, price developments, and investment decisions (Montvydaitė, 2024).

The period is 2014-2023. highlighted several impacts of raw material prices on RE markets in the Visegrad countries. In Poland, specifically in the Upper Silesia region, a clear correlation exists between the growth of commodity prices and the rise in housing prices (Śliwińska et al., 2022; Stašová, 2025). In 2021, when coal prices rose by 45 percent, investments in the real estate sector increased by about 9.8 percent, and housing prices rose by about 12.3 percent (Żelazowski, 2019). Similar trends are also observed in the Moravian-Silesian region of the Czech Republic, where housing prices increased by approximately 10.4 percent in 2022, and investments in this sector rose by about 7.2 percent (OECD, 2025). Both of these increases were driven by raw material exports and profitability, and of course, employment and profitability increased as a result of all this (Calvo, Valero, Valero, 2019).

However, when raw material prices fall, the market experiences opposite trends. For example, in 2015–2016, coal prices fell by more than 50%, which negatively affected the number of jobs in mining regions (Kaczmarek, 2022). In Upper Silesia, the number of unemployed people increased by 8%, and house prices fell by 6.5% in two years (Bragagni & Xhaferraj, 2021). A similar situation was recorded in Slovakia. In the Banská Bystrica region, which has long been reliant on metal mining, the decline in raw material prices in 2015 resulted in a 12% decrease in real estate prices over the following year (OECD, 2022).

Studies show that during periods of rising commodity prices, not only do real estate prices increase, but investment flows into the real estate sector also increase (Sobotková & Bartoš, 2025). In Poland, the growth of investments in the real estate sector from 2021 to 2022, along with the profit of the mining sector, measured by EBITDA, increased by approximately 20 percent (Rybacka, 2024). Such data confirms the assumptions that the development and profitability of the mining sector can become a significant factor in the growth process of the real estate sector.

Identical situations are observed in Hungary, in the Borsod-Abaúj-Zemplén region. Increased raw material prices in the same year led to a rapid recovery of the real estate sector. Housing prices increased by about 14.5 percent, and investments in this sector by about 11 percent (Koppány, Vakhal & Pusztai, 2023). The government also contributed to this growth, utilizing additional budget revenues and various incentive programs to promote more profitable exports of goods (Balasoiu, Chifu & Oancea, 2023).

Materials and Methods

This study employs a quantitative analytical model based on advanced econometric methods to investigate the impact of commodity price fluctuations on house price dynamics and real estate (RE) investment flows in the V4 countries – Poland, the Czech Republic, Slovakia, and Hungary – from 2014 to 2023. The analysis was performed using the latest version of the R programming language (4.3.2) and extended packages, including plm, pdynmc, vars, xgboost, glmnet, caret, and forecast.

The study uses annual data collected from official and reliable sources – Eurostat, World Bank, and national statistical institutions (for instance, GUS, ČSÚ, ŠÚ SR, KSH). The following variables are analyzed:

- Commodity prices: copper, coal, and steel prices (USD per ton),
- Real estate market indicators: house price index (HPI) and real estate investment index (% GDP or standardized index),
- Macroeconomic factors: GDP growth (%), HICP (inflation index), unemployment rate (%), and average wage (EUR/year).

All monetary indicators were deflated using the HICP index to facilitate the comparison of real values across countries and periods. The data were transformed into a balanced panel format suitable for use in a variety of panel models.

The first stage, employing fixed effects (FE) and random effects (RE) models, aims to identify the primary relationships between commodity prices and housing market indicators. The model formulas (Formulas 1 and 2):

$$HPI_{it} = \alpha + \beta_1 Cooper_{it} + \beta_2 Coal_{it} + \beta_3 Steel_{it} + \gamma X_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

$$INV_{it} = \alpha + \beta_1 Cooper_{it} + \beta_2 Coal_{it} + \beta_3 Steel_{it} + \gamma X_{it} + \mu_i + \varepsilon_{it} \quad (2)$$

Where HPI_{it} – house price index, INV_{it} – real estate investment level, X_{it} – macroeconomic variables. Country-fixing effects (μ_i) time-invariant country characteristics controllers. The Hausman test is used for FE and RE model selection.

