Technocolabs Softwares Inc.

Development of a Regression Model for Predicting Prepayment Rates and Associated Risks in Mortgage-Backed Securities

Prepared by : NAJMA EL BOUTAHERI
Supervised by: Mr. Yasin Ashah
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Table of content:

1. Introduction: **3**
2. Understanding Prepayment Dynamics: **3**
2.1 Factors Influencing Prepayment Behavior: 3
2.2 Historical Data Analysis: 5
a) Dataset Overview and Observations: 5
b) Results and Insights: 7
3. Defining Prepayment Target Variable: **7**
3.1 Binary vs. Continuous Target Variable: 7
a) Binary Variable: 7
b) Continuous Variable: 8
c) Timeframes for Prepayment Variable 8
4. Data Exploration and Feature Engineering **9**
4.1 Examining Available Data 9
4.2 Creating Derived Variables: 10
5. Benchmarking Against Industry Standards: **10**
5.1 Reviewing Existing Models: 10
5.2 Comparing Approaches: 11
6. Risk Association with Prepayment: **12**
6.1 Measuring Prepayment Risk: 12
a) Option-Adjusted Spread (OAS): **12**
b) Duration and Convexity: **13**
6.2 Including Volatility and Predictability: 13
Volatility: **13**
Predictability: **13**
7. Target variable definition: **14**
8. Conclusion: **15**
9. References: **16**

1. Introduction:

Prepayment risk is associated with callable fixed-income securities, where the issuer has the option, but not the obligation, to redeem the bond before its scheduled maturity. For callable bonds, the issuer can return the investor's principal early, halting future interest payments. This risk is specific to callable bonds, as issuers of noncallable bonds do not have this option.

In the case of mortgage-backed securities, prepayment risk arises when mortgage holders refinance or pay off their loans early, leading to the security holder losing future interest payments. The uncertainty in cash flows from these securities means that the yield-to-maturity cannot be precisely known at the time of purchase. If a bond was purchased at a premium (above 100), its yield will be lower than initially estimated due to the early return of principal.

2. Understanding Prepayment Dynamics:

2.1 Factors Influencing Prepayment Behavior:

When it comes to managing mortgage-backed securities, understanding and assessing prepayment risk is paramount. Prepayment risk arises when borrowers repay their mortgages ahead of schedule, which can significantly affect the returns on MBS. Several factors influence prepayment behavior, making it a multifaceted challenge for market participants. This section delves into the key factors that impact prepayment risk, particularly in the context of interest rate volatility.

Interest Rate Levels

Interest rates play a crucial role in influencing prepayment risk. The relationship between interest rates and prepayment behavior is often inversely proportional. When interest rates are low, borrowers are more likely to refinance their mortgages to benefit from reduced monthly payments. This increased refinancing activity can heighten prepayment risk for investors in MBS, as the expected cash flows from the underlying loans are disrupted.
Conversely, when interest rates rise, prepayment risk tends to decrease. Higher rates make refinancing less attractive, leading borrowers to stick with their current mortgages to avoid incurring higher payments on new loans.

Example: During the historic lows in interest rates observed during the 2020 COVID-19 pandemic, many homeowners seized the opportunity to refinance their mortgages to lock in lower rates. This surge in refinancing led to a higher prepayment risk for investors in MBS as the anticipated future cash flows from these securities were reduced.

Economic Conditions

The broader economic landscape significantly impacts prepayment risk. Economic conditions, such as job security, income stability, and overall financial health, influence homeowners' decisions to refinance their mortgages. During periods of economic uncertainty, such as a recession, borrowers may be hesitant to refinance due to concerns about their financial stability. This can result in lower prepayment rates.

Conversely, in a robust economic environment characterized by high employment rates and increased income levels, homeowners are more likely to refinance, leading to a surge in prepayment activity.

Example: The 2008 financial crisis highlighted how economic conditions affect prepayment risk. Many homeowners faced challenges in refinancing during this period due to declining property values and tighter credit conditions, leading to a decrease in prepayment activity.

Borrower Credit Profiles

The creditworthiness of borrowers directly influences prepayment risk. Borrowers with higher credit scores are generally more likely to qualify for refinancing and secure favorable terms. As a result, they may be more inclined to refinance their mortgages, thereby increasing prepayment risk.
On the other hand, borrowers with lower credit scores may struggle to refinance or may face higher interest rates, which could deter them from prepaying their loans. This variation in prepayment behavior based on credit profiles can lead to differing prepayment speeds within a pool of MBS.

