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| --- | --- |
| *Student Full Name* | Robert Jonjic |
| *Student Number* | sba24456 |
| *Module Title* | Strategic Thinking |
| *Assessment Title* | CA 2 Capstone Report |
| *Assessment Due Date* | 02/01/2025 |
| *Date of Submission* | 27/12/2024 |

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Contents

[1. Strategic Overview of the Business Problem 2](#_Toc186190444)

[2. Project Plan 2](#_Toc186190445)

[3. Business Understanding 3](#_Toc186190446)

[4. Data Understanding 4](#_Toc186190447)

[5. Data Preparation 6](#_Toc186190448)

[6. Machine Learning Implementation 7](#_Toc186190449)

[7. Findings 7](#_Toc186190450)

[8. Conclusions and Recommendations 8](#_Toc186190451)

[References 8](#_Toc186190452)

**CA 2: Predicting Housing Prices Using Machine Learning**

# 1. Strategic Overview of the Business Problem

The housing market plays an essential role in economic stability and development. Housing prices directly influence household wealth, investment decisions, and urban planning. Fluctuations in housing prices affect not only individual homeowners but also investors and governments, making the prediction of housing prices a critical task for many sectors. Predicting housing prices with accuracy can help stakeholders make informed decisions about investments, development, and economic policies. Traditional statistical methods have long been used to forecast housing prices, but these techniques often fall short when it comes to capturing the complex and dynamic nature of the housing market. Advances in machine learning offer new opportunities to improve the accuracy and reliability of prediction models by analyzing large datasets and identifying patterns in housing prices more efficiently than traditional methods (Case and Quigley, 1991).

This project builds upon the foundations established in CA 1, leveraging the increased availability of housing data to implement a robust machine learning model. The objective remains to develop a reliable solution for forecasting housing prices based on various features such as property size, location, nearby amenities, and infrastructure. The outcomes have practical applications for real estate companies, investors, urban planners, and policymakers who need data-driven insights for decision-making in the ever-changing housing market.

Housing prices are shaped by a wide array of factors, many of which are interdependent. These include macroeconomic indicators such as GDP growth and unemployment rates, microeconomic factors such as household income levels, and environmental elements like urbanization rates. Understanding how these variables interact provides invaluable insights for crafting policies that can promote economic growth and social stability. The integration of machine learning models into this analysis represents a significant leap forward in identifying nuanced relationships that might otherwise remain obscured.

# 2. Project Plan

Timeline and Milestones

The project was structured to align with a systematic project management methodology, ensuring effective prioritization of tasks and monitoring of progress. Key phases and milestones included:

1. Data Understanding and Preprocessing:
   * Week 1-3: Data loading, cleaning, and feature selection.
2. Exploratory Data Analysis (EDA):
   * Week 4-5: Statistical analysis and visualization of key trends.
3. Machine Learning Implementation:
   * Week 6-8: Model training, evaluation, and optimization.
4. Findings and Reporting:
   * Week 9-10: Synthesizing insights and drafting conclusions.

Challenges and Monitoring

Data Quality: Addressed through rigorous preprocessing steps, ensuring consistency and reliability in the dataset. This included resolving data imbalances and confirming uniformity across time-series entries.

Model Optimization: Iterative experimentation with algorithms and hyperparameters to maximize performance. Particular attention was given to balancing model complexity and interpretability.

Time Constraints: Weekly reviews ensured adherence to the timeline while maintaining flexibility for adjustments. Any delays in specific phases, such as EDA, were mitigated by overlapping tasks with subsequent phases.

# 3. Business Understanding

The housing market’s dynamic nature creates a growing need for advanced prediction techniques that account for diverse influencing factors. Housing prices are not only influenced by intrinsic attributes such as property location and size but also by broader economic, demographic, and social trends. These trends include fluctuations in interest rates, shifts in population density, and changes in income distribution across regions. Machine learning models excel in capturing such complex and multi-dimensional relationships, providing a distinct advantage over traditional methods.

By utilizing machine learning models, this project aims to:

* Enhance forecasting accuracy for housing prices by incorporating economic, demographic, and property-specific variables. Machine learning enables the integration of diverse datasets, from historical price trends to real-time economic indicators, ensuring more precise and timely predictions.
* Identify key drivers of price changes to support data-driven decision-making in real estate investment and urban planning. Understanding these drivers helps stakeholders make informed choices about resource allocation, development priorities, and risk management.

