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Innovations In Mortgage-Backed Security Analytics: A Patent-Based Technology Review

Someshwar Mashetty*

*Lead Business Intelligence Developer, Federal National Mortgage Association, Reston, VA, somesharmashetty@gmail.com, ORCID ID: 0009-0008-1803-9508

***Corresponding Author:** Someshwar Mashetty
Lead Business Intelligence Developer, Federal National Mortgage Association, Reston, VA, somesharmashetty@gmail.com, ORCID ID: 0009-0008-1803-9508

Abstract
A Mortgage-Backed Security (MBS) is a type of asset-backed security that is secured by a collection of mortgages. As is common for the majority of securitized assets, investors are concerned with the risk and premium associated with MBS. The economic crisis was spearheaded by the burst of the housing bubble and the deteriorating of subprime mortgage performance. With the first increase in default rates, investors' perception of the risk associated with MBS drastically changed. Monitoring MBS performance and analyzing the quality of cash flows has become a necessary task for investors, pension funds, banks and other financial institutions.
MBS performance depends on the quality of the underlying assets, i.e. the mortgages backing the securities. As with most structured finance products, the main cash flow risk is that of prepayment. Early payoffs, by either mortgage default and foreclosure or payment of mortgages' face value, usually occur during periods of falling interest rates and refinancing of existing higher-interest loans. Investors are therefore concerned with the timing of those cash flows, as well as MBS duration relative to other bonds. Due to the typical negative convexity associated with MBS, the performance is also non-monotonic with respect to movements in interest rates. This means that, other things being equal, longer duration MBS will outperform a given, shorter duration MBS when interest rates move down (up), provided the short MBS remains trading-rich (cheap).

Keywords: Mortgage-Backed Security, Asset-Backed Security, Subprime Mortgage, Housing Bubble, Economic Crisis, Default Rates, Cash Flow Risk, Prepayment Risk, Mortgage Performance, Investor Risk Perception, Interest Rates, Refinancing, Negative Convexity, Bond Duration, Structured Finance, MBS Performance, Mortgage Default, Early Payoff, Financial Institutions, Cash Flow Monitoring.

1. Introduction

The mortgage-backed security (MBS) market is one of the largest fixed income markets. MBS have become increasingly prominent in investment portfolios of financial institutions, mutual funds, and pension funds. MBS are also major funding sources for banks and thrifts and play critical roles in the housing market and monetary policy transmission channels. Various MBS-related instruments, including long Treasury bonds, new securities such as collateralized mortgage obligations, and mortgage futures contracts play important roles in the development of global financial markets as well as MBS markets. Because of the major roles that MBS play in the financial system and the economy, the Treasury and the Federal Reserve have devised and adopted various policies to stabilize MBS markets.
The global financial crisis was largely triggered by the collapse of the MBS markets, and so, policies designed to alleviate MBS turmoil and their effects have played important roles throughout the crisis and its aftermath. Moreover, the Federal Reserve devised and instituted some of the largest monetary expansion programs in history through its MBS purchases to reduce the risk of a deepening recession. Once again, the Federal Reserve's policy initiatives on MBS are under scrutiny as economists and policymakers voice concerns about the negative effects and timing of the Fed's exit from its unprecedented MBS purchases. Given the importance of MBS markets, monitoring current developments and testing various MBS-related economic hypotheses are key tasks that financial market practitioners, academic researchers, and policymakers must undertake to account for the recent developments in MBS and the economy.

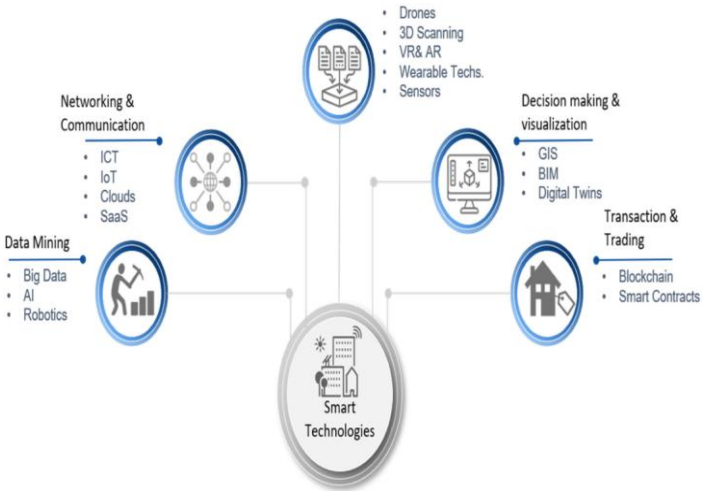

Fig 1 : Leveraging Smart City Technologies for Enhanced Real Estate Development

1.1. Significance of the Study on Mortgage-Backed Securities

Mortgage-derived securities were conceived in the early 1970s with the issuance of Mortgage Pass-Through Certificates by the Government National Mortgage Association in 1970. MBS were made popular in the early 1980s as U.S. interest rates increased and unexpected mortgage prepayments caused large economic losses to the holders of U.S. Treasury securities. However, the prepayment risks borne by holders of MBS were substantially mitigated with the issuance of Collateralized Mortgage Obligations by First Boston Corporation in 1983 and Agency CMOs by the Congress-chartered Government-Sponsored Entities in 1986. These two securitization techniques were developed in 1981. CMOs are the most widely sold MBS structure, accounting for 70%–80% of the dollar volume of the MBS market.