Since housing prices are characterized by inertia and some variables may be endogenous, the Arellano-Bond dynamic GMM method is applied, which allows the use of a dependent variable from previous periods as an explanatory factor (Formula 3):

$$HPI_{it} = \alpha + \delta HPI_{i,t-1} + \beta_1 Cooper_{it} + \beta_2 Coal_{it} + \beta_3 Steel_{it} + \gamma X_{it} + u_{it} \quad (3)$$

This method enables the reduction of biases resulting from reverse causality and temporal dependency in time series, utilizing the variables from Equations 1 and 2.

VAR models are additionally applied to each country, which allows us to analyze how the interrelationships between commodity prices, housing prices, and investment change over time (Formula 4):

$$Y_t = A_1 Y_{t-1} + A_2 Y_{t-2} + \cdots A_p Y_{t-p} + \varepsilon_t \quad (4)$$

Where Y_t – this is a vector of variables (for instance, HPI_t, $Cooper_t$, $Steel_t$). Impulse response functions (IRFs) allow us to estimate how a shock (for instance, a sudden increase in the price of coal) affects house prices over several years.

Granger causality testing is used to determine whether commodity prices help predict housing prices or investment. In addition, ARIMA models (autoregressive integrated moving average models) are used to forecast the long-term housing market, taking into account commodity price cycles and EU policy changes (Formula 5):

$$Y_t = \alpha + \sum_{i=1}^{p} \phi_i y_{t-i} + \sum_{j=1}^{q} \Theta_j \epsilon_{t-j} + \epsilon_t \quad (5)$$

Where Y_t – dependent variable, such as the house price index (HPI), ϵ_{t-j} – a possible causal variable, such as the price of coal, copper, or steel, ϕ_i and Θ_j – relevant coefficients, p, q - time delay (lag) procedures, ϵ_t – random error.

The final part of the study uses advanced machine learning methods for reliable predictions and selection of the most important variables:

- LASSO regression (Least Absolute Shrinkage and Selection Operator) – regression analysis with a penalty that allows you to reduce the complexity of the model and select the most important factors (Formula 6):

$$\min_{\beta} \left\{ \frac{1}{2n} \sum_{i=1}^{n} (y_i - X_i \beta)^2 + \lambda \sum_{j=1}^{p} |\beta_j| \right\} \quad (6)$$

Where Y_t – dependent variable, X_i - vector of independent variables, i.e., predictive factors, β_j – model coefficients: the influence of each independent variable on the dependent variable, n – number of observations, p – number of explanatory variables, λ – regularization parameter.

Each model is tested using cross-validation methods, comparing AIC/BIC, RMSE, and other criteria. Heteroscedasticity, autocorrelation, and multicollinearity tests are performed to assess reliability. Values are presented with clustered standard errors, taking into account the grouping of countries.

Results

This section presents the results of an analysis of commodity prices and housing market indicators, utilizing several advanced econometric and machine learning methods. The analysis is based on data from the four Visegrad countries - Poland, the Czech Republic, Slovakia, and Hungary - for the period 2014 - 2023. Different methods enabled us to assess both direct and indirect relationships, taking into account time and country effects, data dynamics, and potential endogeneity.

The fixed effects model was chosen as the main method due to the small number of groups ($n = 4$ countries), which limits the robustness of random effects (RE) models. The model assessed how copper, coal, and steel prices, as well as macroeconomic factors (GDP, inflation (HICP), unemployment rate, and average wage), affect the house price index (HPI). The results revealed that: Inflation (HICP) had a strong and statistically significant positive effect on the HPI ($p = 0.0012$), indicating that house prices are rising rapidly in an inflationary environment. The copper price was marginally significant ($p = 0.093$), while the impact of coal and steel prices was not statistically significant in this model. GDP, unemployment rate, and wage rate did not have a significant effect on the HPI, which may indicate that house prices during this period were more dependent on price levels than on economic development or household income. Figure 1 illustrates the results of a factor analysis, which reveals how different variables load onto three latent dimensions: raw materials, inflation/purchasing power, and macroeconomic core. Such analysis enables us to identify hidden relationships between variables and organize them into groups, allowing us to simplify complex datasets and avoid multicollinearity problems when applying further models.