For example, urbanization rates—which reflect the population density of urban areas—are critical for identifying housing demand patterns. As urban areas expand, the demand for housing typically rises, influencing price trends and affordability metrics. Similarly, economic indicators like average income levels provide a lens into housing affordability, highlighting disparities across different regions and socio-economic groups. These insights allow stakeholders to implement informed strategies that address challenges such as housing shortages and affordability gaps.

The project’s scope, as defined in CA 1, excludes commercial real estate and rental markets, focusing solely on housing prices within the European Union. This focus ensures that the analysis remains relevant to policymakers and developers who are tasked with addressing pressing housing challenges. The inclusion of economic and demographic variables ensures a targeted and practical approach, as these factors are key determinants of market behavior. For instance, GDP growth can signal economic prosperity, driving increased housing demand, while unemployment rates might indicate potential market slowdowns.

Additionally, this study emphasizes the importance of understanding regional variations. Housing markets are inherently local, with significant differences in trends between urban and rural areas, as well as across countries and regions within the EU. Factors such as infrastructure development, regional GDP contributions, and migration patterns further influence these trends, making localized insights critical for effective decision-making. Policymakers can leverage these findings to tailor interventions that address specific regional challenges, such as affordable housing shortages in metropolitan areas or underutilized properties in less populated regions.

This comprehensive approach ensures that the findings of this project are actionable and valuable for a wide range of stakeholders. Real estate investors can use the insights to identify lucrative opportunities, while urban planners can align their strategies with projected demand trends. Ultimately, the goal is to provide a robust analytical foundation that supports sustainable and equitable growth in the housing market.

# 4. Data Understanding

Dataset Overview

The dataset sourced for this project includes 310 rows and 29 columns, covering housing price indices and economic indicators. The dataset offers a rich array of variables that enable a comprehensive analysis of the factors influencing housing prices. Key variables include:

* Housing Prices: Time-series data from Q1 2020 to Q3 2024, providing a historical perspective on price trends. This data captures fluctuations over time, making it instrumental in identifying seasonal patterns and long-term trends in the housing market.
* Economic Variables: GDP growth rate, unemployment rate, and interest rates. These indicators are critical for understanding macroeconomic conditions that influence housing demand and affordability. For example, rising GDP growth rates often correlate with increased purchasing power, which can drive housing prices upward.
* Demographic Variables: Population growth rate and urbanization rate. These variables reflect societal trends, such as migration to urban areas, which can create increased housing demand in specific regions. A growing population in metropolitan areas often leads to higher property values due to increased competition for available housing.
* Geographic Metadata: Country, city, region, and climate zone. This information allows for location-based analyses, enabling the identification of regional disparities and localized trends in housing prices. For instance, areas with favorable climates may experience higher housing prices due to their attractiveness to both residents and investors.

Key Observations

1. No Missing Values:
   * No missing values were identified in the dataset, ensuring data completeness and eliminating the need for imputation. This enhances the reliability of the subsequent analysis and modeling processes, as no assumptions need to be made about missing data points.
2. Time-Series Trends:
   * The dataset revealed steady growth in housing prices for major cities like Vienna, suggesting sustained demand in urban areas. These trends highlight the importance of urban centers in driving housing market dynamics, often influenced by factors such as economic activity and infrastructure development.
   * Time-series analysis of housing prices also indicated seasonal patterns, where prices peaked during specific periods, possibly due to market cycles or seasonal economic activity. These insights are valuable for anticipating future price movements and identifying optimal investment periods.
3. Correlation Matrix Insights:
   * The correlation matrix highlighted strong relationships between features such as average income and housing prices, reinforcing the importance of economic indicators. High correlations suggest that average income levels and GDP growth are significant predictors of housing prices, offering a foundation for predictive modeling.
   * Interestingly, urbanization rates also showed moderate to strong correlations with housing prices, indicating that as cities expand and populations concentrate, housing demand increases. This aligns with global urbanization trends, where metropolitan areas often experience heightened real estate activity.
4. Regional Disparities:
   * An in-depth examination of the dataset revealed regional disparities in GDP growth and urbanization rates, which significantly influence housing markets. For example:
     + Cities in Central Europe demonstrated more pronounced price growth compared to peripheral regions, likely due to stronger economic performance and higher migration rates to these urban hubs.
     + Peripheral regions, while showing slower price growth, exhibited unique trends influenced by local economic conditions and infrastructure development. For instance, regions with emerging industries or new transportation links showed pockets of rapid housing price increases.
5. Impact of Climate Zones:
   * Geographic metadata, including climate zone classifications, provided additional layers of insight. Regions with milder climates or tourist appeal, such as Mediterranean cities, tended to have higher housing prices compared to colder or less accessible areas. This observation suggests that environmental factors can also play a role in shaping housing demand and prices.
6. Economic Cycles and Housing Prices:
   * The dataset's time span allowed for the identification of housing price sensitivity to broader economic cycles. Periods of economic expansion, marked by rising GDP and declining unemployment rates, coincided with increased housing demand and price growth. Conversely, economic downturns showed a slowdown in price growth, reflecting reduced consumer confidence and purchasing power.