In the 1990s, MBS received a strong impetus from the need of the Federal Reserve in the U.S. to reduce economic volatility by managing changes in interest rates, from global capital market developments and increased demand for MBS by U.S. and foreign pension funds and insurance companies, and from the influence on MBS research, development and analytics. Further impetus was provided by user feedback to the U.S. Government in their analytically oriented speeches and discussions within the Eurodollar Market that brought to the attention of financial engineers, technologists and Wall Street traders the required use and future development of increasingly sophisticated prepayment, pricing and GSE assessment models.

2. Background on Mortgage-Backed Securities

Historically, Mortgage-Backed Securities (MBS) have accounted for about one-fifth of the amount owed on all household mortgage debts. Over that period, the US housing market has weathered considerable crises, and other markets have witnessed considerable changes. MBS have withstood the test of time and have been hailed as the most innovative financial instrument. Crucial to their success has been the ability to break each mortgage loan into its individual features and associated value. For investors, the major characteristics affecting valuation have been the coupon rate, the repayment duration, and the risk of prepayment. Using this same methodology, agency MBS have broadened the investor base from pension funds and life insurers to include banks and mutual funds. The dramatic changes in US demographics have allowed the evolution of an unpredictable housing startup and an equally unpredictable mortgage repayment rate.

The process of securitization, whereby individual loans are pooled and then subsequently sold to investors as securities, has provided the basis for the development of MBS. The main motivation for lenders to undertake securitization is that it provides a source of funds for future lending, mitigates liquidity problems, and allows financial institutions to manage their interest rate risks more effectively. To gain full acceptance for MBS, it was essential that investors have a reliable means of estimating the value of the securities. Valuation would involve predicting the principal and interest cash flows and determining the appropriate interest rate to apply. However, given the uncertainties surrounding the underlying mortgage loans, creating these cash flows is a complex process.

Equation 1: Affordability Analytics Ratio:

$$A_r = \frac{I_m}{H_e}$$

where:

- A_r = Affordability ratio
- I_m = Median household income (target population)
- H_e = Average housing expenditure (rent or mortgage)

2.1. The Role of Data Analytics in Enhancing Mortgage-Backed Security Performance

Although the dollar volume of official MBS transactions rose nine and a half fold from 1983 through 2017, from 76 billion dollars to 803 billion dollars, the dollar volume of transactions constituted by data analytics-driven risk assessment MBS

activity grew more than ten-fold faster over the same period. However, increasing MBS-specific data accessibility and transaction transparency prompted commercial usage of data analytics long before more formal data agencies established them as MBS performance-enhancing processes. The relatively moneyless reliability of these data analytics-driven structures, and related triple-A ratings, became evident with the advent of MBS Explanatory Data. The advantages of ExData-rich CLOS focused increasingly on more commercially utilized models on MBS areas. Wealth managers and economic advisors, however, often simply earmarked ExData outputs as "MBS and Prepayment Spreadsheet Models" for expansion Workstations and Desktop applications. Not until 2000 did the Credit Risk Management Group initiate much broader use of such models with MBS DataFax inputs.

Like non-mortgage debt securities denominated in the same currency, the exponentially expanding money efficiency gap plus the exponentially advancing market power of speculators motivated heavy investor use of data analytics to reduce financial market costs, and thereby investor portfolio costs, including those specific to MBS investments. Once again however, the diminutive size of the MBS market relative to other capital markets highlighted its propensity for performance enhancement. Almost face-to-face competition among institutions offering MBS services amplified the positive effects of the MBS services C Directive. Risk conscious MBS investors responded favorably to this wave of ameliorating demand as the steepening yield curve reduced investment costs associated with MBSs.

Fig 2 : Residential Real Estate's Potential

3. Importance of Analytics in Mortgage-Backed Securities

Analytics are critical in today's MBS market, which is a large, complex, and opaque market driven by many interrelated economic, demographic, and market factors that are in continuous flux. The MBS sector is one of the largest fixed-income sectors, with an aggregate market value of $12 trillion, and is critical for informing the activity and efficiency in other fixed-income sectors. The MBS sector is dominated by agency pass-through securities and collateralized mortgage obligations. Agency CMOs, which are supported by the MBS guarantees of government-sponsored enterprises, account for over 95% of the MBS sector. As of the end of 2021, roughly 70% of the mortgage market is securitized, amounting to $10 trillion.

MBSA is important because the cash flows are claimed by both bondholders and the issuing GSEs, and the order of claims determines the price of the securities and the lending practices and interest rates of GSEs. This importance is raised further by the relatively low return of MBS, which is compensated by the negative correlation of MBS returns with stocks. Low MBS returns and high correlation between MBS and other securities further raise the risk to bondholders. Further issues are introduced by the fact that most mortgages are prepayable in an uncertain manner. Prepayment risk is especially significant when the housing market cools down and prices become random. In this state, housing prices are negative or otherwise do not anticipate the borrowing rates. The prepayment problem can only be partially addressed by building better prepayment models. These are the reasons for our obsession with the analytics behind MBS and for our special focus on the technological innovations in the relevant software tools.

3.1. The Critical Role of Data-Driven Insights in Mortgage-Backed Securities

We start with an overview of the MBS industry and the role of analytic work. MBS are securities pools of home mortgages packaged by either government-sponsored enterprises or private financial institutions. These securities are sold in the secondary market, either as passthrough concerns, which pass the cash flows from mortgage repayments to the owners, or as structured concerns, which slice cash flows into tranches having different bond characteristics. MBS are popular with a wide range of investors because they allow the property market to be traded and offer a high level of liquidity.