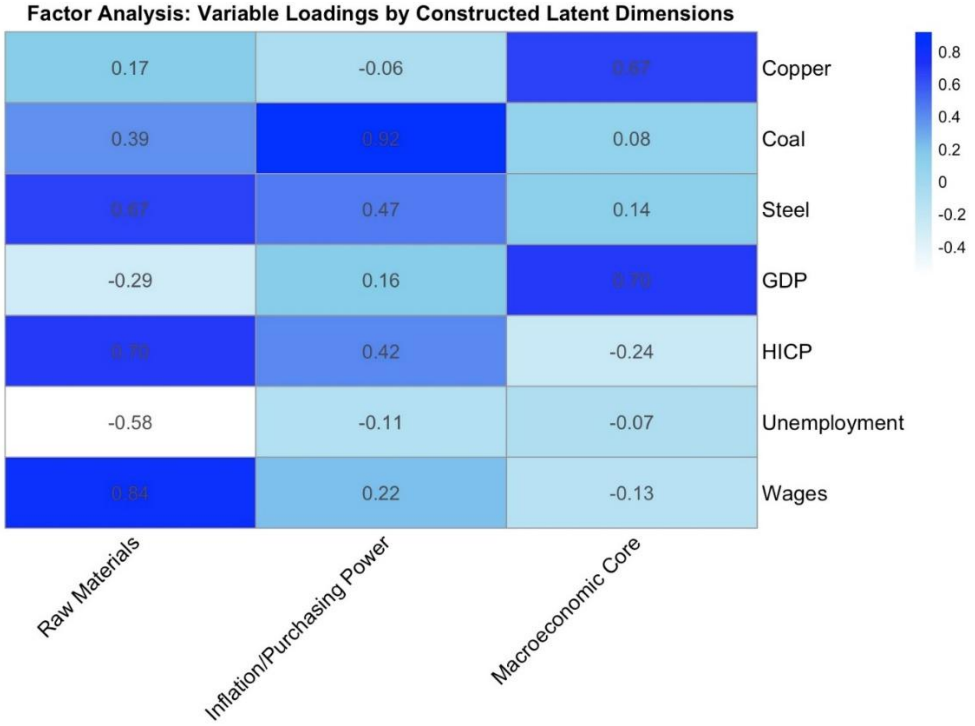

Fig. 1 Factor analysis.

The high explanatory power of the model ($R^2 = 0.90$) confirms the strong fit of the model and suggests that the explanatory variables effectively capture the dynamics of real estate prices.

Since real estate prices are characterized by inertia (i.e., they strongly depend on previous periods), a dynamic panel model with estimation of momentary conditions (GMM – Generalized Method of Moments) was applied. The purpose of this model is to take into account possible endogeneity and preserve the dynamic structure. Main results: Lag(HPI, 1) had a very large positive and significant effect ($\beta = 0.99$, $p < 0.001$), confirming price inertia – price changes strongly depend on the past. The price of coal was statistically significant ($p = 0.035$) – the increase in the price of this raw material had a significant impact on housing prices. The Sargan test ($p = 1$) shows that the instruments used are appropriate, and the AR(2) test ($p = 0.18$) confirms that there is no second-order autocorrelation.

Figure 2 shows the coefficient values of the GMM model with 95% confidence intervals. Lag (HPI, 1) has a strong and significant positive effect, confirming the inertia of real estate prices. Coal has a statistically significant positive effect, which suggests that rising coal prices may have an impact on property prices. Since the coefficients for copper and steel are close to zero, they are not statistically significant.

This figure illustrates the factors that have influenced the study variable. This study allows us to conclude that coal prices have not only a correlational but also a possible causal effect on property prices.

In order to analyze short-term changes in commodity prices, a vector autoregressive (VAR) model was applied separately for Poland. The data were varied to ensure stationarity.

