Federal Reserve Bank *of* Cleveland

# Systemic Risk Analysis Using Forward-Looking Distance-to-Default Series: An Application to US Banks

Model Documentation

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## I. Introduction

A number of approaches and measures have been employed to assess systemic risk in the banking sector.[1] According to Rodríguez-Moreno and Peña (2013), these can be broadly categorized into six types: Measures based on the principal components of banks' credit default swaps (CDS); measures of interconnectedness and capital shortfalls; measures computed from structural credit risk models (Merton 1974); measures based on collateralized debt obligation (CDO) indices and their tranches; multivariate densities computed from CDS spreads; and co-risk measures. Contributions along these dimensions are found in Acharya et al. (2016, 2012) Brownlees and Engle (2016), Adrian and Brunnermeier (2011), Diebold and Yilmaz (2009), Drehmann and Tarashev (2011a, 2011b), and Saldías (2013).

The focus of this document is Saldías (2013), which develops a measure of systemic risk for the European banking system based on the structural credit risk model of (Merton 1974). This paper replicates the Saldías (2013) methodology using US bank data to produce an indicator that can be used to gauge systemic risk in the US banking system. The Merton (1974) credit risk model assumes that the equity of a bank is isomorphic to a call option on the bank's assets. Since liabilities are fixed claims against bank assets with payoffs determined by seniority (debtholders are paid off before equity holders), bank equity can be modelled as a call option on the market value of bank assets with the strike price equals to the face value of debts. As a residual claim, the market value of bank equity equals the market value of bank assets minus the face value of debts. When the market value of bank assets falls below the face value of debts, the bank becomes insolvent and defaults on its debts; the bank equity, or the call option, becomes worthless. The concept of how close a bank is to the default boundary is called the default

[1] For an extensive survey of systemic risk analytics, refer to Bisias, Flood, Lo, and Valavanis (2012)

barrier. The normalized distance between the market value of assets and the default barrier is called the distance-to-default, which can be used to measure a bank's insolvency risk.

Using this conceptual framework, Saldías computes two distance-to-default measures that capture different aspects of insolvency risk in the financial services industry. The first is the average distance-to-default (ADD), which is a weighted average of the individual distance-to-default of a set of major US banks. Using option prices to compute banks' distance-to-default, as in Saldias, has the advantage to capture market participants' forward looking expectations of bank insolvency. This is true to the extent that market prices are forward looking, and that option prices are found to lead stock prices. As such, the ADD provides market information about the average insolvency risk in the banking industry at a particular point in time by averaging individual banks' distance-to-default. The second distance-to-default is the portfolio distance-to-default (PDD). To compute the PDD, we aggregate balance sheet information of individual banks into a single entity and compute the PDD of this hypothetical aggregate bank, using the equity and option prices of this single entity. Our empirical approach to proxy this hypothetical single bank entity is to use the KBE ETF, an exchange traded fund designed to provide returns that correspond to the S&P Banks Select Industry Index, and compute the ADD using the individual firms in the Index. The PDD captures the insolvency risk of the aggregate entity, or the systematic insolvency risk of the portfolio. Since the PDD is a measure of the joint risk of distress of the portfolio, it incorporates correlations among banks in the portfolio as well as any diversification effect in the portfolio. In theory, PDD is higher than ADD due to diversification effect. This joint insolvency of banks in the portfolio provides an indicator of the systematic nature of insolvency in the banking system.

Falling ADD could be concerning because the market signals rising average insolvency risk in banking. However, the ADD alone does not provide a full picture of the banking system as it does not factor in bank heterogeneity, size differences, risk interdependencies, and sector wide tail risks during stressful periods.

Falling PDD could be more concerning because the market signals rising systematic insolvency risk. When the falling PDD converges to the falling ADD, even if both remain positive, the market signals onset of a systemic event. Hence, the spread between the PDD and the ADD provides a market measure of systemic risk.

