Neural Network Model of Mortgage-Backed Security Prepayments

MATHMATICAL MODELLING SEMINAR

Miklós Vörös, MSCI, Nov 2019
US Bond Market

**US Bond Market 2018 (42.4$Tn)**
- Corporate Debt: 9.16
- Treasury: 15.27
- Municipal: 3.83
- Mortgage Related: 9.66
- Monetary Markets: 1.05
- Federal Agency Securities: 1.87
- Asset-Backed: 1.56
- Agency MBS: 8.27
- Non-Agency MBS: 1.39

**US Bond Market 2007 (29.5$Tn)**
- Corporate Debt: 5.33
- Treasury: 4.52
- Municipal: 3.55
- Mortgage Related: 9.39
- Money Markets: 1.79
- Federal Agency Securities: 2.91
- Asset-Backed: 1.96
- Agency MBS: 5.80
- Non-Agency MBS: 3.58
### Why Bother With Housing?

The table below compares the asset return and volatility of housing, bonds, and stocks over a period:

<table>
<thead>
<tr>
<th>Asset</th>
<th>Return</th>
<th>Volatility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Housing</td>
<td>9.31%</td>
<td>2.77%</td>
</tr>
<tr>
<td>Bonds</td>
<td>5.97%</td>
<td>3.47%</td>
</tr>
<tr>
<td>Stocks</td>
<td>5.91%</td>
<td>14.72%</td>
</tr>
</tbody>
</table>

Mortgage-Backed Securities (MBS)

Loan → Originator / Servicer → Securitizer → MBS Pool

Originator / Servicer

Loan

Originator / Servicer

Loan

Originator / Servicer

Loan

Originator / Servicer

Loan

Originator / Servicer

Loan

Originator / Servicer

Loan
Main Risk: Prepayment

Unscheduled Principal Payment

May come from:
• Turnover
• Refinancing
  – Rate, term
  – Cash out
• Default
• Curtailment

Might be affected by:
• General hardship
• Lock out
• Underwriting standards
• Psychology of the individual
• Media effect
• Malicious intent
1% Low Start Rate

Stated Income
No Documentation Loans
100% Finance Available
Interest Only Loans
Debt Consolidation
SE HABLA ESPAÑOL
Modeling Objective

Forecast monthly prepayment rate for Agency RMBS pools

- Measure: monthly SMM - Single Monthly Mortality Rate
- Historical periods: 2003-2015 (train, validate), 2016-2018 (test)
- Raw data:
  - Mortgage characteristics (30 raw attributes from eMBS ~25GB)
  - Macroeconomic and Market conditions:
    - Home Price Index (State level)
    - Mortgage rate
    - Unemployment rate
Machine Learning in Finance

• Consumer credit risk models via Machine-Learning Algorithms (Dr. Andrew Lo, 2010)
  Using machine-learning model for consumer credit delinquency and default
  Generalized classification and regression trees
  Accurately forecasted credit events 3 to 12 months in advance

• Risk and risk management in credit card industry (Dr. Andrew Lo, 2016)
  Analyzed a large dataset consisting of credit card data from six large banks.
  Decision trees and random forests model perform better than logistic regression
  at short time horizon

• Deep learning for mortgage risk (Dr. Kay Giesechke, 2015-2018)
  Using deep neural network to model mortgage prepayment, delinquency and
  foreclosure
  Loan level data
  Compared NNM with a logit model

• Machine Learning and Alternative Data Approach to Investing (JPM, 2017)
  Comprehensive guide for applying machine learning to solve financial problems
Modeling Process

EDA
1. sanity check
2. data cleaning
3. data transformation

Feature selection
1. information value
2. correlation matrix
3. domain knowledge

Build model
1. link weights
2. hyper-parameters

Performance Evaluation
1. error tracking
2. sensitivity

Deep neural network model

Model training
1. Select a set of training data: inputs together with correct/actual output
2. Pass training data through the network to obtain predicted output
3. Feedforward pass: compare actual output with predicted output and determine cost function based on the error calculated
4. Backward propagation: optimize weights and biases (parameters) until some stopping condition has been met by passing the error signal through the network using gradient function

AI Model
Neural Network

Feedforward pass: compare actual output with predicted output and determine cost function based on the error calculated

Select Stochastic Gradient Approach

Tweak weights and biases using gradient function

Values of hidden layers are generated by activation functions with previous layers as inputs, and weights and biases as parameters
Model Setup

The MSCI Machine Learning Model:
• Fully connected, feed forward NN, with multiple hidden layers
• Activation: ReLU
• Optimization: ADAM
• Regularization: dropout, L2, max. norm., batch norm.
• Ensemble: Bagging, averaging
• Hyper-parameter optimization: Grid search