Data-driven insights are key to investment valuation and risk management throughout the investment lifecycle, from origination to settlement, trading, and portfolio management. Typical analytic work includes determining the prepayment, interest rate, and credit transition expectations that drive the cash flows on MBS; pricing the securities; modeling the pricing and related interest rate and credit risk volatility; and managing the risks. For example, in origination and structuring, mortgages are pooled to meet the requirements of the expected funding cost for a specified pool and the related prepayment, market, and credit characteristics of bonds issued. Cash-flow expectations for a loan and security are based on a loan-level causal model that has bank account, mortgage loan, and house price indices as drivers. The investors who buy MBS to hedge a long position in the mortgage loan market are the main analysts in this area. The leading variable-forecasting model incorporates a vector of historical series to determine systematics and a vector of assumed smoothed values for the foreseeable future. These prepayment models primarily examine borrower and market incentive explanations for prepayments and borrower transaction costs.

4. Overview of Patent Analysis Methodology

To examine innovations from the perspective of applied science, we use patent data. Patents are a valuable data source when it comes to identifying technological change. Patents embody expansive scientific knowledge, and their key element claims allow researchers to categorize innovations by technological field. Patent records can signify who develops or transfers technology, patent commercialization, patenting viability, and patent markets. Patents also allow insurers and banks to identify how hazard mitigation technology changes over time. Moreover, patents are one of the few quantitative data sets accessible worldwide. Patent families cover more than 95% of innovations valued at over $1 million. Thus, patents would cover marketable security innovations.

We comb through 22,354 patents records across 440 patent classes to develop a new patent classification scheme focusing on MBS and broadly, capital markets. We did this initial scrubbing to provide researchers an opportunity to analyze MBS patent development and MBS modeling tools and to advance any clinically applicable techniques that serve those objectives. We employ the methodology across two sets of keywords used to harvest classes, keywords similar to existing venture capital categorizations including the capital markets, MBS keywords, and their synonyms. Our primary objectives are to identify applied science and patent market activity within MBS technology, class patent distribution, patent applicant plurality, and the top patent actors. Patent lifecycle analysis tracks patent counts over time. Patent development matched with patent class lifecycles reveals the new patent focus, emergent patenters, turnaround actors, and obsolescing patenters.

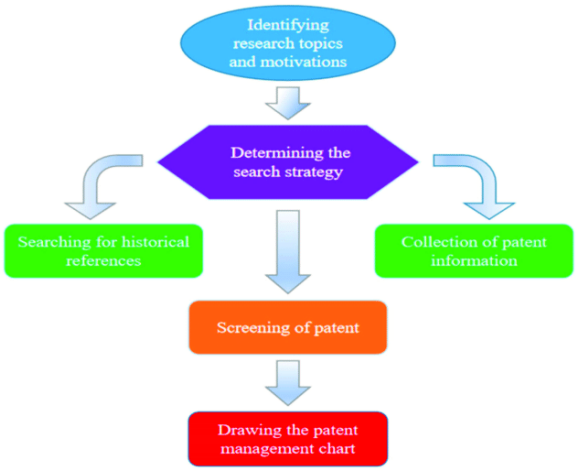

Fig 3 : patent analysis for the energy

4.1. Methodological Framework for Patent Analysis in Mortgage-Backed Securities

To understand the analytics innovations born in the Mortgage-Backed Security (MBS) sector, it is critical to comprehend the roots of innovation in economic-modelling practices. To achieve this goal, we propose to conduct patent-based analysis, which has become a tried-and-tested framework for analysing innovation within various industrial sectors, with a focus on their intellectual property structures. A patent is defined as a legal right to exclude others from making, using, offering for sale, or selling the invention throughout the United States or importing the invention into the United States, for a limited time in exchange for a public disclosure of the invention. Patents are derived from a know-how defence mechanism created by governments throughout history to stimulate private-sector investments in R&D. On a global scale, the institute that has granted the largest number of patents is the relevant patent office.

Nevertheless, patent analysis is a data collection and information extraction scheme that has some weaknesses: (1) patents tend to lag in time and space; (2) patents do not account for the numerous trade mishaps that occur every year and for which patenting is not a defence mechanism; (3) relying solely on a patent data sample would substantially underestimate innovativeness, especially in certain high-speed technological fields; (4) patent document collections provide a very narrow perspective on the reasons for conducting the research that led to the invention; (5) not all innovations are patented; and (6) the variant qualitative levels of innovations covered by various patent documents are not taken into account, nor the differences in the life cycle phases of different products.

5. Key Innovations in Mortgage-Backed Security Analytics

Several patent filings emerging from major financial corporations in this area demonstrate a focus on technologies for data preparation, risk assessment, predictive analytics, and advanced machine-learning-based applications. Here we summarize the intersections of the disclosed technologies for mortgage-backed security analytics applications and patent activity, organized in segments according to the topical area discussions in the greater body of the work. Empirical examples are presented along the way to highlight insightful relationships between innovation trends and technology transfers of derivative concepts. Innovations in Data Processing Techniques: As with any area rich in model-based science applications, especially those that have a business risk management dimension like MBS analytics, supporting processes to prepare and manage data are unsurprisingly a significant focus of invention disclosures. Data management techniques present in MBS security analytics patent filings may be organized into subcategories of market design, input and output libraries, post-processing, and data augmentation. Substantial investment of effort in process development of this kind is important in avoiding data errors, mitigating the consequences of system breakdowns, and delivering model results in useful forms. These concerns are

highlighted here. Innovations in Risk Assessment Models: MBS security analytical modules could be broadly classified into two categories according to their respective objectives: risk assessment and value/trading. The former set of risk models represent the bulk of submitted patent disclosures and patenting activity and center upon evaluating MBS security risks and implementing risk transfer solutions. The risk focus is typically carried through into the latter valuation/trading module set as a means of optimizing the interaction between market-making efforts, primary and secondary market pricing, and MBS security risk exposures. Although the set of solution strategies may vary, the objective is effectively the same: to mitigate exposure to MBS securities market risks over defined time horizons.