Why not just look at the PDD to gauge systemic risk? The PDD by itself is a less powerful tool because without the ADD reference, there is no information about comovement and correlation. For example, when PDD falls but remains well above zero, it is not clear whether such a fall is systematic or not. Hence, the ADD would be necessary to provide a reference point to the PDD.

Why not just look at the spread between PDD and ADD? To monitor systemic risk, we are interested in the downside tail risk of the banking system. Hence, we need information about what direction PDD and ADD are moving, as well as how close the banking system is to the default boundary. Hence, the spread, PDD, and ADD must be interpreted jointly to infer the correct market signal about systemic risk.

In summary, the approach in Saldías (2013) provides a useful tool to monitor systemic risk in banking. It has two major advantages over other approaches. First, it uses option prices, which tend to lead stock prices. Hence, the inputs in our indicator are very forward looking. This is not to say that the indicator has forecasting power, and studying the forecasting properties of the indicator is beyond the scope of this paper. At the moment, our indicator is best viewed as a coincident indicator.[2] [3] Second, since options are traded daily, both ADD and PDD, and the spread, can be updated as frequent as daily except when the exchange closes. This is one of the few systemic risk indicators at daily frequency.

The systemic risk indicator needs to be interpreted with caution. While market prices are forward looking, they sometimes overshoot especially when the market is volatile and liquidity is low. Some of these seem to be evident in the data, as negative spreads between PDD and ADD were obtained in our computation in a number of days. Hence, the users of this indicator may want to consult other indicators at their discretion.

To deal with the potential irregularities in daily market data, one may want to look at the trend, the persistence, or the moving averages of the indicator. This is an area for future research.

The rest of this paper is organized as follows: Section II describes the data; Section III discusses computation of ADD and PDD. Section IV reports the results and Section V concludes.

## II. Data

The date range of the sample used to compute the PDD and the ADD series spans from March 22, 2008, to December 12, 2016.

Calculations of PDD and ADD are based on constituents of the KBE, an exchange traded fund (ETF) managed by State Street Global Advisors and formally known as the SPDR S&P Bank ETF. The KBE exchange traded fund is a marketable security that is designed to provide returns that correspond to the S&P Banks Select Industry Index, an index fund for the banking

[2] Refer to Borio and Drehmann (2009) and Arsov *et. al*. (2013)
[3] Saldias (2013) provides exhaustive tests (Granger Causality, Breakpoint Tests and Exceedance Correlations) with other market based measures and show strong support for the forward-looking feature of the ADD and PDD series.

sector. As of September 30, 2016, the index is composed of 64 financial institutions, at approximately equal weights. Refer to Table 1 for a list of constituent institutions. Prior to October 24, 2011, the KBE ETF tracked another banking index, the BKX, which is constructed by NASDAQ and Keefe, Bruyette & Woods (KBW), Inc., and formally known as the KBW Bank Index[4].

Other data employed to compute the PDD and ADD include total liabilities obtained from COMPUSTAT, market capitalization obtained from COMPUSTAT, weights in the index from State Street Global Advisors, equity option implied volatility from CBOELiveVol, and the 10 year constant maturity U.S. Treasury for risk-free interest rate from the US Department of Treasury. These are described in Table 2. Quarterly balance-sheet data (liabilities) and market capitalization are obtained from COMPUSTAT. For balance-sheet data, we utilize the most recent quarterly observation as daily data.[5] For historical simulation prior to September 30 2016, we employ a one-quarter lag in obtaining balance-sheet data. For example, balance sheet information for first quarter of 2014 is assumed to be available on the last business day of second quarter of 2014.[6]

Equity implied volatility is obtained from data supplied by CBOE LiveVol. To compute daily implied volatility, we take the following steps. 1) For each expiring month, we pick two contracts with strike prices that are closest to at-the-money (ATM), and we compute implied volatility for each expiration date by taking the weighted average of implied volatility (provided by LiveVol) of the two ATM contracts; i.e. implied volatility is linearly interpolated between the