Training:
10 - 90% train, valid split
~3 hours, 150 hours total

GTX 1080 Ti
128GB memory

Main hyper-parameters – and optimal values:
• Number (5) of hidden layers (512, 256, 125, 32, 8)
• Batch size (1024)
• Max-norm constraint (0.5)
• Dropout rate (0.4)
• Activation function (ReLU)
Error Tracking

MSCI ML model and legacy model vs. observed annual prepayment speeds
Effect of Risk Factors

- **FICO**
  - Pre-2008
  - Post-2008

- **Current Loan Size**

- **SATO**

- **CLTV**
Conclusion

Deep neural network models can be used to predict MBS prepayments

The ML model:
• Is able to capture complex prepayment patterns and signals
• Can be built much faster than a manual model
• May also provide valuable insights for manual model building
• Domain knowledge can still contribute (feature selection)
Acknowledgements

Joint effort of MSCI and Ernst & Young

MSCI, Securitized Products Research
• David Zhang, Managing Director
• Joy Zhang, Executive Director

Ernst & Young
• Jan Zhao, Principal, Advanced Analytics
• Fei Teng, Senior Quantitative Analysts, Quantitative Advisory Services
• Siyu Lin, Senior Quantitative Analysts, Quantitative Advisory Services
• Henry Li, Executive Director, Quantitative Advisory Services

Publications:
• Blogpost on msci.com
About MSCI

MSCI is a leading provider of critical decision support tools and services for the global investment community. With over 45 years of expertise in research, data and technology, we power better investment decisions by enabling clients to understand and analyze key drivers of risk and return and confidently build more effective portfolios. We create industry-leading research-enhanced solutions that clients use to gain insight into and improve transparency across the investment process. To learn more, please visit www.msci.com.
## Contact us

<table>
<thead>
<tr>
<th>AMERICAS</th>
<th>EUROPE, MIDDLE EAST &amp; AFRICA</th>
<th>ASIA PACIFIC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Americas</td>
<td>+1 888 588 4567 *</td>
<td>China North</td>
</tr>
<tr>
<td>Atlanta</td>
<td>+1 404 551 3212</td>
<td>China South</td>
</tr>
<tr>
<td>Boston</td>
<td>+1 617 532 0920</td>
<td>Hong Kong</td>
</tr>
<tr>
<td>Chicago</td>
<td>+1 312 675 0545</td>
<td>Mumbai</td>
</tr>
<tr>
<td>Monterrey</td>
<td>+52 81 1253 4020</td>
<td>Seoul</td>
</tr>
<tr>
<td>New York</td>
<td>+1 212 804 3901</td>
<td>Singapore</td>
</tr>
<tr>
<td>San Francisco</td>
<td>+1 415 836 8800</td>
<td>Sydney</td>
</tr>
<tr>
<td>São Paulo</td>
<td>+55 11 3706 1360</td>
<td>Taipei</td>
</tr>
<tr>
<td>Toronto</td>
<td>+1 416 628 1007</td>
<td>Thailand</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Tokyo</td>
</tr>
</tbody>
</table>

* = toll free

msci.com
clientservice@msci.com
Notice & disclaimer

This document and all of the information contained in it, including without limitation all text, data, graphs, charts (collectively, the “Information”) is the property of MSCI Inc. or its subsidiaries (collectively, "MSCI"), or MSCI’s licensors, direct or indirect suppliers or any third party involved in making or compiling any Information (collectively, with MSCI, the “Information Providers”) and is provided for informational purposes only. The Information may not be modified, reverse-engineered, reproduced or redisseminated in whole or in part without prior written permission from MSCI.

The Information may not be used to create derivative works or to verify or correct other data or information. For example (but without limitation), the Information may not be used to create indexes, databases, risk models, analytics, software, or in connection with the issuing, offering, sponsoring, managing or marketing of any securities, portfolios, financial products or other investment vehicles utilizing or based on, linked to, tracking or otherwise derived from the Information or any other MSCI data, information, products or services.

The user of the Information assumes the entire risk of any use it may make or permit to be made of the Information. None of THE INFORMATION PROVIDERS MAKES ANY EXPRESS OR IMPLIED WARRANTIES OR REPRESENTATIONS WITH RESPECT TO THE INFORMATION (OR THE RESULTS TO BE OBTAINED BY THE USE THEREOF), AND TO THE MAXIMUM EXTENT PERMITTED BY APPLICABLE LAW, EACH INFORMATION PROVIDER EXPRESSLY DISCLAIMS ALL IMPLIED WARRANTIES (INCLUDING, WITHOUT LIMITATION, ANY IMPLIED WARRANTIES OF ORIGINALITY, ACCURACY, TIMELINESS, NON-INFRINGEMENT, COMPLETENESS, MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE) WITH RESPECT TO ANY OF THE INFORMATION.

