Guided Tour of Machine Learning in Finance

Week 2-Lesson 3-part 3:

Modeling Bank Failures with Neural Networks

Igor Halperin

NYU Tandon School of Engineering, 2017

ML for bank failure modeling

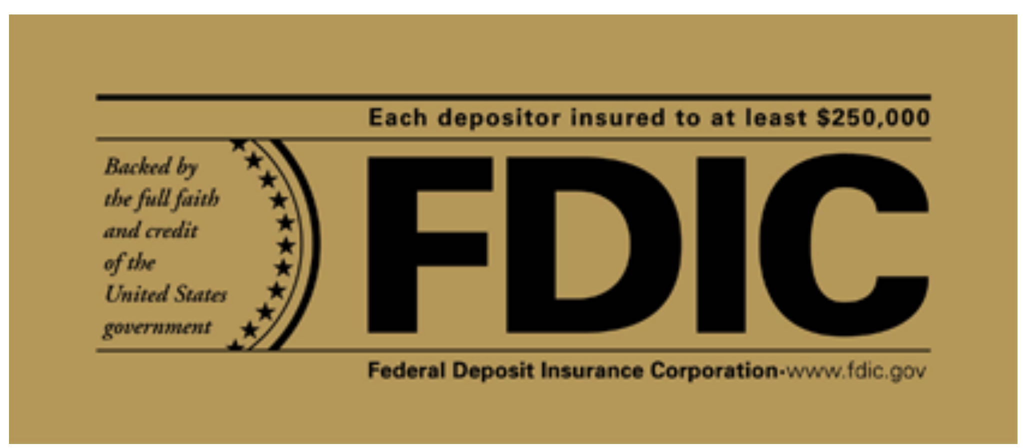
- Here, we apply different ML methods to an open-source dataset of a great practical interest - quarterly reports of all US-based commercial banks collected by FDIC (Federal Deposit Insurance Corporation)

- Why of great practical interest:
  - Inter-bank lending and trading
  - Applications for trading banks' stocks
  - Relevant for modeling of corporate bankruptcies and defaults
  - Can help improve internal default and rating models for regulatory work on stress tests such as CCAR

- Finally, it can be used for benchmarking different ML algorithms as an interesting financial data for Machine Learning, like a "financial MNIST".

Federal Deposit Insurance Corporation

- US-based commercial banks are regulated by the Federal Deposit Insurance Corporation (**FDIC**) (jointly with the Federal Reserve Board and OCC)
- FDIC provides deposit insurance for commercial banks, and charges them insurance premium according to an internal (and non-public) rating based on the **CAMELS** supervisory rating system (see below)
- The FDIC may decide to close a troubled bank and take over its assets and its liabilities
- The most common cause of a bank closure is capital inadequacy



Look for this sign when you come to a bank!

CAMELS measures

- Capital strength
- Asset quality
- Management quality (*)
- Earnings
- Liquidity
- Sensitivity to market risk

Substantial freedom in using specific variables for these 6 categories

Details of the CAMELS rating methodology, and ratings themselves, are **not available to the public**. Some firms produce CAMELS-like ratings or try to reverse-engineer the actual CAMELS ratings.

FDIC ratings are 1 to 5. Banks with ratings of 4 or 5 falls into a “trouble bank list”. Some of troubled banks end up being closed.

(*) Management quality is more subjective, and is sometimes omitted from a quantitative analysis

FDIC call report data

- **Call report** = Consolidated Report of Condition and Income
- Filed quarterly by all commercial banks in the US
- Every National Bank, State Member Bank, and insured Non-Member Bank are required by the Federal Financial Institutions Examination Council (**FFIEC**) to file a call report no later than 30 days after the end of each calendar quarter.
- FDIC oversees insured financial institutions' adherence to the FFIEC requirements, and collect call reports
- **FDIC** call report data is freely available to the public, and is widely used in the industry (hundreds of fields)
- In practice, call reports are not easy to use due to continuous changes in reporting formats (which leads to a lot of missing values…)
- In addition, FDIC provides historical data for failed banks (https://www.fdic.gov/bank/individual/failed/)
- Looks like a good dataset for **Machine Learning**!
- Machine learning methods operate on financial ratios and other variables describing a financial institution such as a bank without enforcing strong assumptions on the functional form of predicted function.

Call report content (schedules)

- **RI—Income statement**
- **RI-A—Changes in bank equity capital**
- RI-B—Charge-offs and recoveries on loans and leases and changes in allowance for loan and lease losses
- RI-C—Disaggregated Data on the Allowance for Loan and Lease Losses
- RI-D—Income from foreign offices (FFIEC 031 only)
- RI-E—Explanations
- **RC—Balance sheet**
- RC-A—Cash and balances due from depository institutions
- RC-B—Securities
- **RC-C, Part I—Loans and leases**
- **RC-C, Part II—Loans to small businesses and small farms**
- RC-D—Trading assets and liabilities
- **RC-E—Deposit liabilities**
- RC-F—Other assets
- RC-G—Other liabilities
- RC-H—Selected balance sheet items for domestic offices (FFIEC 031 only)
- **RC-I—Assets and liabilities of IBFs** (FFIEC 031 only)
- **RC-K—Quarterly averages**
- RC-L—Derivatives and off-balance sheet items
- RC-M—Memoranda
- **RC-N—Past due and non-accrual loans, leases and other assets**
- RC-O—Other data for deposit insurance and FICO assessments
- RC-P—1-4 family residential mortgage banking activities
- RC-Q—Assets and liabilities measured at fair value on a recurring basis
- RC-R—Regulatory capital
- RC-S—Servicing, securitization, and asset sale activities
- RC-T—Fiduciary and related services
- RC-V—Variable interest entities Optional narrative statement—concerning the amounts reported in the reports of condition and income