[4] The Bank Holding Companies (BHCs) in the index constitute approximately 69 percent of total banking system assets.
[5] Because not all holdings of the KBE ETF are depository institutions, categorization between short-term liabilities and long-term liabilities is avoided and we construct default barrier as total liabilities. Saldías (2013) constructs default barrier as short-term liability plus half long-term liability.
[6] For daily index computation in real time, we use new data as soon as they become available.

two implied volatilities that enclose the at-the-money price. 2) We filter out all contracts with expiration less than 20 business days. Then, for each underlying symbol and option type (put/call), we average out all the ATM implied volatilities computed in step 1 across all expirations (time-to-maturity). 3) For each underlying symbol, we derive a final implied volatility number by averaging out put and call implied volatilities. 4) For a specific date, if either put or call implied volatility is missing, the final implied volatility reflects value of the non-missing put or call; if both put and call are missing, we use the most recent observation as a proxy. If implied volatility data are not available for all dates for a particular stock ticker, we utilize a rolling 22-trading-day realized volatility. As of September 30, 2016, all constituents in the portfolio (KBE ETF) have options traded.[7]

Portfolio weights for the KBE ETF are obtained on a daily basis from the State Street Global Advisors' (SSGA) website.[8] For data prior to September 30, 2016, only quarterly weights are obtained from SSGA. To compute daily weights from quarterly weights, we multiply quarter-end weights by the daily adjusted price divided by the quarter-end adjusted price,[9] with the assumption that all rebalancing take place on the third Friday of every quarter-ending month.

[7] However, historically, there were seven constituents that did not have implied volatility data. The institutions are: FleetBoston Financial Corp, Mellon Financial Corp., Commerce Bancorp NJ, North Fork Bancorporation Inc., Bank One Corp, SouthTrust Corp, Compass Bancshares

[8] URL: https://www.spdrs.com/product/fund.seam?ticker=KBE

[9] $\sum_{i=1}^{63} Daily\ Weights = Weights_{Quarter-end} \times \frac{Price_{daily}}{Price_{Quarter-end}}$. All prices are distribution adjusted.

## III. Computing ADD and PDD

The contingent claims analysis approach first described in Merton (1974) and used by Saldías (2013) to compute the ADD and PDD is grounded on three precepts: (1) the firm's asset value follows a geometric Brownian motion; (2) the liabilities on the balance sheet are based on different priorities (debt versus shareholders); (3) the economic value of liabilities plus equities is equal to the economic value of assets[10]. Figure 2 provides a schematic on the balance sheet information and market information inputs that go into the ADD and PDD computation as part of contingent claims analysis.

Equity is a junior claim to debt, modeled as a standard call option on the assets with an exercise price equal to the value of risky debt, which is referred to as the default barrier.

$$E = \max\{0, A - D\} \tag{1}$$

where $A$ is asset, $D$ is risky debt, and $E$ is equity. The Black-Scholes option pricing formula is invoked (Refer to Black and Scholes 1973) to yield a closed-form expression of equity $E$. Equation (2) shows a European call option on the bank's assets $A$ at maturity $T$.

$$E = AN(d_1) - e^{-rT} DN(d_2) \tag{2}$$

where $r$ is the growth of assets, $N(\bullet)$ is the cumulative normal distribution, and $T$ is debt maturity in years.[11] The values of $d_1$ and $d_2$ are expressed as follows:

[10] Refer to Crosbie and Bohn (2003) which is the original Moody's KMV application: http://www.defaultrisk.com/pp_model_35.htm

[11] Here, the time period is T=1 year.