Mortgage Incentives

Various incentives can impact prepayment behavior. For example, some mortgage agreements include prepayment penalties designed to discourage borrowers from refinancing early. These penalties can effectively reduce prepayment risk.
In contrast, government programs or lender initiatives aimed at promoting homeownership, such as refinancing programs, can encourage borrowers to refinance, thereby increasing prepayment risk.

Example: The Home Affordable Refinance Program (HARP) was introduced to assist underwater homeowners in refinancing their mortgages. This program led to increased prepayment risk in certain pools of MBS due to the higher rate of refinancing among eligible borrowers.

Geographic Location

The geographic location of properties within a mortgage-backed security also affects prepayment risk. Housing markets can vary significantly across regions, influencing prepayment patterns. In areas with rapidly appreciating home values, borrowers may be more inclined to sell or refinance their properties, leading to higher prepayment risk.
Conversely, in regions with stagnant or declining home values, prepayment risk may be lower as borrowers are less likely to move or refinance their homes.

Seasonality

Seasonal factors can also influence prepayment risk. Certain times of the year, such as spring and summer, are typically more active for home purchases and refinancing. This seasonality can result in higher prepayment rates during specific periods, which investors need to consider when assessing prepayment risk.

Mortgage Type

The type of mortgage held by borrowers can impact prepayment risk. Adjustable-rate mortgages (ARMs) are more sensitive to interest rate fluctuations, which can lead to more variable prepayment patterns. Fixed-rate mortgages, with their stable interest rates, generally exhibit more predictable prepayment behavior.

Investor Behavior

Finally, investor behavior can influence prepayment risk. Investors who anticipate increased prepayment risk may adjust their investment strategies, such as selecting MBS with different characteristics or varying coupon rates and maturities, to mitigate the impact of prepayments on their portfolios.

2.2 Historical Data Analysis:

To understand prepayment dynamics and assess prepayment risk, analyzing historical mortgage loan data is crucial. Here, we analyze a sample of historical mortgage loan data with features such as credit score, first payment date, occupancy, and loan performance metrics. This analysis aims to identify trends and patterns in prepayment behavior based on the provided dataset.

a) Dataset Overview and Observations:

The dataset provides various features related to mortgage loans, including borrower credit scores, mortgage insurance premiums (MIP), loan-to-value ratios (LTV), debt-to-income ratios (DTI), and loan performance metrics. Below is a detailed analysis based on the provided dataset and additional remarks.

Factors Influencing Prepayment Behavior

Credit Scores

- **Distribution**: The majority of borrowers have credit scores ranging between 500 and 800. A significant number of borrowers, however, have scores ranging from 0 to 19. This unusual range may indicate data anomalies or errors, suggesting a need for further investigation or data cleaning.

- **Implications**: High credit scores generally correlate with a higher likelihood of refinancing and prepayment. The presence of anomalous data points needs to be addressed to ensure accurate risk modeling.

Mortgage Insurance Premium (MIP)

- **Categorical Variable**: MIP values predominantly range between 0 and 1, indicating that most loans either have no insurance premium or a basic level of coverage. MIP should be treated as a categorical variable reflecting the type of insurance policy.
- **Implications**: Understanding the MIP categories can provide insights into the risk profiles associated with different insurance policies.

Original Combined Loan-to-Value Ratio (OCLTV)

- **Distribution**: OCLTV values primarily fall between 80% and 84%, with a notable percentage between 95% and 99%. A small percentage of loans have OCLTVs between 20% and 40%.
- **Implications**: High OCLTV ratios indicate a higher risk of lending, as borrowers have less equity in their properties. This suggests a potential higher prepayment risk for high-OCLTV loans.

Debt-to-Income Ratio (DTI)

- **Distribution**: A significant number of borrowers have a DTI of 0, suggesting strong financial health. Conversely, many have DTI values around 29% or 30%, indicating a stable income relative to debt.
- **Implications**: Low DTI ratios are associated with lower financial risk, which could influence prepayment behavior as financially stable borrowers might refinance to benefit from lower rates.