- 28 schedules in total
- Form FFIEC 031 - for banks with both domestic (US) and foreign offices
- Form FFIEC 041 - for banks with domestic (US) offices only
- Schedules used in this study are in the bold

Control question

Q: Select all correct statements:

1. The Federal Deposit Insurance Corporation (FDIC) provides insurance for deposits at US-based commercial banks.
2. The FDIC assigns CAMELS ratings to all banks, and charges them insurance premia that depend on the assigned CAMELS rating.
3. The FDIC Call Report data is freely available to the public.
4. Both the details of the CAMELS methodology and actual CAMELS ratings assigned to all banks are available to the public at the FDIC home page https://www.fdic.gov
5. The Asset Size (the second letter in the name CAMELS) is the most important factor in the final CAMELS rating assigned to a bank. If Assets are in excess of $30 Bn, the bank is given rating 1 or 2. This precludes a failure by this bank, and thus enhances the overall financial stability.

Correct answers: 1, 2, 3.

Corporate defaults vs bank failures

Many analogies:

- Both are about predictions of rare binary events
- Both use similar predictors (Assets/Debt and other financial ratios)
- Both involve analyzing high-dimensional sequences
- Both can rely on either purely statistical approaches, or on analysis of decision-making processes

There are also **some differences**:

- Some predictors are different as corporations deal with production of goods
- The mechanics of decision-making is very different for corporations vs banks

Corporate defaults: The Merton model

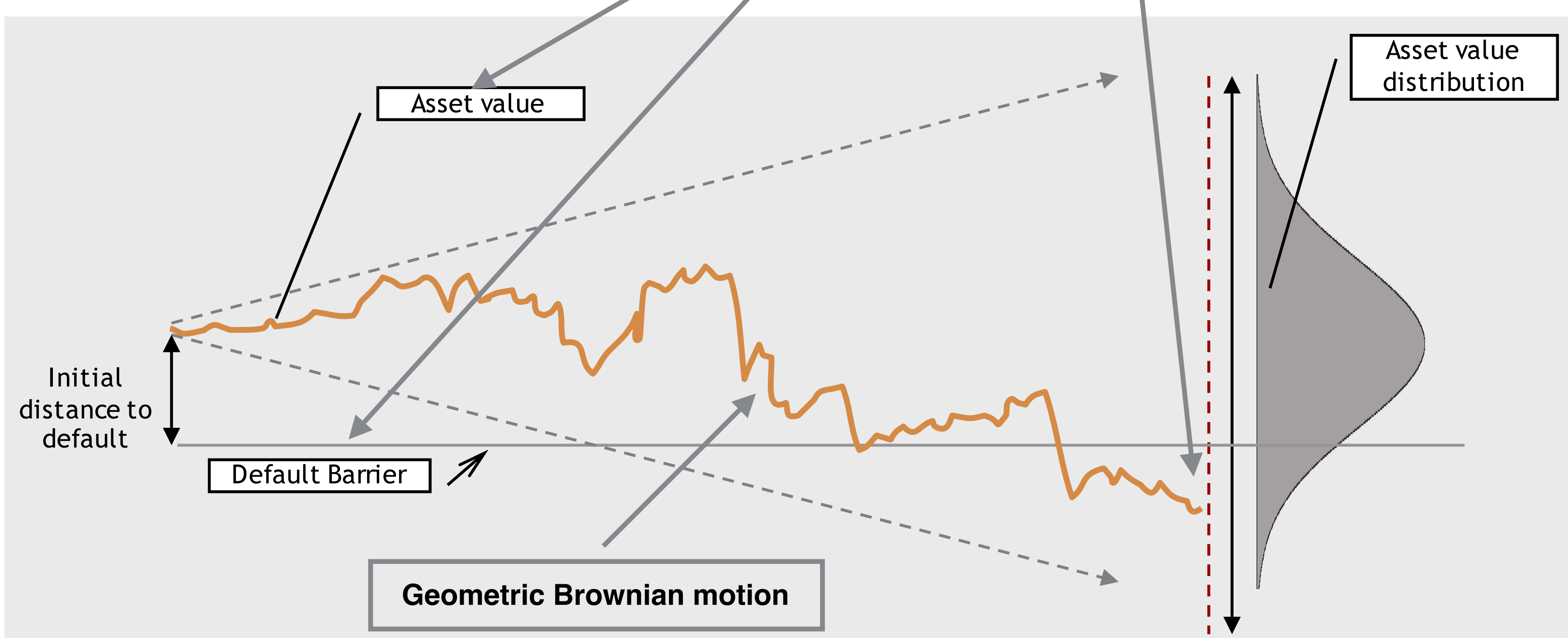
The **Merton model** of corporate defaults (1974-present) is the most popular modeling framework, used as a benchmark for many studies.