$$R_d = \sum_{i=1}^{n} (N_i \cdot W_i)$$

Equation 2 : Data-Guided Resource Distribution Index:

R_d = Resource distribution index

N_i = Need score of region i (based on analytics)

W_i = Weight based on population impact or policy priority

n = Number of regions or zones considered

5.1. Data Processing Techniques

The recent development of new and modified methods and systems for processing different sets of asset performance data for facilitating improved accuracy of mortgage-backed security models is of paramount importance. The inventors' patent research identified data processing techniques publications accounting for more than two thirds of the reviewed patent dataset, consisting of 334 individual patents. The growing quantity of underlying inventions, and their innovativeness, underline the importance of asset performance processing in MBS analytics.

A major limitation of existing asset performance data processing techniques applied in similar papers is that their result is the sum of the performance consequence of all the factors affecting it. This generates negative consequences for the accuracy of MBS analytics model outputs, using product relative durations and convexities measures, informed by modeled product prepayment risk profiles. Nevertheless, the quantification of the performance consequence of the levels of the principal factors and their changes in time on the asset performance for each deal should enable analysts to create more accurate duration and convexity adjustments.

Additionally, the sample predictions, when checked against actual MBS deal performance, are not very good, as they do not check the prediction against the actual observed percentage changes in the deal prepayment speeds. Therefore, the modeling accuracy of the stated sample algorithm and explanation of changes in asset cash flow are major limitations of existing quantitative MBS deal analysis of the prepayment risk, and distribution of the deal cash flow among the MBS deal tranches. Existing MBS prepayment speed analytical methods do not take into account the fact that the changes in the level of MBS mortgage loans are determined by the influence of a combination of diversifiable prepayment causes.

5.2. Risk Assessment Models

Innovations in models addressing the risk assessment of mortgages, mortgage issuers, or issuers of MBS are discussed in this section. Not frequent are innovations related to models explicitly assessing term structure models using prices of mortgage assets to price options simultaneously with term structure and asset prices. The majority of patented models assume a setting where observed MBS prices were not estimated based on the original pool of mortgage assets backing the MBS, at least not for a significant number of MBS and/or original pool parameters were not jointly estimated with the MBS cover or factor amount.

Models that estimate or predict mortgage prepayment rates, forecast default rates, assess or predict how fast a pool of mortgages will run off, or predict one or more of these risk dimensions related to one or more pools are reported. Note the apparent absence of patents proposing models for assessing the FDIC Bank Insurance Fund Risk Formula. It appears that when attending parenting seminars or inadvertently engaged in making public its mortgage prepayment model trade secret did not patent such a workhorse model. Models for workshop risk factor estimation and computational speedup approaches are included. Models for predicting whether anything will occur are described. Models related to risk assessment in the context of pricing, pricing impacts, and risk mitigation are proposed. No breakthroughs in MBS pricing are found. However, a handful of private and public model developers are making unpatented advances. Most are cost basis models recently utilized by loan origination companies placing MBS, particularly deep discount MBS assemble pools expected to be lower coupon and higher price point MBS on a “good deal” basis. Additionally, some pipeline heavier issuers, even hedge funds that are MBS traders somewhat covertly offer better prices now.

Table 1. Matrix of Task Analysis by Level of Analysis and Degree of Discretion

Degree of Discretion Level of Analysis	Low Discretion	Medium Discretion	High Discretion
Micro (Individual)	Data Entry, Issuing Licenses or Permits	Placing Children in Foster Care, Sentencing/Parole	Emergency Response
Meso (Organizational)	Facilities Operations	Hiring Processes, Performance Management	Goal Setting, Strategic Planning
Macro (Institutional)	Statutory Obligations	Policy Formulation	Crisis Response and Management

Source: Adapted from Young, Bullock, and Lecy (2019). Used with authors' permission.

Table 2. Potential Use of AI Tools for Tasks by Degree of Discretion.

Low Discretion	Medium Discretion	High Discretion
Automation	Decision Support Tool, Predictive Analytics	New Data Generation, Reduction of Data Complexity, Relationship Discovery

Source: Adapted from Young, Bullock, and Lecy (2019). Used with authors' permission.

Fig 4 : Algorithmic Risk Management

5.3. Predictive Analytics Applications

When predicting prepayment speeds, only a few patents provide a direct prediction methodology. Usually, prepayment speeds are calculated at various interest rate changes or at selected maturities of their respective zero rate curves. A model provides high-quality prepayment predictions from term structure movements based on interest rate shift probabilities. The interest rate effect on present values of refinancing costs is also noted. Gauges such as the ratio of savings accounts deposits to debt holdings, the ratio of mortgage debt to house prices, the ratio of home equity to housing prices, flood claims and state income taxes describe the time path of US prepayment behavior.