$$d_1 = \frac{\ln\left(\frac{A}{D}\right) + \left(r + \frac{1}{2}\sigma_A^2\right)T}{\sigma_A\sqrt{T}} \tag{3}$$

$$d_2 = d_1 - \sigma_A\sqrt{T} \tag{4}$$

where $\sigma_A$ is asset volatility. Merton (1974) links equation (2) to the volatility of a bank's equity using Ito's lemma to obtain the expression:

$$E\sigma_E = A\sigma_A N(d_1) \tag{5}$$

where $\sigma_E$ is equity volatility. The implied asset value *A* and the asset volatility $\sigma_A$ are not observable. We numerically solve equations (2) and (5) to obtain the distance-to-default as given in expression (6):

$$\text{Distance-to-default } (DD_i) = \frac{\ln\left(\frac{A}{D}\right) + \left(r - \frac{1}{2}\sigma_A^2\right)T}{\sigma_A\sqrt{T}} \tag{6}$$

where *E* is the market value of equity, $\sigma_E$ is the equity implied volatility, and *r* is the 10-year constant maturity US Treasury yield. As a bank's assets decline and move closer to the default barrier (D), the risk of a bank default increases, and when it crosses the default barrier, the firm is assumed to be insolvent.

The average distance-to-default (ADD) is obtained by taking the weighted average across individual bank distance-to-default series and is expressed as follows:

$$ADD_t = \sum_{i=1}^{N} w_{it} DD_{it} \tag{7}$$

where $DD_{it}$ is the individual distance-to-default, *T* periods ahead, computed off equation (6). The time horizon *T* is set to 1 year. $w_{it}$ is the individual bank *i*'s weight in the index at time *t*. The risk free interest rate, $r_{i,t}$, is approximated by the 10 year constant maturity US Treasury yield. The two unobservable variables: the implied value of assets $A_{i,t}$ and implied assets volatility $\sigma_{i,t}^{A}$, are estimated using the Newton-Raphson method to solve the system of equations (2) and (5).

The portfolio distance-to-default (PDD) is computed by first aggregating individual banks in the Index into one single entity, then apply equation (8) as follows:

$$PDD = \frac{\ln\left(\frac{A^P}{D^P}\right) + \left(r - \frac{1}{2}\sigma_P^2\right)T}{\sigma_P\sqrt{T}} \qquad (8)$$

where $D^P$ is the weighted average of individual distress barriers across all banks in the index, $A^P$ is the value of the asset portfolio, and $\sigma_P$ is the implied volatility of the option on the banking index (KBE).

## IV. Results: Interpretation of the ADD, the PDD, and the PDD-ADD Spread

In this section, we present the results for the ADD, PDD, and the spread between the two series over the period March 22 2008 to December 12 2016. Figure 3 plots the ADD and the PDD series, their difference (the spread), and the KBE as a reference. Table 3 provides summary statistics for the ADD, the PDD, and the spread. PDD is mostly higher than ADD over the sample period. The PDD has a higher standard deviation than the ADD series as well (2.27 versus 1.65), which implies that the PDD contains more information and is sensitive to comovements across the sample. The PDD also has a larger positive skewness (0.12 versus -0.19).

Falling ADD could be concerning because the market signals rising average insolvency risk in banking. However, the ADD alone does not provide a full picture of the banking system as it does not factor in bank heterogeneity, size differences, risk interdependencies and sector wide tail risks during stressful periods. Falling PDD could be more concerning because the market signals rising systematic insolvency risk. When the falling PDD converges to the falling ADD, even both remain positive, the market signals the onset of a systemic event. Hence, the spread between the PDD and the ADD provides a market measure of systemic risk. This can be seen in Figure 3 just before the 2009 financial crisis, the falling PDD converged to the ADD when both remained positive.

From the data, the convergence of the ADD and PDD usually take place during periods of high market volatility, low equity return, and high return comovement across banks. Figure 4 plots the difference between the implied volatility of the portfolio index (KBE) and the weighted average of the implied volatilities of index constituents versus the spread (PDD-ADD). We interpret this as follows: The PDD-ADD spread is dependent on the volatility regime of the equity market. Crisis periods are marked by periods of high volatility, and comovements are much stronger. Under low-volatility regimes, comovements are less.