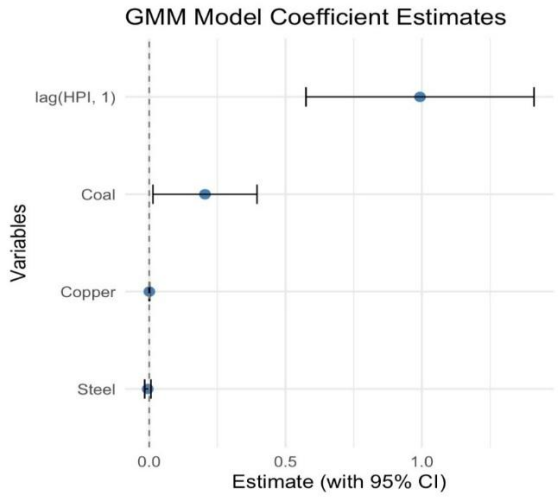

Fig. 2 Generalized method of moments.

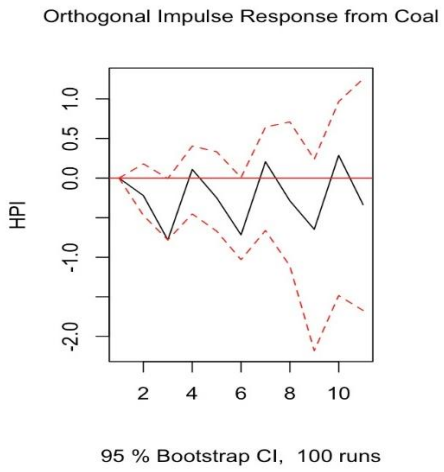

Fig. 3 Vector autoregressive model.

This impulse response function illustrates how a one-time carbon price shock impacts the House Price Index (HPI) over a 10-period period. It can be seen that the initial impact is negative, with house prices falling briefly, and then the response remains fluctuating and unstable. This may indicate that increased energy or manufacturing costs initially dampen housing demand, but the effect is not long-lasting. Since the response does not exceed the 95% confidence intervals (shown in red), the shock is statistically significant only in the short term. This result reveals the potential temporary sensitivity of the housing market to changes in commodity prices (see Figure 3).

The impulse response function (IRF) shows how a one-time shock to the coal price affects the HPI over time. The results indicate that the effect is fluctuating and predominantly negative, particularly in the first 2 to 5 periods. Despite the wide confidence intervals, this suggests a possible negative short-term relationship between coal and house prices.

The ARIMA(0,1,0) model with drift was applied to forecast HPI data until 2028. The model best fits the trend of house price growth. The forecast indicates further housing price growth unless unforeseen catastrophes occur in the future. The HPI is expected to reach approximately 300 index points by 2028. The growth is accompanied by a wide 95% confidence interval, indicating risks and uncertainties.

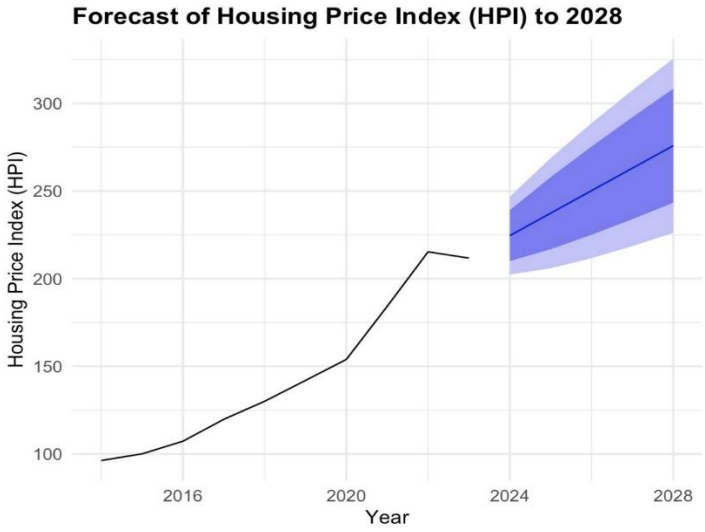

Fig. 4. Forecast of HICP.

Figure 4 shows the expected change in the House Price Index up to 2028. The forecast is based on historical data, or in other words, a time series. The blue line indicates the expected direction of price growth, and the surrounding area shows possible deviations. From the research conducted, it can be concluded that prices should increase, although there may be larger fluctuations as the data changes in the future. This forecast is useful for assessing general patterns; however, it should be noted that it can be influenced at any time by economic, geopolitical, or other factors.

