Modeling Correlated Systemic Liquidity and Solvency Risks in a Financial Environment with Incomplete Information

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Perspectives on Risk Modeling

"All models are wrong but some are useful."

George Box

Prior (We Hope Useful) Portfolio Simulation Risk Studies

Topic	Countries
Modeling integrated market and credit risk in high yield bond portfolios	**U.S.**
Modeling Bank Solvency Risk	**South Africa, Japan, Brazil, Saudi Arabia, Slovakia**
Modeling Sovereign Risk	**Ecuador, Indonesia**
Modeling Integrated Banking System and Sovereign Risk	**Brazil**

In our model systemic banking system risk is the probability of multiple banks failing at the same time.

Systemic banking system risks are largest when:

1. Many bank borrowers in particular sectors or regions *simultaneously* face financial stress and default,
2. Numerous banks with risky loan portfolios *concentrated* in particular sectors, regions, or Sovereigns fail,
3. Banks have substantial inter-bank credit risk,
4. Solvent banks encounter correlated liquidity risk in part due to incomplete information.

In our view, systemic banking system risks were poorly modeled, understood and managed in recent crises

Most risk assessment methodologies do not adequately model the *interaction* of the four main drivers of bank solvency risk:

- correlated financial and economic environment volatility *by sector and region*,
- bank loan portfolio credit quality *by sector and region,*
- bank loan portfolio sector, region, and Sovereign concentration levels which in some cases (e.g. US real estate lenders) may double or triple needed bank capital levels,
- bank capital levels.

There is an understandably strong preference for simple models (e.g. ratios) and mathematically sophisticated closed form risk models that have a limited number of readily available inputs.

Such models often provide useful information **much** of the time.

However **when useful risk assessments were most needed to inform managerial, regulatory, and policy decisions regarding *severe financial stress events the outputs from structurally inadequate models were often both wrong and misleading***.

Principal Contributions of Paper

- **model correlated solvency risk** in significant detail for 10 stylized banks simultaneously,
- **model correlated liquidity risk** for 10 stylized banks simultaneously,
- **estimate the probability of banking system systemic solvency and liquidity risks**, and
- **evaluate measures that may be adopted *in advance*** to reduce the probability of such systemic risks and their potential impacts.

Our methodology draws on a number of theoretical structures

- **State Preference Theory**
  - All entities (individuals, businesses, financial institutions, regulators, and governments, etc.) existing at a particular point in time will be impacted simultaneously by the same financial and economic environment events ("state of the world")
  - All analyses are conditioned on a particular state of the world with numerous correlated systematic risk drivers (e.g. correlated interest rates, exchange rates, sector returns, regional real estate prices, etc.),

- **Capital Market Theory** (correlated systematic risk variables drive correlated borrower asset and liability values),
- **Contingent Claims Theory** (borrower debt to value ratios, default rates, and recovery rates vary by state of the world and are correlated)
- **Portfolio Theory** (bank loan portfolio concentration levels by sector, region, and Sovereign are crucial risk variables and are modeled explicitly.)

We propose and demonstrate a forward looking simulation methodology applied to:

- the financial and economic environment (e.g. 50 correlated and systematically important risk variables),
- reasonably detailed bank balance sheets (e.g. loan concentrations by sectors, regions, credit quality)
  - 500 securities are used in the modeling of each bank's assets and liabilities,
- 10 banks (banking system) simultaneously.

In our model, banks fail from a solvency perspective when their simulated capital ratios fall below some critical level (e.g., 2 percent).

Banks experience liquidity problems when their risk of future insolvency, or the banking system's overall risk of insolvency, rises to an unacceptable level (e.g., 10 percent).

Correlated systemic risks materialize when multiple banks become insolvent or face liquidity risks simultaneously.

Systemic risks are driven in part by large adverse regime shifts in the financial and economic environment that catch many entities by surprise resulting in dramatically higher default rates and loss rates on loans in particular sectors and regions for many banks simultaneously.

Banks experiencing funding outflows may fail and are likely to contract lending with significant potential impacts on the real economy.

Asset and liability structures that expose the bank to interest rate, exchange rate, and liquidity risk are also potentially important risk factors.

Important potential policy actions to reduce systemic risk levels include:

- The achievement of reasonably stable economic growth and avoidance of asset price bubbles.
- Limitations on the quantity of high credit risk loans with high loan to value ratios.
- Managing loan concentration risk in banks and across the banking system.

- More accurate assessments of bank capital requirement levels that account for the interaction between infrequent but severe financial and economic volatility, loan portfolio credit quality, and loan portfolio concentrations.
- Persistent enforcement of bank capital requirements even during extended periods when banks experience low loan portfolio loss rates.