Dynamic models were patented that include some of the above indicators. In particular, a moving seasonal average technique was applied and included the previous month's seasonally adjusted prepayment number. The forecast version is called dynamic seasonal moving average. Dynamic standard models apply to the whole group of mortgages outstanding. The working method is called annualized monthly dynamization, initialized every year with previous month data.

Another methodology that can deliver prepayment predictions is segmentation along risk profiles and estimating the three key parameters survival time, loss given default and default probability. Even so, much more is written in the open sector based on historical data analysis than patenting activity related to the creation of prediction models. Amongst many, the structure of the cohort analysis model is mentioned.

5.4. Machine Learning Integrations

A small, but growing, number of developments are enhancing methods for mortgage-backed security investment with greater integration of machine learning. The general idea here is to improve inputs and estimation by using expansion of artificial neural networks, convolution neural networks, and recurrent neural networks. There is a diversity of models that are intended to enhance various applications including prediction of housing prices by geographic region; prediction of transition, prepayment, and default rates; prediction of mortgage loss severity; prediction of mortgage default risk via stratification; explanation of the causes of mortgage defaults; evaluation of servicer loss mitigation performance; comparison of private-label securities and agency methodologies; via optimization of analyst investment processes for mortgage-backed securities and private-label securities; quantitative exploration of the secondary effects of agency purchases on the real economy; big-data analysis of the housing or mortgage markets; the impact of technological disruptions on housing markets with emphasis on fintech; mortgage fraud detection; and estimation of refinancing thresholds in heterogeneous mortgages using survival analysis. Most of these models are for prediction, but there are a significant number for explanation.

Not only do these models apply to various aspects of mortgage refinancing, but they make use of alternative sources of data that are not commonly found in most analytic models. The main form employed is geographical analysis and big data. Certain terms are central to the use of the non-standard data such as "geosocial" or "supra-local" in reference to the housing or mortgage markets, and so-called advanced technologies for computer appreciation of photo data. Important digital channels also include those that provide big data for communications, consumer purchasing behavior, and mobility.

6. Patent Landscape of Mortgage-Backed Security Analytics

This section presents a patent-based technology review of MBS analytics. It begins by depicting the historical trend related to MBS patenting activity. A more specific description of recent innovations, including details about the assignees and the geographical distribution of patents are included next.

MBS patents were already granted in the 1980s, before the creation of the first MBS market index. Annual patenting activity was relatively high during the 1980s and then decreased through the 1990s. The lowest point was reached between 2000 and 2005. In 2008, perhaps driven by the financial crisis, credit rating agencies were again criticized for the poor quality of the MBS tranches they were rating, and MBS patenting activity peaked again until 2011. Afterwards, the number of patents declined again, and in 2015 it even reached the same low point of 2005.

Six of the ten software patents granted in the last ten years are related to MBS credit risk (interest risk is also covered by some of them). These patents aim at estimating the expected prepayment rates on MBS products to further derive their cash-flows and prices. The method most frequently covered is based on a Cox proportional hazard regression model. Other methods include models based on kernel regression or semiparametric survival modeling approaches. In the banking industry, MBS modeling is used by large banks mainly for risk management and, to a lesser extent, capital allocation purposes since they have

the need to comply with stress-testing requirements raised by regulatory authorities. Moreover, if a certain level of MBS investment is reached, the bank needs to retain part of the MBS exposure in order to comply with the so-called "risk retention rule." Furthermore, the models can also be used for MBS trading strategies.

6.1. Historical Patent Trends

This section reviews the trend of patent publications in MBS analytics over years. Before tracking patent activity in the MBS analytics space, we explain the concept of patent classifications and the reasoning used for our data filtering.

In a patent document, the International Patent Classification (IPC) system assigns symbols to denote the subject matter of the invention. While the IPC establishes a common taxonomy across different fields or sectors, each country may have proprietary patent classifications in their local patent office. The United States Patent and Trademark Office uses Cooperative Patent Classification (CPC), a public-domain classification system while the European Patent Office backlinks both IPC and CPC systems.

To track the patent publications related to MBS analytics, we consult multiple patent classification lists. We then consult the title and abstract of each patent in our initial list and filter out patents that do not address MBS-related topics. We find seven IPC subclasses and six CPC subclasses that relate to MBS modeling and analytics issues. Two classes assigned the most number of patents are G06Q with tag "Data or document processing or management" and "G06F" for "Computing" of IPC Classification and CPC class for "Processing of financial data".

Figure 3(A) shows the annual number of patent filings, while the number of MBS analytics patents issued is plotted in Figure 3(B). The graph shows a strong growth from 1985 to 2000, followed by a plateau period. Patent activity until 1997 was very low with an average of only three patents issued per year. The rise of MBS patent activity seems to be aligned with a constitutional period during the following years. The 2000 spike occurred after two consecutive years of negative returns from commercial MBS. However, the plateau period started just when MBS 2000 returns surged to more than 13% pegging almost every rating category.

6.2. Recent Innovations in Patents

Advances in computing technologies, especially large scale distributed computation, have tremendously facilitated default risk and credit loss estimates of complex mortgage pools with millions of loans, many of which are serviced by subsidiaries. Not surprisingly, there have been several recent patents, mainly from a few large banks, which are active in originating and issuing a large portion of MBS. Some examples include methods using a form of the Cox proportional-hazards model to estimate loss probabilities at the loan and pool levels. These patents allow deriving the hazard rate function for each loan in the pool and for the pool as a whole. These hazard functions do not need to be estimated from historical performance data. The patents elaborate on these models and at what granularity the predictions can be made.