The Granger causality test between copper and HPI in Hungary showed that the copper price does not Granger-determine HPI ($p = 0.2003$), i.e., copper prices cannot help to predict future changes in housing prices in Hungary.

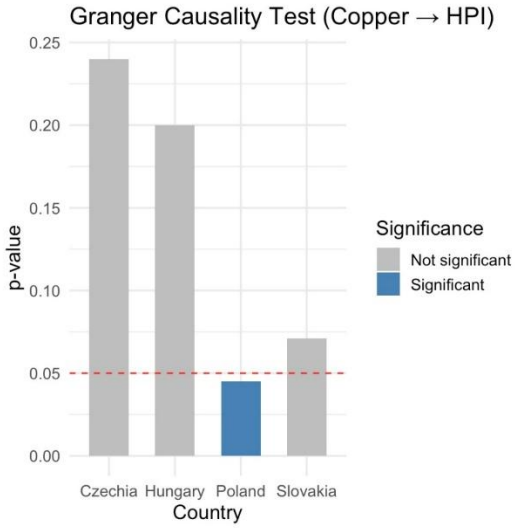

Fig. 5. Granger Causality Test.

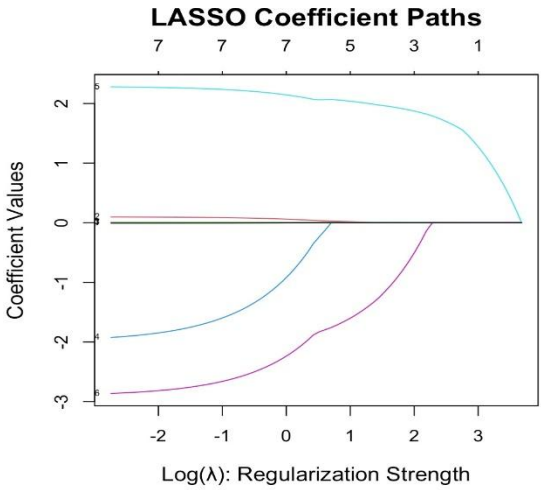

Fig. 6. LASSO Coefficient Paths.

Figure 5 presents the results of Granger causality tests assessing whether copper prices help predict the House Price Index (HPI) in the four Visegrad countries. Only in Poland is the relationship statistically significant ($p < 0.05$), while in the other countries, the significance threshold is not reached. This suggests that copper prices have a predictive value for house prices only in the Polish context, and such a relationship is not confirmed elsewhere.

This finding is also consistent with the GMM results, which indicate that the copper price was not statistically significant.

The LASSO model (cv.glmnet) was used to select variables and assess their relative importance in predicting HPI. The most important factors selected were: HICP (inflation) – a positive effect (2.28); coal – a significant positive effect (0.098); and unemployment – a significant negative effect (-2.86).

Figure 6 shows the trajectories of the LASSO model coefficients as the strength of regulation (λ) changes. The larger the value of λ, the greater the penalty – and the more coefficients approach zero. This enables us to identify which variables remain significant even under stringent regulation. Only a few variables have a consistent non-zero effect, which helps to select the most important factors for the real estate market price model.

These results support the economic rationale that inflation and rising commodity prices can increase property prices, while high unemployment can decrease them.

Discussion

The analysis of the fixed effects model showed that inflation (HICP) is a statistically significant and positive factor explaining changes in house prices in the V4 countries. This is consistent with the trend observed in many literature sources, which indicate that in an inflationary environment, real estate (RE) prices increase as a counterweight to monetary depreciation (Rong et al., 2024; Fu, 2025; Smith, 2004; Wolski, 2024; Yoshida, 2020; Duca, 2021). This result suggests that investments in RE can be treated as an inflation-hedging strategy, especially in regions where economic expectations are uncertain (Amenc, Martellini & Ziemann, 2009; Nwosu et al., 2023). Although the price of copper was only marginally significant, its sign (positive) and economic logic suggest that changes in raw material prices may be related to construction costs in the RE sector (Bhuwalka et al., 2023). Meanwhile, steel and coal prices were not statistically significant in this model, but this may be related to the fact that the impact of these raw materials does not occur immediately, but rather over a longer period. The analysis of such dynamics reveals more in other models (Şen, Akpolat & Balkan, 2024). Macroeconomic factors – including GDP, unemployment rate, and wages – did not appear to be significant in this model, which may be due to small differences between countries or the aggregation of data at the annual level. This suggests that short-term changes in real estate prices in the region may be more related to external cost factors and the value of money than to population income or overall economic activity (Asadov, Ibrahim & Yildirim, 2023).