Additional Insights

The diversity of variables in the dataset offers significant opportunities for in-depth analyses, such as:

* Clustering Analysis: Grouping cities based on similar economic and demographic profiles to identify patterns in housing price behavior.
* Trend Analysis: Examining long-term changes in housing prices across different regions to forecast future trends.
* Feature Interaction Effects: Investigating how combined factors, such as GDP growth and urbanization rates, jointly impact housing prices. For instance, high GDP growth in highly urbanized regions may amplify housing demand compared to less urbanized areas with similar economic conditions.

# 5. Data Preparation

Preprocessing Steps

Building upon CA 1, the following steps were taken to prepare the data:

1. Feature Selection:
   * Selected relevant features, including GDP growth rate, unemployment rate, population growth rate, interest rate, average income, and urbanization rate.
   * Target variable: Housing price index for Q3 2024, chosen for its relevance to stakeholders planning near-term investments.
2. Data Cleaning:
   * Ensured numeric consistency across variables.
   * Removed categorical columns irrelevant for modeling (e.g., Country, City) to streamline the dataset.
3. Data Splitting:
   * Training set: 80% of the dataset.
   * Testing set: 20% of the dataset, used for evaluation.
4. Feature Engineering:
   * Created lagged variables for GDP growth and unemployment rates to capture temporal dynamics.
   * Generated interaction terms (e.g., GDP growth rate x Urbanization Rate) to explore compounded effects on housing prices.

# 6. Machine Learning Implementation

Model Selection

As identified in CA 1, Random Forest was chosen for its ability to handle non-linear relationships and provide feature importance insights. The model was trained using the selected features and evaluated based on predictive accuracy. Additionally, Linear Regression was included as a baseline model for comparison.

Results

* Root Mean Squared Error (RMSE): 5.47
* R² Score: 0.87

Feature Importance

The most influential predictors of housing prices were:

1. Average Income
2. Urbanization Rate
3. GDP Growth Rate

These findings align with the hypotheses outlined in CA 1, emphasizing the critical role of economic and demographic factors in housing price dynamics. Notably, Average Income’s dominance as a predictor reflects its strong association with purchasing power and housing affordability.

# 7. Findings

Trends

1. Housing prices exhibited consistent growth across most regions, with metropolitan areas experiencing sharper increases compared to rural areas.
2. Economic indicators such as GDP growth and average income were the strongest predictors of housing prices, validating their inclusion in the feature set.
3. Demographic factors, particularly urbanization rates, highlighted the evolving demand for housing in densely populated regions.

Model Insights

The Random Forest model effectively captured the relationships between features, achieving high predictive accuracy. Feature importance analysis provided actionable insights into the primary drivers of housing price changes. Scatter plots of predicted versus actual values demonstrated the model’s robustness, with minimal residual errors observed.

# 8. Conclusions and Recommendations

Conclusions

This project successfully applied machine learning techniques to predict housing prices with high accuracy. The insights generated provide valuable guidance for stakeholders in the real estate sector, enabling informed decision-making. By identifying key predictors such as Average Income and Urbanization Rate, the analysis underscores the importance of addressing economic and demographic disparities to ensure housing accessibility.

Recommendations

Algorithm Improvements:

* Perform hyperparameter tuning to optimize the Random Forest model further, particularly by expanding the search space for parameters like minimum samples split and maximum features.

Data Enhancements:

* Incorporate additional datasets, such as housing supply-demand metrics and environmental data, to improve model generalizability.
* Expand the dataset to include more geographic regions for broader applicability, particularly in underrepresented areas.

Visualization and Deployment:

* Develop an interactive dashboard for real-time housing price predictions, allowing users to input different economic scenarios and receive tailored forecasts.

By addressing these areas, this project can further its impact, offering even greater value to real estate investors, policymakers, and urban planners.

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GitHub link: <https://github.com/CCT-Dublin/ca-1-Robert-Jonjic>