In addition, the patents describe different levels of granularity for the estimation of the embedded depreciation and prepayment functions of pooled loans. Although the field doesn't elaborate on their usefulness, an application could be in deciding when to issue new securities backed by seasoned to maturity loans with a low LTV ratio. One patent proposes a new class of multivariate generalized affine models with a specific variance martingale structure that can be simply affine linear in dynamic factors. These factors are estimated using latent factor estimation methods common in the econometric time series literature and have an affine state equation. The model allows for the same risk premiums of multidimensional affine models with a Gaussian state variable. It can be used in the MBS sector, especially for pricing long-end STRIPs since it allows for a simple risk-return trade-off. Other patents explore the passage of cumulative cash flows through the MBS trust structure and the adverse impact on pricing, and thus security duration, of servicing cash flows associated with elevated prepayment speeds. In such environments, pricing, hedging and decision making with regard to MBS securities become very difficult if policy innovations to avoid such "safety traps" are not implemented.

6.3. Geographical Distribution of Patents

We have used the main patent database for our research, with the full expectation that the great majority of patents on MBS analytics, especially the very early ones describing the fundamental building blocks of MBS, data, cash flow models, prepayment and default risk models, and investment analytics, would be found in this database. Indeed, virtually all these patents are held by US-based inventors and organizations: universities, banks and their affiliates, hedge funds, data and analytics technology firms, mathematical software firms, or other information technology firms. Only a small number of patents of the total are filed in the European Patent Office database. None have been filed in the international Patent Cooperation Treaty, nor in other foreign patent offices in various countries. In the case of the patents in the EPO database, there are multiple overlapping patents in the main database. For this analysis, we have ignored these overlapping patents.

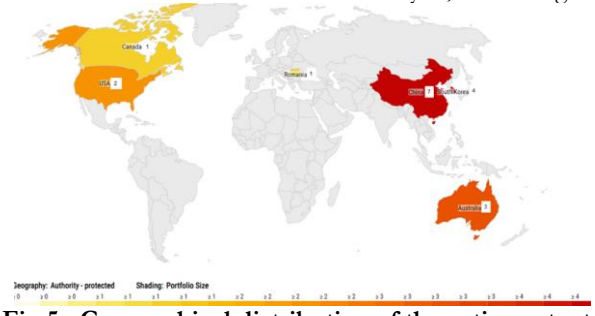

Fig 5 : Geographical distribution of the active patents

The patents filed thus far are dominated by a handful of large organizations: Bank of America, IBM, MSDW, Citigroup, and a small number of patents filed by individual inventors and other organizations. However, the patents are geographically dispersed among these organizations. The bottom line is that the great majority of patents are filed in the main database by US inventors and firms. Both the total numbers of patents, as well as the distribution of patents on MBS analytics, evolve over time as more and more inventions and innovations in MBS analytics achieve patent approval. Some patent clustering occurs during certain periods.

7. Challenges in Implementing Innovations

Implementing technology innovation is challenging, especially for the financial services industry. Certainly, the financial services industry is one of the most regulated industries and regulations cover many aspects, such as product design, company structure, capital requirements, entry and exit, operations and management, and IT security and data privacy. Moreover, the nature of financial services requires a delicate balance of protecting customers and keeping the market open for competition. Consequently, regulation can stall the implementation of excellent ideas. Ideas on price transparency in markets have been abandoned again and again because of the restrictions set by the applicable regulations; such was the case with the price transparency in equity markets. Analysts consider the proposed changes on price transparency for equity markets very carefully. There is openly talk about the need to rethink and rethink the established regulations – given the available technologies, what makes sense today would not have been imaginable a short time ago.

The same dilemma applies to the implementation of technology innovation in the collateralized debt obligation market. The markets were a natural candidate for early algorithmic trading, as the efficiency of electronic bond trading in corporate debt markets would show. Advanced trading models were introduced to managing and returning prop trading desks in investment banks. But: very few bond positions are above a threshold size which warrants algorithmic market making – and the incentive structures of involvement in infra-marginal trades, in the size of a few million wash-trades, are still the subject of the resisting enforcement problems. The sheer size of trading systems requires a continual stable collaboration between vendor and client; even front offices at the investment banks are burned using new technology once too often.

7.1. Regulatory Constraints

Government-backed MBS companies have set in place controlling rules and regulations that need to be strictly adhered to whenever necessary. Industry participants, be they servicing companies, mortgage investors, servicers, or subservicers, must always be in compliance with federal government regulations. The rules are sometimes exacting and inflexible depending on the nature of the market risk or securities that the MBS company is handling. The guidelines were drawn to protect mortgagors, investors, and the MBS programs, and instead of relying solely on vendor relationships, the companies put in place strict, program-specific regulations to ensure compliance. MBS servicers must maintain MBS cash flow for remittance, pay up for all principal and interest shortfalls, and know basically everything going on with the borrower while reporting accurately to the deal trustee and paying tax and insurance on time.

This requirement can seem cumbersome to a servicer, especially if they have to create in-house programs or systems to comply. Assembling different functions throughout the organization to create a uniform compliance program can be advantageous, but programs can be difficult to devise. Vendors are observed closely, but finding new vendors that provide better service can help. Standardizing vendor relationships is important because the MBS servicer must provide a multitude of customers—the quality and accuracy service they each demand as well as remain in compliance with the rules and regulations set in place by loan-level servicers who lay down strict regulatory requirements to be followed.