The Arellano–Bond GMM model demonstrated a particularly important property of real estate market inertia. The results show that last year's real estate prices strongly predict current prices, which is typical of markets where

price formation is slow and depends on expectations (Granziera & Kozicki, 2015). This inertial dynamic is also confirmed by other regional studies, which note that house prices react sluggishly to changes in fundamental indicators. In addition, the price of coal turned out to be statistically significant in this model, the positive effect of which on house prices is economically justified: as construction prices increase (coal is an energy source for industry), the final price of buildings also increases (Hastriawan et al., 2020; Rivera & Loveridge, 2022). Interestingly, this raw material proved significant in the GMM model but not in the fixed effects analysis, indicating that its short-term effect is only evident in the dynamic structure, where endogeneity is taken into account. It is also worth noting that the model passed all diagnostic tests (Sargan, AR(1) and AR(2)), so these results are reliable and statistically valid. The GMM model indicates that the carbon price can be a significant short-term factor in real estate price changes, and the process of real estate price formation itself is characterized by strong dynamics that must be considered in every serious analysis of real estate prices (Zeng et al., 2023).

The application of a vector autoregressive (VAR) model was developed to analyse how commodity price shocks affect house prices over time, particularly in the case of Poland. The impulse response function, which calculates the carbon price shock, revealed that the short-run effect on the HPI is fluctuating but often negative, especially in the first five periods. This is quite interesting, as it may mean that markets initially respond not to increasing prices, but to decreasing housing demand due to increased construction or energy costs (Melecky & Paksi, 2024). This result is consistent with the literature on the impact of cost shocks on the housing market, which argues that energy price shocks can lead to price pressures, but due to supply inertia, this is not immediately reflected (Amonhaemanon, 2014; Fan, 2022). VAR analysis is also important because it allows for the analysis of variable interactions without requiring strict assumptions about cause and effect. However, the limiting factor is the small number of observations, which may affect the stability of the impulse response functions, so the results should be interpreted with caution. However, they open up the possibility of a practical analysis of the impact of shocks, such as during economic crises or energy shocks.

ARIMA(0,1,0) with drift model was applied to forecast the long-term trend of house price (HPI) data until 2028. The model agreed well with historical trends and confirmed the assumption that real estate price growth will continue unless there are major economic shocks. The forecast showed a significant increase in the HPI in the coming years, which can be interpreted as a market reaction to long-term inflationary pressures, rising commodity prices, and a lack of investment alternatives (Díaz, Cunado & de Gracia, 2024). ARIMA models are based solely on a time series structure and are not grounded in economic fundamentals; therefore, they are not suitable for causal analysis. However, they are extremely useful when projections are needed for informed decision-making. In the literature, ARIMA models are often used in urban development planning, real estate market monitoring, and business strategy development (Ratcliffe, Stubbs & Keeping, 2021). The forecast obtained in this study may be useful for policymakers and investors seeking to understand long-term price development trends in the real estate sector in the V4 region.

The Granger causality test was conducted to determine whether commodity prices help predict changes in house prices, i.e., whether commodity variables are useful in predicting house prices based on their time structures. The study analyzed copper prices and the HPI in Hungary. The result – $F = 2.88$, $p = 0.2003$ – indicates that copper prices are not a statistically significant Granger cause of house prices, at least in this country and over this period. This means that past copper price changes do not provide additional information about future house price changes compared to past HPI dynamics alone. This result can be interpreted in several ways. First, it could mean that house prices respond to other goods (for instance, coal or energy sources), or that copper prices act indirectly – through long-term construction costs rather than short-term price dynamics (Ma, Liu & Reed, 2017). Second, it highlights the country contextuality – results may differ in another country or over a longer period. In the literature, Granger tests are often used as an additional tool for causality assessment; however, they are limited to the time structure and do not assess economic reasons. Therefore, they are recommended to be combined with structural models (Shojaie & Fox, 2022). The results obtained in this study help to better understand which raw materials actually have predictive value, allowing us to distinguish the nature of their impact.