A firm is run by equity holders. At time T, they pay the face value of the debt D if the firm (asset) value is larger than D, and keep the remaining amount. If the firm value at time T is less than D, bond holders take over, and recover a "recovery" value V_T, while equity holders get nothing:

$$B_T = \min(V_T, D) = D - \max(D - V_T, 0)$$

$$S_T = \max(V_T - D,\ 0)$$

Limited liability of equity holders



Merton model as a structural default model

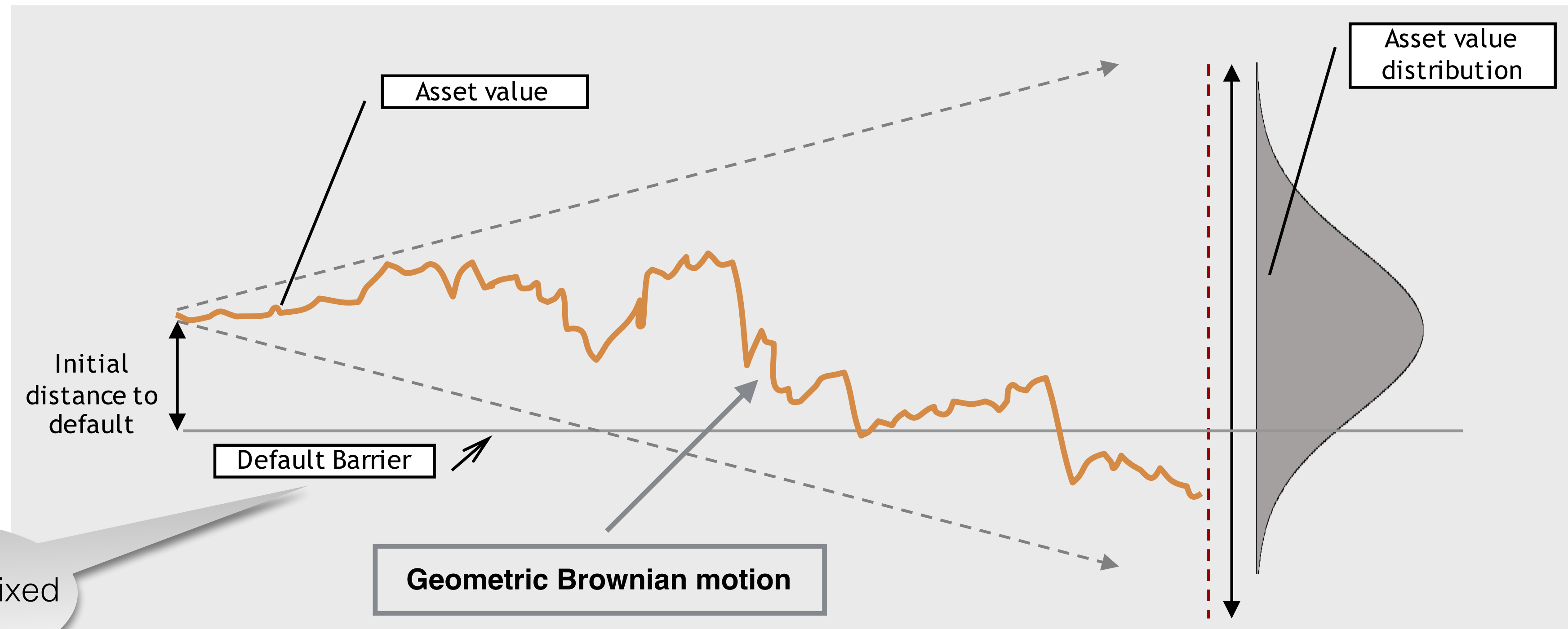
Default probability in the Merton model:

Probabilistic structural model

$$\Pr(default) = \mathbb{E}\left[\mathbb{I}_{V_T<D}\right] = \Pr(V_T < D) = N(-d_2)$$

$$d_2 = \frac{\log\frac{V_t}{D} + \left(r - \frac{\sigma_V^2}{2}\right)(T-t)}{\sigma_V\sqrt{(T-t)}}$$

Depends only on the Assets/Debt ratio and asset volatility



The barrier is fixed and static

Modeling financial institutions

Why financial institutions are difficult to model with the structural Merton approach (Leland 2009):

- High degree of leverage
- Complex debt structure with a large fraction of short-term debt (including deposits and repos)
- Volatility of financial institutions is typically low in normal times, but increases substantially during crises or periods of economic uncertainty.

Predictions with logistic regression

Logistic Regression

$$\Pr\left(\mathrm{Y}_{t+T}=1\mid \mathbf{X}_t\right)=\frac{1}{1+e^{-\sum_i W_i X_{it}}}=\sigma\left(\sum_i W_i X_{it}\right)$$

Indicator of bank failure at time T

Features (financial ratios, categorical etc.)

Sigmoid activation function

Adjustable parameters (sigmoid weights)

Data: 471 failed/assisted banks with at least 2Y of history of FDIC call reports, plus 9375 non-failed banks

Downsampling: 471 failed banks 1Y prior to closing by FDIC, plus 500 largest non-defaulters at random times.