Our view is in line with:

- The literature relating bank runs to extreme episodes of market discipline,
- the empirical evidence on the causes of the 2008–2009 global crises, and
- current supervisory approaches for stress testing in which a systemic liquidity shock is triggered by solvency concerns, (e.g. Bank of England, Aikman et al., 2009, Wong and Hui, 2009, and van den End and Tabbae, 2009).

Critique of Our Model

- has a number of moving parts (is not simple),
- has substantial data requirements (that are not always easily available),
- is wrong (Thank You Dr. Box),
- we believe that with effort the methodology *has the potential to produce results that are useful* to inform managerial, regulatory and policy decisions designed to minimized the probability and severity of systemic financial crises.

Application to the U.S. Banking System

Sequential Modeling Steps

1. Identification of systematically important market and credit risk variables (interest rates, exchange rates, GDPs, sector returns, regional real estate prices),
2. Simulation of many correlated risk variables to create a potential future economic state at T1,
3. Credit risk analysis on borrowers (individuals, firms, Sovereigns, etc.) in the various simulated states.
4. Revaluation of all 10 bank's assets and liabilities, calculation of capital ratios, and identification of banks that failed at T1 due to solvency problems.
5. Implementation of network model to assess inter-bank credit losses and potential additional bank solvency failures at T1 (systemic solvency risk).
6. Estimation of probability of banks solvency failures at T2.
7. Estimation of T1 funding withdrawals based on probability of failure at T2.
8. Estimation of fire sale of assets and/or reductions in lending and bank liquidity failures.
9. Implementation of network model to assess inter-bank credit losses and potential additional bank liquidity and solvency failures at T1 (systemic liquidity risk).
10. Identify policy actions that can be taken in advance of crises to moderate risk levels (financial and economic environment, portfolio concentrations, portfolio credit quality, liquidity buffers, capital levels, etc.)

Modeling Steps

1. Identification of systematically important and correlated market and credit risk variables:

   - interest rates,
   - exchange rates,
   - GDPs,
   - sector returns,
   - regional real estate prices.