LASSO regression was applied as an advanced machine learning method, enabling both the reduction of model complexity and the selection of the most significant variables affecting changes in real estate prices. The advantage of this method lies in the automatic filtering of variables and the solution of multicollinearity, a common problem in econometric analysis involving variables of similar nature (Chan et al., 2022). The results showed that the most important factors remaining in the model with the optimal penalty parameter (λ) were HICP (inflation), Carbon (carbon price), and Unemployment (unemployment rate). These results are consistent with the conclusions of previously used econometric models, when inflation was consistently significant. The significance of carbon in the LASSO model additionally strengthens its effect, highlighted in GMM and VAR analyses. The negative effect of the unemployment rate is also justified economically – growing unemployment reduces the purchasing power of the population, which suppresses the demand for real estate. In the literature, LASSO models are increasingly used in real estate market analysis, especially when the goal is forecasting or feature selection (Ludwig, Feuerriegel & Neumann, 2015; Xin & Khalid, 2018; Chen & Wang, 2024). They are particularly useful when the data set contains many interrelated variables, as in this study. The results of this method complement classical regression

analysis and help ensure that the explanatory variables used are statistically and economically significant. The results of LASSO are also important for real estate investors and policymakers, as they isolate the most significant price drivers and enable them to focus on targeted policies.

Conclusions

This study aimed to assess how the real estate (RE) market in the Visegrad countries has been affected by commodity price dynamics, particularly those of energy and metal resources (coal, copper, and steel) over the past decade. Based on data from 2014–2023 and applying several advanced methods – panel fixed effects models, dynamic GMM analysis, VAR models, ARIMA forecasts, Granger causality tests, and LASSO regression – the aim was to reveal the relationships between commodity prices, macroeconomic factors, and RE prices and investments. The results showed that certain factors, in particular inflation (HICP) and coal prices, have a consistent and statistically significant impact on house prices. Other factors (GDP or wages) are not significant. Real estate prices had a short-term negative impact from changes in raw material prices. The models used helped to identify the main factors, reveal their structure, and offer possible forecasts for the further development of the real estate market.

RQ1: Based on fixed effects, GMM, and LASSO models, it can be stated that commodity price fluctuations had a significant impact on real estate market activity; in particular, the impact of coal prices on house prices was observed in both econometric and machine learning models. This suggests that energy commodities are a crucial component of construction and housing price formation.

RQ2: The study revealed that the prices of certain commodities (coal) are significantly related to house prices, which may indirectly be related to investment in the real estate sector. However, as the study focused on the HPI, additional investment data would be needed to fully confirm the hypothesis. Preliminary results – partially support RQ2.

RQ3: The ARIMA forecast showed that house prices will continue to rise if current trends continue. In light of the European Union's policy of a neutral economy and its promotion of carbon reduction, it can be expected that the importance of raw materials will decrease in the future, which should lead to a change in the price structure of real estate. In the long term, the forecasts show an upward trend, but with high uncertainty.

The study faced several significant limitations. First, the small number of countries (n = 4) limited the applicability of certain models (for instance, random effects) and increased sensitivity to differences between groups, creating the problem of multicollinearity. Second, the data were annual, making it impossible to analyze the effects of seasonality. Third, it was not possible to include all EU policy changes as separate variables due to the excessive and difficult-to-define amount of data, thus interpreting the impact of EU green policies indirectly. In addition, the limited amount of data on real estate investment prevented a detailed analysis of the dynamics of this variable.

Given the results obtained, it is recommended that RE policymakers and investors monitor the price developments of raw materials, especially coal and energy sources, more actively, as this may indicate future changes in RE prices. Inflation dynamics should also be integrated into RE pricing and valuation methodologies, especially during periods of macroeconomic uncertainty. Future research is suggested to extend the data period and frequency (for instance, quarterly data). Include an extended policy analysis component, such as EU climate target implementation indices. Separately examine investments in the RE sector as a dependent variable using accurate investment data. Finally, extend the study to other Eastern European regions to compare the response of the RE market in different economic contexts.

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