7.2. Data Privacy Issues

As with any industry that exploits the vast amounts of data generated nowadays, privacy is a significant issue that the mortgage industry faces. This is especially the case with analytics that mine for specific customer behavior. The use of consumer financial data for advertising, marketing, or promotional purposes has long been subject to restrictions, governed primarily by rules established under relevant regulations. Financial institutions are required to periodically disclose their privacy policies to customers and allow them to opt out of having their nonpublic personal information shared or sold for commercial purposes with nonaffiliated third parties. In addition, the use of customer's credit report information for these non-transactional purposes requires the imposition of additional restrictions.

The complexities of compliance requirements are exacerbated by the increasing sophistication of cybercriminals. As financial services firms collected and analyzed greater volumes of consumer, business, banking, credit card, and investment data, they became more attractive targets for hackers, who stole their data via the Internet. For these and other reasons, third-party vendors and financial institutions alike have implemented strict internal and external Gatekeepers, which set out minimum requirements for managing the consumer financial data to ensure privacy and data protection. For example, external Gatekeepers impose due diligence obligations on financial services companies to monitor the data privacy practices of any third party to whom they outsource services. The Gatekeeper obligation requires these institutions to select only those service providers who have demonstrated sufficient capability to perform the required services in compliance with applicable rules. They then monitor their vendors' compliance with the service agreements, contracts, and any regulations, which help minimize data privacy issues.

7.3. Integration with Legacy Systems

A primary challenge experienced by software developers and credit risk analysts is performing integration of analytical solutions using innovative technologies with legacy systems that support long established mortgage company investor-server architectures. However, the mortgage industry as a whole is conservative and slow to adopt new technologies, such as cloud-

native architectures or big data frameworks. Risk analytics implemented in these cutting-edge technologies offer distinct advantages to mortgage securitizers and market participants. New cloud-native risk analytics solutions deployed as a service on a subscription basis provide substantial cost savings to smaller mortgage entities and large mortgage banks that do not have the resources to build these platforms in house.

Mortgage business entities that belong to large banks will have some experience with similar cutting-edge proprietary technologies. Nevertheless, the enterprise-wide specialized software solution for handling the origination and administration of several hundred billion dollars' worth of residential, commercial, government, and asset-backed mortgage loans must necessarily be cloud neutral and country specific. This means that building, validating, and implementing new state-of-the-art credit risk modeling technologies will take at least 5-10 years to go live. These systems will also require either inside programmers or external contractors to constantly maintain and upgrade their analytical capabilities in order to stay relevant and up to date. This trail of custom development, maintenance, and upgrade work would typically run 3-4 times the cost of a single custom build for even a 500-person internal development team. Implementation and deployment would also likely take at least twice the amount of time for industry experts to assemble the required data each period and re-implement the models when external consultants with little industry experience would be utilized.

8. Future Directions in Mortgage-Backed Security Analytics

While mortgage-backed security analytics on residences are fairly mature, there are needs for research and implementation of analytics on other types of collateralized mortgages as well as on the debt instruments themselves. Commercial mortgage-backed securities are backed by commercial mortgages on properties such as office buildings, shopping malls, hotels, and hospitals, and these debt instruments tackle their own sets of challenges regarding default and prepayment risk. Auto mortgage-backed securities are backed by auto loans diagnosed as susceptible for default, while student loan mortgage-backed securities are backed by secured student loans usually arranged through for-profit colleges and universities, and their debt instruments similarly require some unique risk adjustment analytics. Other types of structured finance products also share issues with mortgage liquidity and mutation, cutbacks, loans, and trends. The lessons learned and community built in the mortgage analytics sphere can leverage its strengths with emerging technologies to impact these debt markets as well.

Determining future directions for these debt and mortgage analytics will require milestones in general mortgage liquidity prediction for our country with repetitions for geographic differences, investigations into effects motivating respective market disruptions, and the sharing of sufficient amounts of validated performance data with other members of the Nation's agencies. Recent revisions to the rules and forbearances also caused their effects on the home mortgage demand, while investors are increasingly worried about mortgage prepayments. A resulting reduction in the liquidity of the mortgage-backed securities market would hamper the ability of both Fannie Mae and the Federal Reserve to manage ongoing scenarios with economic fallbacks triggered after a sudden onset. Furthermore, constraints caused by climate change and the current war have shifted the yields on both MBS and hypothetical bonds, confounding liquidity next steps together with mortgage rate reduction risk.

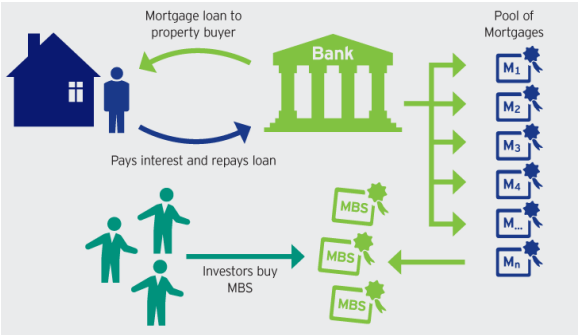

Fig 6 : Mortgage Backed Security (MBS)

8.1. Emerging Technologies

There's currently a major interest in crypto assets, machine learning and AI based trading systems, advanced pricing models for complex financial instruments based on stochastic calculus, deep learning computer vision and natural language processing applications, decentralized finance protocol innovations, quantum computing for supply chain, financial, or trading systems optimization, real-time data analytics for better understanding of nonlinear time dynamics via edge computing and fog computing, better risk management and fraud detection systems. All these topics would greatly leverage the MBS analytics infrastructure. Currently the majority of existing world Financial Systems, Housing Market Systems States, and borrower characteristics are captured via simple spreadsheets.