Features: Log_TA, NI_to_TA, NPL_to_TL, etc. (13 ratios in total), plus 7 MEV factors (real_gdp_growth, stock_mkt_growth, bbb_spread, etc.)

Training/test split: train: 310 failed/330 healthy. Test: 161 failed/170 healthy

Control question

Q: Select all correct statements:

1. Financial institutions are more difficult to model than corporations because they have a higher leverage and a more complex debt structure.
2. Financial institutions are more difficult to model than corporations because their fate is in the hands of the FDIC, rather than shareholders, and who knows what they will decide?
3. In the Merton model, there is only one "predictor" d_2 that depends only on the asset-to-debt ratio and asset volatility, but not on other balance sheet or income statement variables.
4. The Logistic Regression model just presented uses two features: d_2 and d_1, where $d_1 = d_2 + \sigma_V \sqrt{(T-t)}$

Correct answers: 1, 3.

LR: performance measures

Logistic Regression:

$$\boxed{p_n(\theta) = p\left(y_n = 1 \mid \mathbf{x}_n\right) = \sigma(\theta^{\mathbf{T}}\mathbf{x}_n) = \frac{1}{1+\exp(-\theta^{\mathbf{T}}\mathbf{x}_n)}}$$

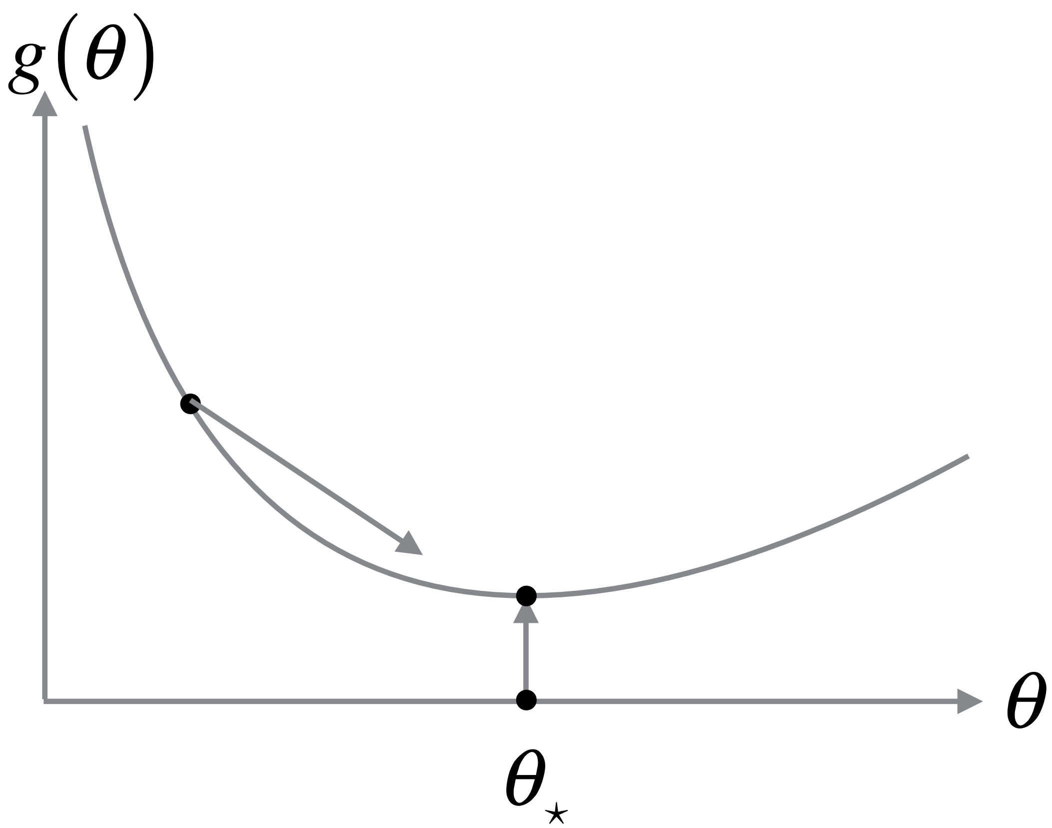
Likelihood:

$$p(\mathbf{D} \mid \mathbf{M}, \Theta) = \prod_{n=1}^{N} p_n(\theta)^{y_n} \left(1 - p_n(\theta)\right)^{1-y_n}$$

observed values {0,1}

Negative LL:

$$-\log p(\mathbf{D} \mid \mathbf{M}, \Theta) = \sum_{n-1}^{N} \left[y_n \log p_n(\theta) + (1 - y_n) \log\left(1 - p_n(\theta)\right) \right]$$