Property Values

- **Distribution**: Most properties are valued between $8,000 and $250,000, with a small percentage falling outside this range.
- **Implications**: Property value distribution affects the overall loan size and risk. Loans for high-value properties may have different prepayment dynamics compared to those for lower-value properties.

Interest Rates

- **Distribution**: Interest rates are primarily between 6% and 7.5%, with a few extreme values above 7% or below 6%.
- **Implications**: Interest rates within this range are typical for the dataset. Extreme values may indicate special cases or loans with unique terms.

Loan Terms

- **Repayment Periods**: All loans have a 360-month term, but the repayment periods observed range from 30 to 200 months.
- **Implications**: The concentration of repayment periods between 30 and 75 months suggests commonality in the dataset. Longer periods may represent long-term loans, and shorter periods could indicate early prepayments.

b) Results and Insights:

The analysis reveals that most borrowers are not first-time buyers, suggesting that their prepayment behavior may be influenced by previous mortgage experiences. This background could impact their decisions regarding prepayment and refinancing. Additionally, the data shows that the majority of loans are classified as "O" for owner-occupied properties. This classification is important for assessing prepayment risk, as owner-occupied properties often exhibit different refinancing patterns compared to rental properties.
Generally, the dataset shows that California is the most frequent property state, indicating a concentration of loans in this region. This concentration means that regional economic conditions and housing market trends in California will significantly influence prepayment behavior and associated risks. Most loans have repayment periods between 30 and 75 months, with a median around 50 months, reflecting a typical loan duration. However, some loans extend beyond 200 months, representing long-term loans that may exhibit different prepayment dynamics. Interest rates are predominantly between 6% and 7.5%, with rates outside this range potentially indicating unique loan conditions or anomalies. This common range aligns with typical market conditions, though variations in interest rates can impact prepayment behavior. Additionally, the distributions of OCLTV (Original Combined Loan-to-Value) and LTV (Loan-to-Value) ratios are similar, suggesting that borrowers rarely take out second mortgages. This similarity indicates a consistent level of equity in the properties.

3. Defining Prepayment Target Variable:

When building a regression model to analyze prepayment risk in mortgage-backed securities, defining the target variable accurately is crucial.

3.1 Binary vs. Continuous Target Variable:

a) Binary Variable:

A binary prepayment target variable classifies loans into two categories—prepayment versus no prepayment. This approach offers the advantage of simplicity, making it easier to model and interpret, particularly for classification problems. Additionally, it provides clear and straightforward insight into whether prepayment occurred, which can be beneficial for initial risk

assessments. However, this method has the drawback of limited detail, as it lacks granularity in understanding the extent of prepayment. It only indicates whether prepayment happened without providing information on the amount or percentage of the loan that was prepaid.

b) Continuous Variable:

A continuous prepayment target variable quantifies the percentage of the loan amount that has been prepaid, calculated using the formula:
Prepayment Percentage= **(Amount Prepaid/Original Loan Amount)×100**
Here, the Amount Prepaid represents the total amount repaid before the loan's original term ends, while the Original Loan Amount refers to the principal loan amount at inception.
This approach offers the advantage of providing detailed insights into the extent of prepayment, making it particularly valuable for regression models that aim to predict the actual amount or percentage of prepayment. This enhanced level of detail improves the predictive power of the model, enabling a better understanding and forecasting of varying prepayment behaviors, which contributes to more nuanced risk assessments. However, the use of a continuous target variable also introduces complexity, as it requires handling continuous data and may necessitate more sophisticated modeling techniques.

c) Timeframes for Prepayment Variable

12-Month Prepayment: This metric represents the percentage of the loan amount that has been prepaid within the first 12 months of the loan term.

Pros:

- **Short-Term Insights**: It is valuable for identifying early prepayment behavior and assessing the immediate impact of changes in interest rates or economic conditions.
- **Actionable Data**: Provides timely insights into short-term prepayment trends, which can be crucial for formulating immediate risk management strategies.

24-Month Prepayment: This metric measures the percentage of the loan amount that has been prepaid within the first 24 months of the loan term.

Pros:

- **Longer-Term Trends**: It captures a more extended view of prepayment behavior, reflecting longer-term economic factors and borrower decisions.
- **Comprehensive Analysis**: Offers a more thorough understanding of prepayment patterns, enhancing the accuracy of future prepayment risk predictions.