## V. Conclusion

This documentation replicates the method of Saldías (2013) to develop an indicator that can be used to gauge systemic risk in the US banking system. The method takes a structural-credit-risk-model approach to compute the average distance-to-default (ADD) and the portfolio-distance-to-default (PDD) using option data. The analysis starts from March 22, 2008 to December 12, 2016.

To monitor systemic risk, we are interested in the downside tail risk of the banking system. We need information about what direction PDD and ADD are moving, as well as how close the banking system is to the default boundary. Hence, PDD, ADD, and their spread must be interpreted jointly to infer the correct market signal about systemic risk. Finally, this systemic risk indicator needs to be interpreted with caution. While market prices are forward looking, they sometimes overshoot especially when the market is volatile and liquidity is low. To be conservative, we encourage readers to consult other indicators at their discretion.

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Table 1: This table provides the list of constituent institions that comprise of the KBE Bank Index as of Q3:2016 (present).

| | Ticker | Name | GVKey | KBE start | KBE end |
|---|---|---|---|---|---|
| 1. | ASB | Associated Banc-Corp | 11842 | Q4-11 | present |
| 2. | BXS | BancorpSouth, Inc. | 14219 | Q4-13 | present |
| 3. | BAC | Bank of America Corporation | 7647 | Q4-05 | present |
| 4. | BOH | Bank of Hawaii Corporation | 2005 | Q4-11 | present |
| 5. | BK | Bank of New York Mellon Corporation | 2019 | Q4-05 | present |
| 6. | OZRK | Bank of the Ozarks, Inc. | 65106 | Q3-14 | present |
| 7. | BKU | BankUnited, Inc. | 185824 | Q4-13 | present |
| 8. | BBT | BB&T Corporation | 11856 | Q4-05 | present |
| 9. | CATY | Cathay General Bancorp | 23500 | Q2-15 | present |
| 10. | CIT | CIT Group Inc. | 149738 | Q4-11 | present |
| 11. | C | Citigroup Inc. | 3243 | Q4-05 | present |
| 12. | CFG | Citizens Financial Group, Inc. | 21825 | Q1-15 | present |
| 13. | CMA | Comerica Incorporated | 3231 | Q4-05 | present |
| 14. | CBSH | Commerce Bancshares, Inc. | 3238 | Q3-08 | present |
| 15. | CFR | Cullen/Frost Bankers, Inc. | 3643 | Q3-08 | present |
| 16. | EWBC | East West Bancorp, Inc. | 118042 | Q4-11 | present |
| 17. | FNB | F.N.B. Corporation | 18049 | Q1-14 | present |
| 18. | FITB | Fifth Third Bancorp | 4640 | Q4-05 | present |
| 19. | FHN | First Horizon National Corporation | 4737 | Q4-11 | present |
| 20. | GWB | Great Western Bancorp | 021616 | Q3-16 | present |
| 21. | FRC | First Republic Bank | 14275 | Q4-12 | present |
| 22. | HOPE | Hope Bancorp Inc. | 066235 | Q3-16 | present |
| 23. | FULT | Fulton Financial Corporation | 14172 | Q4-11 | present |
| 24. | GBCI | Glacier Bancorp, Inc. | 16832 | Q3-14 | present |
| 25. | HBHC | Hancock Holding Company | 24232 | Q4-11 | present |
| 26. | HOMB | Home BancShares, Inc. | 164633 | Q2-16 | present |
| 27. | HBAN | Huntington Bancshares Incorporated | 5786 | Q1-07 | present |
| 28. | IBKC | IBERIABANK Corporation | 24466 | Q2-14 | present |
| 29. | ISBC | Investors Bancorp Inc. | 164364 | Q2-14 | present |
| 30. | JPM | JPMorgan Chase & Co. | 2968 | Q4-05 | present |
| 31. | KEY | KeyCorp | 9783 | Q4-05 | present |
| 32. | MTB | M&T Bank Corporation | 4699 | Q4-05 | present |
| 33. | MBFI | MB Financial, Inc. | 31692 | Q4-14 | present |
| 34. | MTG | MGIC Investment Corporation | 24379 | Q2-13 | present |
| 35. | NYCB | New York Community Bancorp, Inc. | 29282 | Q4-10 | present |
| 36. | NTRS | Northern Trust Corporation | 7982 | Q4-05 | present |
| 37. | PACW | PacWest Bancorp | 136265 | Q2-14 | present |
| 38. | PBCT | People's United Financial, Inc. | 16245 | Q4-07 | present |
| 39. | PNC | PNC Financial Services Group, Inc. | 8245 | Q4-05 | present |