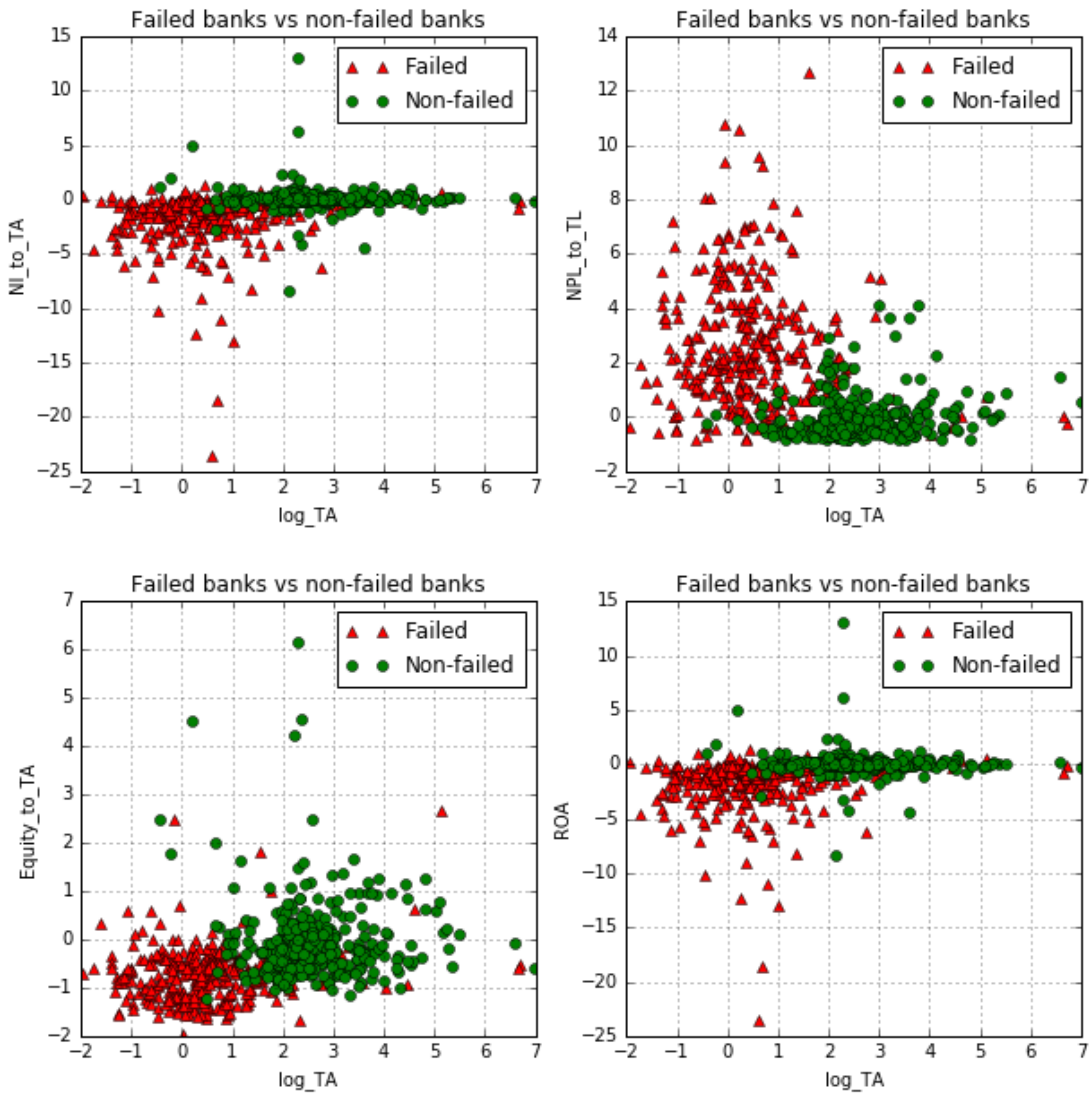


Can be minimized by gradient descent

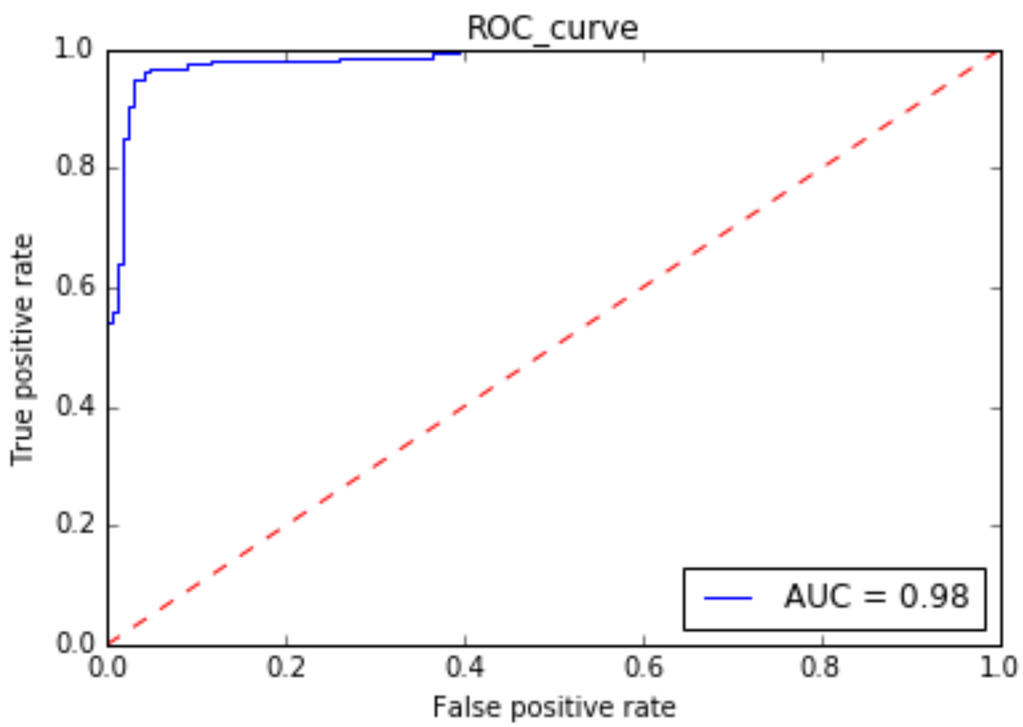
Convex function of θ

Unique solution