Summary

For a regression model aimed at analyzing prepayment risk, the continuous variable approach—measuring the percentage of the loan prepaid—provides detailed insights into prepayment behavior. The choice of timeframe (12 months vs. 24 months) should align with the

goals of the analysis and the characteristics of the dataset. This detailed approach enables more accurate prediction and management of prepayment risk in mortgage-backed securities.

4. Data Exploration and Feature Engineering

In building a regression model to predict prepayment behavior in mortgage-backed securities, data exploration and feature engineering are critical steps. This process involves examining the available data to identify relevant features and creating derived variables that can enhance the model's predictive power.

4.1 Examining Available Data

Relevant Features:

- **Interest Rates**: Interest rates significantly impact prepayment behavior. Higher rates might discourage refinancing, while lower rates often lead to increased prepayments as borrowers seek better terms.
- **Loan Term**: The length of the loan term can affect prepayment behavior. Shorter terms might result in quicker prepayments due to the higher cost of borrowing.
- **Borrower Income DTI):** Income levels influence a borrower's ability to prepay. Higher income levels might enable borrowers to make additional payments or refinance more easily.
- **Credit Score**: The creditworthiness of borrowers can affect their ability to refinance and their propensity to prepay.
- **Loan-to-Value Ratio (LTV)**: A high LTV ratio might indicate higher prepayment risk if borrowers seek to refinance to reduce their debt relative to the property value.
- **Occupancy Type**: Whether the property is owner-occupied or rented can influence prepayment behavior, as owner-occupiers might be more inclined to refinance.

Considered Features:

- **Interest Rates**: Historical interest rates on the loans.
- **Loan Term**: Original term of the loan and remaining term.
- **Borrower Income**: Annual income or income categories.
- **Credit Score**: Numerical value representing creditworthiness.
- **Loan-to-Value Ratio**: Ratio calculated as the loan amount divided by the property value.

4.2 Creating Derived Variables:

Interest Rate Spread:
The interest rate spread is defined as the difference between a loan's interest rate and the prevailing market rate. This metric helps to assess the attractiveness of refinancing options. Calculated using the formula:
Interest Rate Spread=Loan Interest Rate−Market Interest Rate
it measures how favorable the current loan terms are in comparison to the market rates. This assessment plays a crucial role in influencing prepayment decisions, as a larger spread often indicates that refinancing might be beneficial for borrowers.

Loan Maturity:
The remaining maturity of a loan is defined as the length of time left until the loan is fully repaid. This factor can significantly influence prepayment behavior, as shorter maturities may lead to greater sensitivity to changes in interest rates. The timing and likelihood of prepayment are often affected by the remaining maturity, with shorter-term loans potentially experiencing more pronounced reactions to interest rate fluctuations.

Other Potential Features:
Seasonal trends can significantly impact prepayment behavior, with certain times of the year showing increased refinancing activity. For example, prepayment rates may rise during specific seasons due to factors such as favorable economic conditions or tax considerations. Additionally, geographical location influences prepayment patterns, as regional housing market conditions, including local economic factors and interest rates, can affect borrowers' decisions to prepay their loans. Furthermore, the type of property—whether single-family or multi-family—can also impact prepayment risk. Different property types may exhibit varied prepayment behaviors due to their unique market characteristics and economic conditions.

Summary:
Data exploration and feature engineering are crucial for building an effective regression model to predict prepayment risk. By examining relevant features and creating derived variables such as LTV, interest rate spread, DTI, and loan maturity, you can enhance the model's ability to capture the complexities of prepayment behavior. These steps ensure a thorough analysis and improve the predictive accuracy of the model.

5. Benchmarking Against Industry Standards:

Benchmarking against industry standards is essential to ensure that the methodologies and models employed for prepayment risk analysis are robust and aligned with best practices. This section provides an overview of common methodologies used in prepayment risk analysis and assesses their suitability for our dataset.

5.1 Reviewing Existing Models:

Cox Proportional Hazards Model:

The Cox Proportional Hazards Model is a widely used technique in survival analysis that models the time until an event, such as loan prepayment, occurs. It evaluates the impact of various covariates on the hazard rate, which represents the risk of prepayment at any given time. This model is particularly useful for analyzing time-to-event data and is capable of handling censored data, such as loans that have not been prepaid by the end of the study period. Its advantages include the ability to incorporate multiple covariates, handle censored data, and the flexibility of not requiring a specific distribution assumption for the baseline hazard function. However, the model assumes proportional hazards, meaning the effect of covariates is constant over time, which may not always hold true.