The ongoing technological innovations in these fields deserve a separate research effort to modify the currently deeply developed MBS analytics technology framework, to include those methods as essential assistant components. The MBS analytics connects Capital Market, Risk Pricing Algorithms, Housing Market Economics, Borrower Underwriting Departments. Each type of computer system has its supporting infrastructure under it. The modules output to each other, synchronizing their infrastructure states. At some point, a state event might occur that triggers the communication between the various components of the MBS analytics framework and modules, which can be seen as an indicator of a risk issue with the bond pricing, CMS or MBS model dynamics used in standard operations by the various departments who own the systems.

Equation 3: Community Development Outcome Score: $C_o = \frac{Q_a - Q_b}{Q_b}$

where:

- C_o = Community improvement ratio
- Q_a = Quality of life score after intervention
- Q_b = Baseline quality of life score before intervention

8.2. Potential Market Disruptions

The architecture for this cross-security analytics effort is largely dependent on inter- and intra-atomic tokenization of any and all bonds into industry standard contract compliant digital tokens. Until this happens, today's nation-state currency and banking product money transfer rails form the likely infrastructure for all financial market transaction disbursements and payments globally. This means that the potential number of sovereign currency authority disruptions to MBS and other bond markets is broad, varied, real-world overdue, and thus the content of this section is broad and multi-faceted.

China's digital yuan and crypto-backed meta-dollar are examples of software-defined nation's state sponsored currency innovation disruptions to both fixed income and bank deposit markets globally. Cryptographic clearing is one of the next developed market and laws approved infrastructure to begin disrupting sub-4% interest rates banks global payments, currency markets, global currency transition payments, and central bank yield curve monetization interests over the next two decades. Each of these currency systemic disruptions is tied to the key statement of inflation being a money stock measurement and that industrial capitalism and regulated labor market equilibrium requires a nation-state controlled level of capital asset price inflation, labor income wage inflation, and thus politically difficult to influence and forward guide interest rates at low levels to help stimulate consumer goods demand and thus GDP growth.

9. Conclusion

We conclude our review by proposing a condensed summary of important points contained in the paper. We provide insights on potential future directions for the mortgage-backed securities industry, and we outline implications for future research, investment, the practice of creating innovation in the MBS space, and the academic community. The mortgage-backed securities market, as part of the larger financial system, is both a prison and a solution to the so-called paradox of maturity: want natural protection against a sudden and unexpected increase in interest rates? The answer is to hold more long-term debt and more short-term debts. The paradox is that a centrally human capital-intensive economy with many long-term and many short-term debts cannot replicate itself without the danger of suddenly rising interest rates triggering credit defaults and bankruptcies. It is also dangerous to a centrally controlled economy that mimics slow-moving economies. The answer? A supporting private, market economy filled with short-and long-term debts denominated in tradable currencies. It is precisely this supporting external private economy that brings the security against an unanticipated damaging increase in interest rates. Mortgage-backed securities were undertaken and designed to provide this confirmation. But they create problems of their own. Some of those grew, during the last 40 years, into the very size of importance that made the economists believe this entire model was empty. MBS plausibly have been too big.

This industry closes the loop. Potential future directions for innovation in the MBS space include the following. First, unnecessary MBS issuance is likely in the absence of either design-based or disaster-reducing incentives. The elevation of the GSEs to public corporations may possibly help with the first. But evidence suggests large MBS issuance is strongly disincentive-based. Second, if the US GSEs rely too heavily on a private system, it may be too liable to tonic.

9.1. Final Thoughts and Implications for the Future of Mortgage-Backed Securities

This paper has reviewed some of the important innovations in MBS analytics that have been patented since 2000, just after the first patent on MBS-specific analytics was issued. We have organized the patents according to the MBS lifecycle and the relevant MBS metrics. Many more patents related to fixed cash flow asset classes are available. Likewise, many innovations could be commercially deployed in MBS sectors, including credit risk, prepayments, delinquencies, defaults, and loss-givens ideas for add-ons. As such, we believe that these add-ons will be patented in the future. The small number of patents in MBS analytics does not mean the analytics are overrated. The triumphs of the analytics were somewhat serendipitous; these analytics were non-existent or overlooked prior to 2000, due to large monopolies and their loose control over MBS sales and MBS math. Over the past two decades, as has been clear in the various commercial tools, technology innovators have utilized or improved these patented innovations. As a result, MBS investor interest has soared, as this asset class is now clearly seen to maximize pre-tax risk-adjusted returns. Liabilities trade cheap in some markets versus collateralized funding. During these decades, technology innovators have utilized or improved these patented innovations to provide commercial wisdom and serve MBS investors.

We turn next to some implications of what lies ahead. MBS have organizational maturity and seem like a permanent fixture of the investment tool chest. Seen in further and further longer time horizons, MBS for investors only gets better. Innovation potential is high since growth capital markets are maturing. Indeed, the incentives of MBS investors in search of higher conditional profits from portfolios of linked CMOs, are evidently large. In addition, MBS are insulated from the recent dynamic growth of government debt and problems of government agencies under capitalized by regulatory incentives to develop innovative talent.

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