Data: 2D views



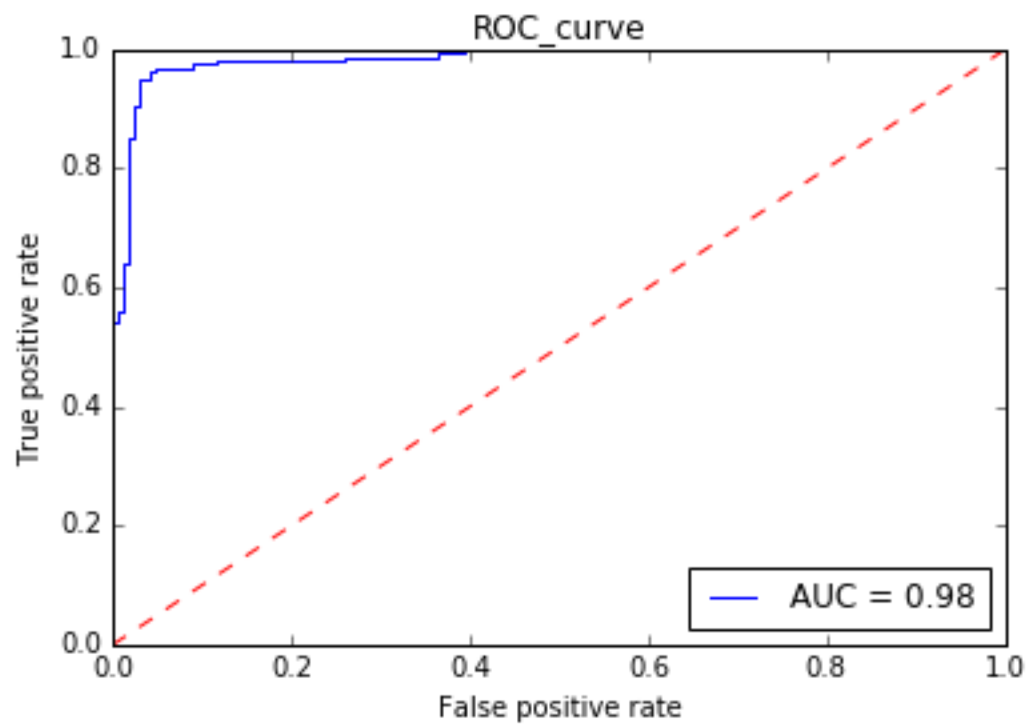
Logistic regression: results

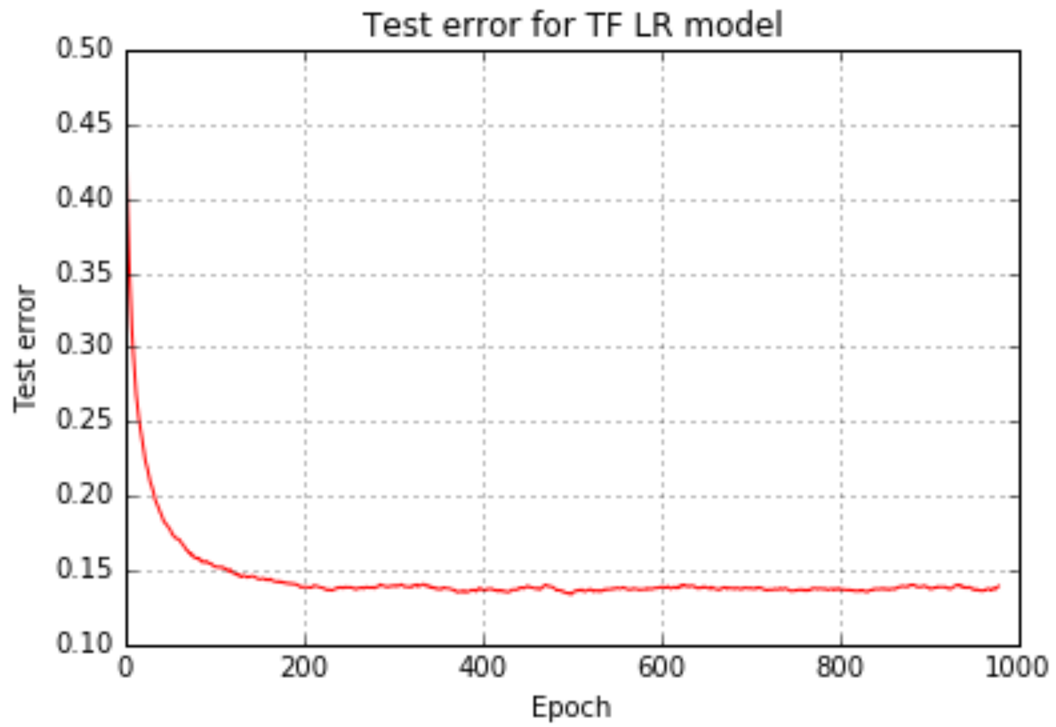


Logistic Regression
Out-of-sample test:

Accuracy score = 96%
AUC score = 98%
KS test = 92%

Logistic regression: results





Logistic Regression
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Accuracy score = 96%
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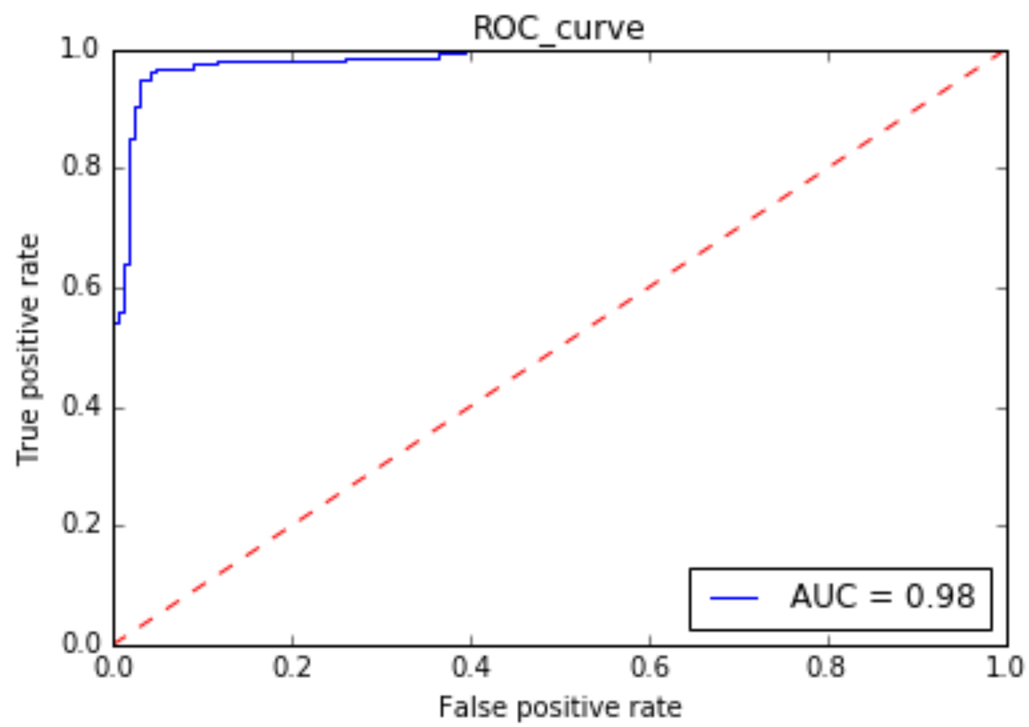
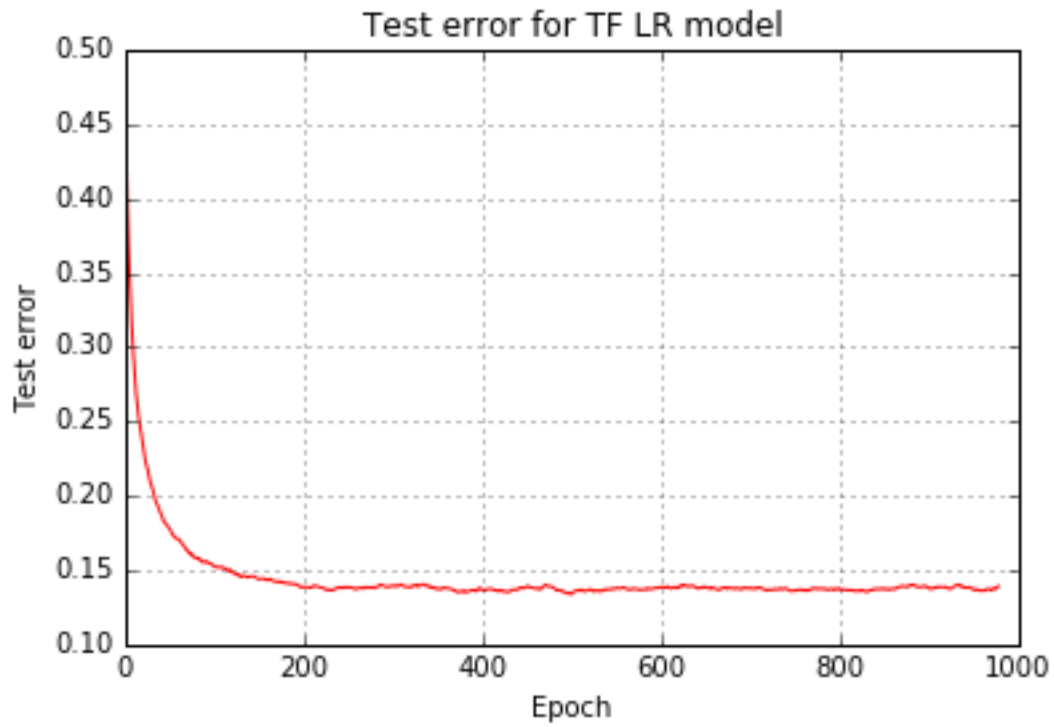
Logistic regression: results