Logistic Regression:

Logistic regression models the probability of a binary outcome, such as whether a loan is prepaid or not. It estimates the odds of prepayment based on various predictor variables and is well-suited for classification problems where the outcome is categorical. This approach is often used when prepayment is treated as a binary event. The advantages of logistic regression include its simplicity, ease of implementation, and straightforward interpretation, as it provides probabilities for prepayment based on the predictor variables. However, it has limitations, such as potentially oversimplifying prepayment behavior by treating it as a binary outcome and assuming a linear relationship between the predictors and the log-odds of the outcome.

Survival Analysis Models:

Survival analysis techniques, such as the Kaplan-Meier estimator and Weibull regression, are employed to model the time until an event, like loan prepayment, occurs. These methods are particularly useful for analyzing the duration until prepayment and effectively handling censored observations, where the event has not yet occurred by the end of the study period. The advantages of survival analysis include providing valuable insights into the timing of prepayment and managing censored data effectively. However, these techniques may require complex data preparation and rely on certain modeling assumptions, which can present challenges.

Machine Learning Approaches:

Advanced machine learning techniques, including Random Forests, Gradient Boosting Machines, and Neural Networks, can be effectively applied to prepayment risk modeling. These methods are particularly adept at handling complex, non-linear relationships and interactions between variables. The advantages of using these techniques include their ability to capture intricate patterns and interactions in the data, often resulting in superior predictive performance. However, they also have limitations, such as the need for larger datasets and the potential for reduced interpretability compared to traditional statistical models.

5.2 Comparing Approaches:

The suitability of different modeling approaches for prepayment risk assessment varies depending on the dataset and the complexity of the relationships within the data. The Cox Proportional Hazards Model is effective for modeling the time to prepayment, particularly when the dataset includes censored observations. It offers a detailed analysis of time-dependent covariates and their effects on prepayment risk but assumes proportional hazards, which may not apply to all datasets, necessitating careful interpretation of time-dependent effects.
Logistic Regression, on the other hand, is suitable when prepayment is treated as a binary outcome. It provides a straightforward and easy-to-implement approach for analyzing prepayment likelihood, making it an excellent starting point for modeling prepayment risk. However, it may oversimplify prepayment behavior if not extended to handle more complex patterns or time-dependent effects.
Survival Analysis Models are particularly useful for modeling the timing of prepayment, especially when dealing with censored data. These models offer detailed insights into the duration until prepayment and handle censored observations effectively but may require more complex data preparation and modeling.
Lastly, Machine Learning Approaches are well-suited for capturing complex relationships and interactions in large datasets, often resulting in high predictive accuracy. They are capable of handling non-linear relationships and interactions, leading to improved predictive performance. However, these approaches can be less interpretable and require substantial computational resources, with careful model tuning and validation being crucial for their successful application.

Conclusion:
The Machine Learning Approaches may be the most suitable choice. These methods, including Random Forests, Gradient Boosting Machines, and Neural Networks, excel at capturing non-linear relationships and intricate interactions within the data, often resulting in improved predictive performance. While they may require larger datasets and more computational resources, their ability to model complex patterns makes them highly effective for prepayment risk modeling.

6. Risk Association with Prepayment:

6.1 Measuring Prepayment Risk:

a) Option-Adjusted Spread (OAS):

Definition: The Option-Adjusted Spread measures the yield spread of a mortgage-backed security (MBS) adjusted for the risk associated with the option to prepay. It reflects the

compensation investors receive for bearing prepayment risk, considering the potential for prepayment that can affect cash flows.
Application: A higher OAS indicates greater compensation for prepayment risk, while a lower OAS suggests reduced prepayment risk. OAS is crucial for understanding how prepayment risk impacts the overall yield and pricing of MBS.
Importance: Investors use OAS to compare securities with varying levels of prepayment risk and to evaluate the value of the prepayment option embedded in MBS.

b) Duration and Convexity:

Duration: This metric measures the sensitivity of an MBS's price to changes in interest rates, representing the weighted average time until the security's cash flows are received.

Convexity: This measures the curvature in the relationship between the security's price and interest rates, providing insight into how the duration of the security changes with interest rate fluctuations.