| | | | | | |
|---|---|---|---|---|---|
| 40. | BPOP | Popular, Inc. | 2002 | Q4-11 | present |
| 41. | PVTB | PrivateBancorp, Inc. | 121816 | Q4-14 | present |
| 42. | PNFP | Pinnacle Financial Partners Inc. | 139025 | Q3-16 | present |
| 43. | PB | Prosperity Bancshares, Inc.(R) | 115876 | Q4-11 | present |
| 44. | RDN | Radian Group Inc. | 25895 | Q2-13 | present |
| 45. | RF | Regions Financial Corporation | 4674 | Q4-05 | present |
| 46. | SBNY | Signature Bank | 160776 | Q4-11 | present |
| 47. | STL | Sterling Bancorp | 117161 | Q4-15 | present |
| 48. | STI | SunTrust Banks, Inc. | 10187 | Q4-05 | present |
| 49. | SIVB | SVB Financial Group | 17120 | Q4-11 | present |
| 50. | SNV | Synovus Financial Corp. | 13041 | Q4-08 | present |
| 51. | TCB | TCF Financial Corporation | 15363 | Q4-11 | present |
| 52. | TCBI | Texas Capital Bancshares, Inc. | 150306 | Q4-13 | present |
| 53. | USB | US Bancorp | 4723 | Q4-05 | present |
| 54. | UMBF | UMB Financial Corporation | 10916 | Q1-14 | present |
| 55. | UMPQ | Umpqua Holdings Corporation | 65228 | Q4-13 | present |
| 56. | UBSI | United Bankshares, Inc. | 17248 | Q1-15 | present |
| 57. | VLY | Valley National Bancorp | 11861 | Q4-11 | present |
| 58. | VOYA | Voya Financial, Inc. | 16384 | Q4-13 | present |
| 59. | WAFD | Washington Federal, Inc. | 17145 | Q2-14 | present |
| 60. | WBS | Webster Financial Corporation | 17150 | Q2-13 | present |
| 61. | WFC | Wells Fargo & Company | 8007 | Q4-05 | present |
| 62. | WAL | Western Alliance Bancorporation | 163920 | Q4-14 | present |
| 63. | WTFC | Wintrust Financial Corporation | 63781 | Q1-14 | present |
| 64. | ZION | Zions Bancorporation | 11687 | Q4-05 | present |

Table 2: This table provides the source of data and description of data

| Variable | Data Description | Source (Mnemonic) |
| --- | --- | --- |
| Total Liabilities | Total liability reported on quarterly reports, millions. | CompuStat (TLQ) |
| Risk-free Rate | 10-year constant maturity US Treasury yield. | US Treasury |
| Weights | Daily index weights (quarterly for historical weights prior to Sep 2016 | State Street Global Advisors |
| Market Capitalization (Equity) | Total market capitalization, millions. | COMPUSTAT |
| Equity Implied Volatility | Daily at-the-money implied volatilities of call and put options on individual banks | CBOE LiveVol |
| Index Implied Volatility | Daily at-the-money implied volatilities of call and put options on KBE | |