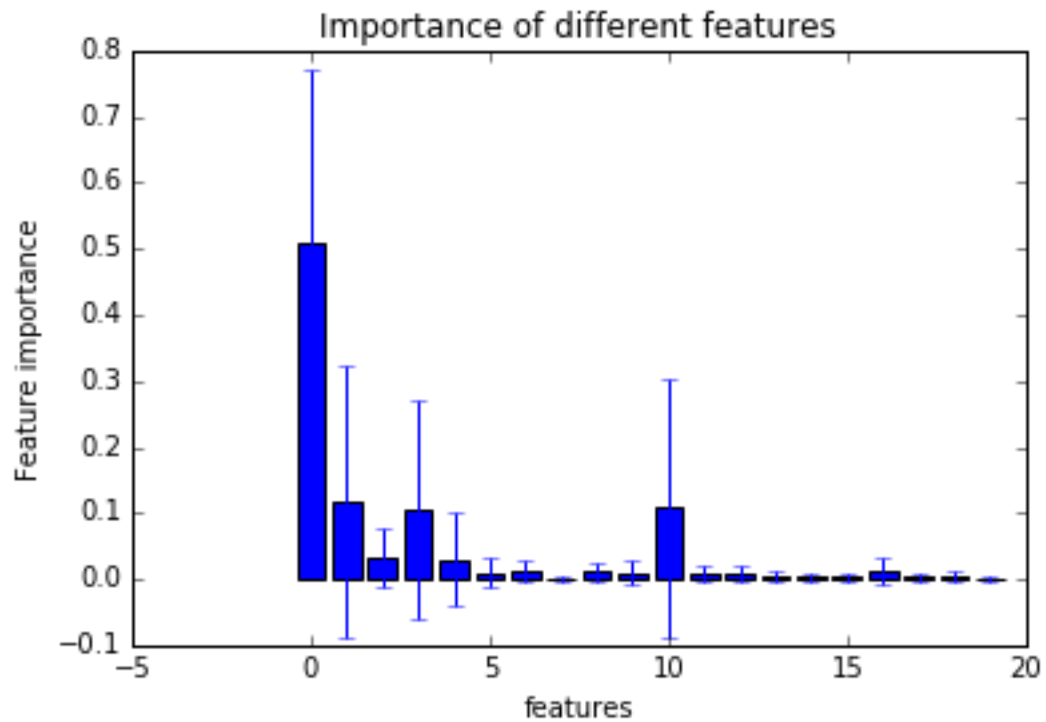


Logistic Regression
Out-of-sample test:

Accuracy score = 96%
AUC score = 98%
KS test = 92%

Random Forest
Out-of-sample test:

Accuracy score = 95%
AUC score = 99%
KS test = 93%



Additional slide: SCOR Model (FDIC internal)

- Developed and used internally by FDIC in 1998
- Used as an off-site monitoring tool by FDIC, in addition to annual on-site audit of insured institutions
- Relies on the Call Report Data
- Uses 13 indicators expressed as ratios of total assets (see https://www.fdicig.gov/reports02/02-033.pdf)

1. Total equity capital
2. Past due loans 30 days
3. Non-accrual loans
4. Net Charge-offs
5. Net Income
6. Volatile liabilities
7. Loans and Long-term Securities
8. Loan Loss Reserve
9. Past Due Loans 90 days
10. Other Real Estate Owned
11. Provision for Loan Losses
12. Cash Dividend Declared
13. Liquid Assets

Additional slide: LR: correction for sub-sampling

We estimated the logistic regression on the down-sampled balanced set.
Call these probabilities $\Pr'\left(Y_{t+T}=1\,|\,\mathbf{X}_t\right)$:

$$\Pr'\left(Y_{t+T}=1\,|\,\mathbf{X}_t\right)==\sigma\left(\sum_i W_i^{'} X_{it}\right)$$

For "true" probabilities $\Pr\left(Y_{t+T}=1\,|\,\mathbf{X}_t\right)$ and sub-sampling ratio $r=\frac{\Pr\left(Y=0\right)}{\Pr'\left(Y=0\right)}=\frac{N_{Y=0}^{sub-sampl}}{N_{Y=0}^{total}}$,
we have:

$$\frac{\Pr\left(Y=1\,|\,\mathbf{X}_t\right)}{\Pr\left(Y=0\,|\,\mathbf{X}_t\right)}=\frac{\Pr\left(Y=1\right)}{\Pr\left(Y=0\right)}\frac{\Pr\left(\mathbf{X}_t\,|\,Y=1\right)}{\Pr\left(\mathbf{X}_t\,|\,Y=0\right)}$$

$$=\frac{\Pr'\left(Y=1\right)}{r\Pr'\left(Y=0\right)}\frac{\Pr'\left(\mathbf{X}_t\,|\,Y=1\right)}{\Pr'\left(\mathbf{X}_t\,|\,Y=0\right)}=\frac{1}{r}\frac{\Pr'\left(Y=1\,|\,\mathbf{X}_t\right)}{\Pr'\left(Y=0\,|\,\mathbf{X}_t\right)}$$

This produces correction formulas for weights $W_i^{'}$ computed using under-sampling:

$$\boxed{\begin{aligned} W_0 &= W_0^{'}+\log r < W_0^{'} \\ W_i &= W_i^{'},\ i>0 \end{aligned}}$$