Duration assists investors in assessing the price volatility of mortgage-backed securities (MBS) in response to changes in interest rates, while convexity provides further insights into how price sensitivity evolves with larger movements in interest rates. Accurate measurement of both duration and convexity is crucial for effectively managing interest rate risk and understanding how prepayments affect MBS pricing.

6.2 Including Volatility and Predictability:

Volatility:

Definition: Volatility captures the variability in prepayment rates over time, reflecting how much prepayment rates fluctuate due to changes in interest rates, economic conditions, and borrower behavior.
Application: High volatility in prepayment rates indicates greater uncertainty and risk for investors. Analyzing volatility aids in understanding the stability of prepayment behavior and its impact on cash flows.
Importance: Measures of volatility help investors and analysts assess the risk associated with MBS and develop strategies to manage or hedge against unexpected changes in prepayment rates.

Predictability:

Definition: Predictability refers to how well prepayments can be forecasted based on historical data and model predictions, assessing the accuracy of forecasts regarding future prepayment behavior.
Application: Predictable prepayment behavior allows for more accurate risk assessment and

better investment decision-making. Models that can accurately predict prepayment trends facilitate optimized investment strategies and risk management.
Importance: High predictability enhances the ability to forecast cash flows and manage prepayment risk, leading to more informed and strategic investment decisions.

7. Target variable definition:

Prepayment Target Variable:

The chosen prepayment target variable is the percentage of the loan that has been prepaid, which is a continuous variable. This selection offers detailed insights into the extent of prepayment, moving beyond a simple binary outcome. By using a continuous variable, the analysis and modeling of prepayment behavior become more nuanced. This approach allows the regression model to capture variations in prepayment levels and better understand the factors influencing the degree of prepayment.

Potential Features:

- **Interest Rate**: The rate at which the loan was originated and its current rate. Higher interest rates may deter prepayment, while lower rates may incentivize it.
- **Loan Term**: The original duration of the loan. Shorter terms may lead to higher prepayment rates as borrowers seek to avoid higher long-term payments.
- **Loan-to-Value Ratio (LTV)**: The ratio of the loan amount to the property value. Higher LTV ratios can indicate higher prepayment risk as borrowers may refinance to improve their loan terms.
- **Debt-to-Income Ratio (DTI)**: The ratio of the borrower's debt payments to their income. Higher DTI ratios may affect the likelihood of prepayment.
- **Prepayment Penalties**: Fees charged for early repayment. Higher penalties may reduce prepayment risk.
- **Property Value**: The market value of the property, which can influence prepayment decisions.

Explanation: Each feature is selected based on its relevance to prepayment behavior. Interest rates and loan terms directly affect prepayment incentives, while LTV and DTI provide insights into the borrower's financial situation. Prepayment penalties and property value further influence prepayment decisions.

Recommendations:

To enhance the accuracy of the model, further analysis should be conducted to explore additional features, such as macroeconomic indicators and borrower credit profiles. These factors could provide a more comprehensive understanding of prepayment behavior. Model adjustments should also be considered, including the incorporation of non-linear relationships and interactions between features, which can help capture the complex patterns inherent in prepayment behavior. Additionally, it is crucial to regularly update the model with new data to

ensure that it remains relevant and accurate in reflecting changes in prepayment trends and market conditions.

8. Conclusion:

In conclusion, the analysis of prepayment risk within mortgage-backed securities highlights the intricate relationships between borrower characteristics, loan features, and market conditions. By focusing on a continuous target variable that measures the percentage of loan prepayment, this study provides a detailed understanding of prepayment behavior. The exploration of key features, such as loan-to-value ratios, interest rates, and debt-to-income ratios, along with the creation of derived variables, contributes to the robustness of the predictive model.

Benchmarking against industry standards reveals the effectiveness of various methodologies, while the inclusion of risk metrics such as Option-Adjusted Spread (OAS), duration, and convexity underscores the complexity of prepayment risk. The consideration of volatility and predictability further enhances the model's ability to capture dynamic market conditions.

The findings suggest that incorporating additional features, exploring non-linear relationships, and ensuring regular updates to the model are essential steps for maintaining accuracy and relevance. These insights not only advance our understanding of prepayment behavior but also offer valuable recommendations for future analysis and model refinement.

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