Without limiting any of the foregoing and to the maximum extent permitted by applicable law, in no event shall any Information Provider have any liability regarding any of the Information for any direct, indirect, special, punitive, consequential (including lost profits) or any other damages even if notified of the possibility of such damages. The foregoing shall not exclude or limit any liability that may not by applicable law be excluded or limited, including without limitation (as applicable), any liability for death or personal injury to the extent that such injury results from the negligence or willfull default of itself, its servants, agents or sub-contractors.

Information containing any historical information, data or analysis should not be taken as an indication or guarantee of any future performance, analysis, forecast or prediction. Past performance does not guarantee future results.

The Information should not be relied on and is not a substitute for the skill, judgment and experience of the user, its management, employees, advisors and/or clients when making investment and other business decisions. All Information is impersonal and not tailored to the needs of any person, entity or group of persons.

None of the Information constitutes an offer to sell (or a solicitation of an offer to buy), any security, financial product or other investment vehicle or any trading strategy.

It is not possible to invest directly in an index. Exposure to an asset class or trading strategy or other category represented by an index is only available through third party investable instruments (if any) based on that index. MSCI does not issue, sponsor, endorse, market, offer, review or otherwise express any opinion regarding any fund, ETF, derivative or other security, investment, financial product or trading strategy that is based on, linked to or seeks to provide an investment return related to the performance of any MSCI index (collectively, “Index Linked Investments”). MSCI makes no assurance that any Index Linked Investments will accurately track index performance or provide positive investment returns. MSCI Inc. is not an investment adviser or fiduciary and MSCI makes no representation regarding the advisability of investing in any Index Linked Investments.

Index returns do not represent the results of actual trading of investible assets/securities. MSCI maintains and calculates indexes, but does not manage actual assets. Index returns do not reflect payment of any sales charges or fees an investor may pay to purchase the securities underlying the index or Index Linked Investments. The imposition of these fees and charges would cause the performance of an Index Linked Investment to be different than the MSCI index performance.

The Information may contain back tested data. Back-tested performance is not actual performance, but is hypothetical. There are frequently material differences between back tested performance results and actual results subsequently achieved by any investment strategy.

Constituents of MSCI equity indexes are listed companies, which are included in or excluded from the indexes according to the application of the relevant index methodologies. Accordingly, constituents in MSCI equity indexes may include MSCI Inc., clients of MSCI or suppliers to MSCI. Inclusion of a security within an MSCI index is not a recommendation by MSCI to buy, sell, or hold such security, nor is it considered to be investment advice.

Data and information produced by various affiliates of MSCI Inc., including MSCI ESG Research LLC and Barra LLC, may be used in calculating certain MSCI indexes. More information can be found in the relevant index methodologies on www.msci.com.

MSCI receives compensation in connection with licensing its indexes to third parties. MSCI Inc.’s revenue includes fees based on assets in Index Linked Investments. Information can be found in MSCI Inc.’s company filings on the Investor Relations section of www.msci.com.

MSCI ESG Research LLC is a Registered Investment Adviser under the Investment Advisers Act of 1940 and a subsidiary of MSCI Inc. Except with respect to any applicable products or services from MSCI ESG Research, neither MSCI nor any of its products or services recommends, endorses, approves or otherwise expresses any opinion regarding any issuer, securities, financial products or instruments or trading strategies and MSCI’s products or services are not intended to constitute investment advice or a recommendation to make (or refrain from making) any kind of investment decision and may not be relied on as such. Issuers mentioned or included in any MSCI ESG Research products may include MSCI Inc., clients of MSCI or suppliers to MSCI, and may also purchase research or other products or services from MSCI ESG Research. MSCI ESG Research materials, including materials utilized in any MSCI ESG indexes or other products, have not been submitted to, nor received approval from, the United States Securities and Exchange Commission or any other regulatory body.

Any use of or access to products, services or information of MSCI requires a license from MSCI. MSCI, Barra, RiskMetrics, IPD and other MSCI brands and product names are the trademarks, service marks, or registered trademarks of MSCI or its subsidiaries in the United States and other jurisdictions. The Global Industry Classification Standard (GICS) was developed by and is the exclusive property of MSCI and Standard & Poor’s. “Global Industry Classification Standard (GICS)” is a service mark of MSCI and Standard & Poor’s.

MIIFID2/MIFIR notice: MSCI ESG Research LLC does not distribute or act as an intermediary for financial instruments or structured deposits, nor does it deal on its own account, provide execution services for others or manage client accounts. No MSCI ESG Research product or service supports, promotes or is intended to support or promote any such activity. MSCI ESG Research is an independent provider of ESG data, reports and ratings based on published methodologies and available to clients on a subscription basis. We do not provide custom or one-off ratings or recommendations of securities or other financial instruments upon request.

Privacy notice: For information about how MSCI ESG Research LLC collects and uses personal data concerning officers and directors, please refer to our Privacy Notice at https://www.msci.com/privacy-pledge.