Table 3: Summary statistics for PDD, ADD, and the PDD-ADD spread series

| | Benchmark model | | |
| --- | --- | --- | --- |
| | PDD | ADD | PDD-ADD |
| Mean | 5.110 | 4.194 | -0.916 |
| Median | 5.028 | 4.282 | -0.709 |
| Maximum | 12.427 | 8.192 | 0.874 |
| Minimum | -0.033 | -0.196 | -4.235 |
| Std. Dev. | 2.273 | 1.649 | 0.741 |
| Skewness | 0.122 | -0.189 | -0.858 |
| Kurtosis | 2.359 | 2.568 | 3.262 |
| Jarque-Bera statistic | 71.610 | 50.220 | 459.300 |
| Observations | 3,656 | 3,656 | 3,656 |

Figure 2: This figure provides a schematic on the balance sheet information and market information inputs that go into the ADD and PDD computation.

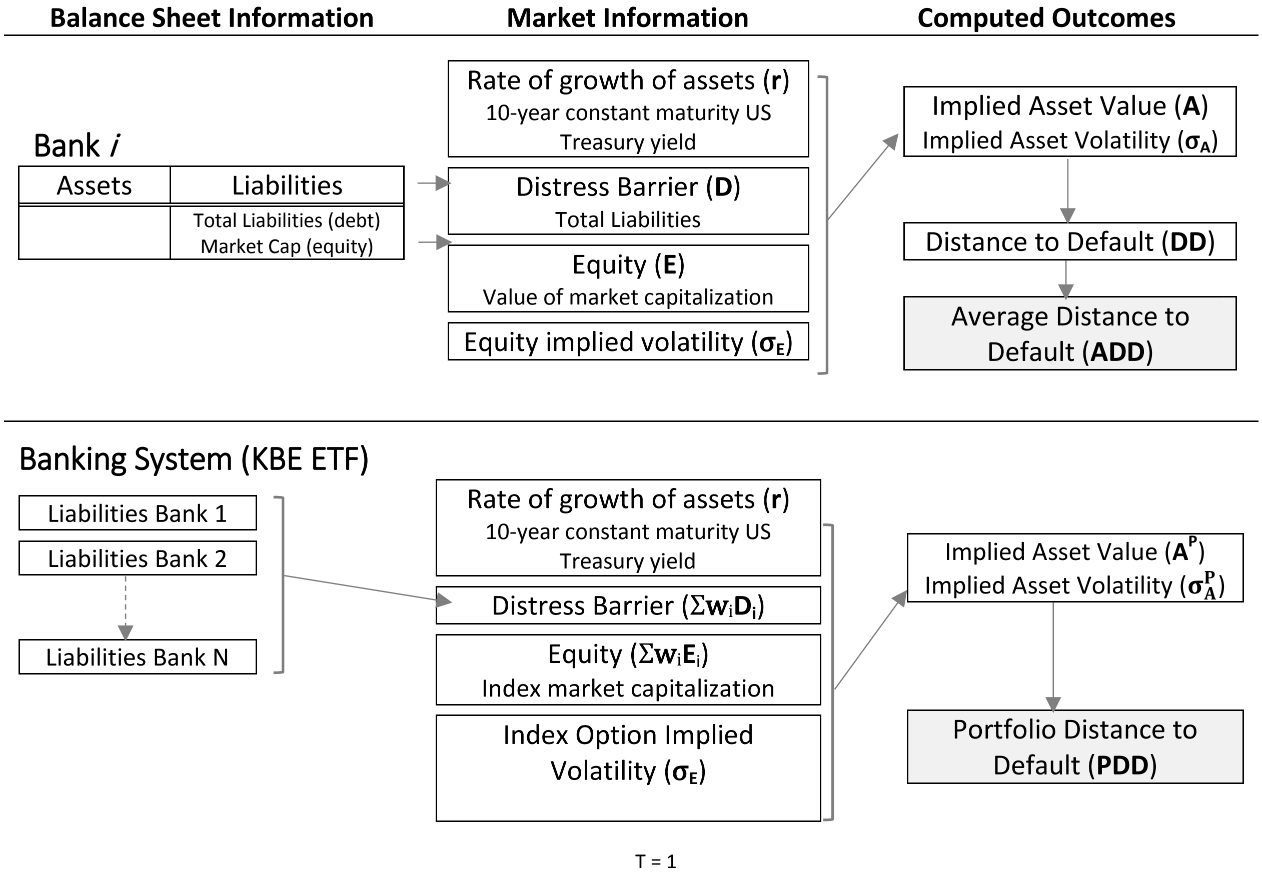

Figure 3: Forward looking Distance-to-Default series from March 22 2008 to December 12 2016. This figure plots the PDD, ADD and the difference between the PDD and ADD (the spread).

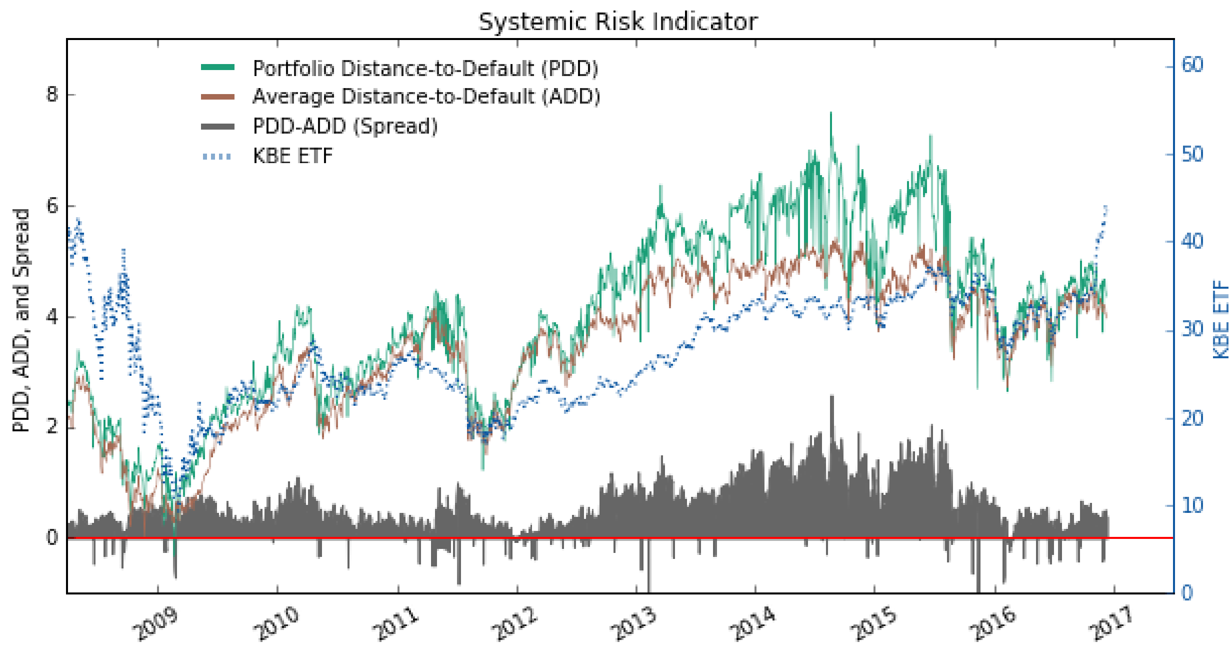


Figure 4: This figure plots the difference between the implied volatility of the KBE ETF and the weighted average of implied volatilities across the fund's constituents versus the spread (PDD-ADD).