U.S. Perspective

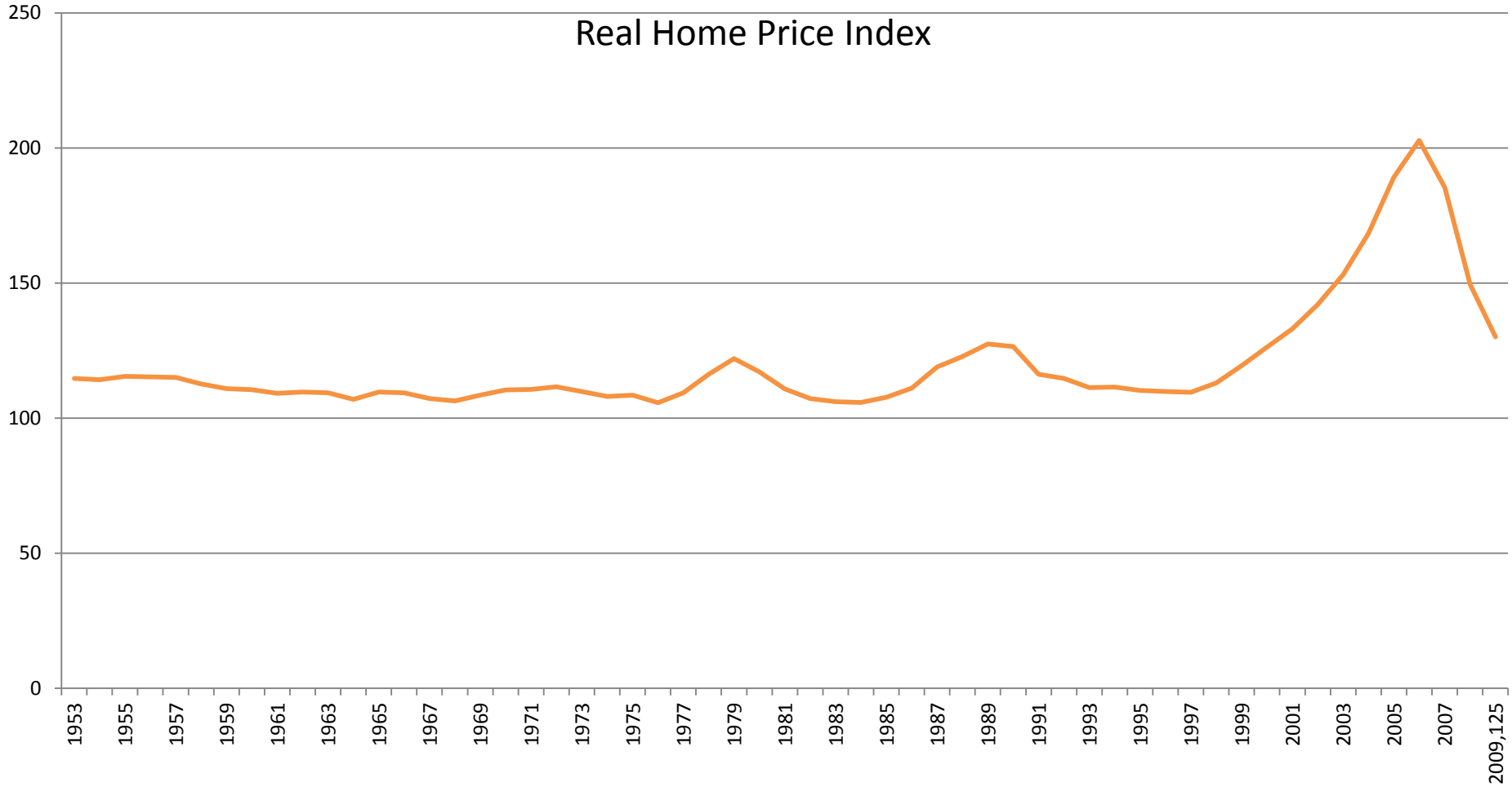


Table 3. Percentage Bank Failure Rates and Percentage Changes in Real Estate Prices by State 2007–2011

State	Percentage of banks in states failing between Jan 2007 - Feb 2011	Percentage change in home price index Jun 2007 - Dec 2010	State	Percentage of banks in states failing between Jan 2007 - Feb 2011	Percentage change in home price index Jun 2007 - Dec 2010
NV	0.244	-0.543	PA	0.017	-0.083
AZ	0.175	-0.517	VA	0.017	-0.208
GA	0.174	-0.310	AR	0.014	-0.151
FL	0.153	-0.431	TX	0.012	-0.033
OR	0.150	-0.277	OK	0.012	-0.002
WA	0.144	-0.257	SD	0.011	0.018
MO	0.143	-0.186	MS	0.011	-0.164
CA	0.119	-0.382	NE	0.008	-0.085
UT	0.074	-0.249	IN	0.006	-0.090
MI	0.069	-0.285	LA	0.006	-0.074
IL	0.061	-0.213	MA	0.006	-0.132
MD	0.059	-0.229	KY	0.005	-0.038
SC	0.057	-0.150	IA	0.003	-0.057
NM	0.056	-0.136	AK	0.000	-0.033
ID	0.053	-0.329	CT	0.000	-0.165
MN	0.035	-0.209	DC	0.000	-0.036
CO	0.033	-0.119	DE	0.000	-0.142
NC	0.027	-0.131	HI	0.000	-0.179
WY	0.026	-0.082	ME	0.000	-0.112
AL	0.025	-0.141	MT	0.000	-0.114
NJ	0.024	-0.166	ND	0.000	0.053
NY	0.020	-0.085	NH	0.000	-0.173
KS	0.020	-0.053	RI	0.000	-0.208
OH	0.020	-0.149	TN	0.000	-0.143
WI	0.018	-0.148	VT	0.000	-0.108
			WV	0.000	-0.031

Sources: FDIC, Freddie Mac.

Percent_Bank_Failure_Rate =

-.021 -0.387 Percent_Change_Real_Esate_Prices

T-Stat -2.74 -10.1

Adjusted R-Square 0.667

Modeling Steps

2. Simulation of *numerous* correlated *systematic* risk variables to create a potential future economic state at T1,

Table 2. U.S. Financial and Economic Calibrations (1987–2006 and 2007–2010)

Variable	Trend 1987-2006 (Percent Per Year)	Volatility 1987-2006 (Percent Per Year)	Trend 2007-2010 (Percent Per Year)	Volatility 2007-2010 (Percent Per Year)
Spot Price 2 (FX Rate 9) Yen	n.a.	0.094	n.a.	0.091
Spot Price 3 (FX Rate 10) Euro	n.a.	0.083	n.a.	0.105
Spot Price 4 (FX Rate 11) Pound	n.a.	0.083	n.a.	0.101
U.S. Industrial Production	0.029	0.018	-0.014	0.034
U.S. Unemployment Rate	-0.020	0.087	0.204	0.106
U.S. CPI	0.030	0.009	0.021	0.018
MexBol	0.080	0.359	0.043	0.317
Ibov	0.149	0.500	0.181	0.403
Cac	0.074	0.189	-0.082	0.288
Dax	0.085	0.220	0.014	0.307
NKY	-0.028	0.251	-0.061	0.209
UKX	0.069	0.147	-0.076	0.235
S&P Consumer Staples	0.114	0.134	0.064	0.133
S&P Consumer Discretionary	0.113	0.169	0.023	0.252
S&P Commercial and Professional Services	0.087	0.169	-0.026	0.208
S&P Energy	0.171	0.187	0.044	0.241
S&P Financials	0.177	0.185	-0.144	0.323
S&P Health Care	0.137	0.147	0.020	0.168
S&P Industrials	0.126	0.158	0.026	0.258
S&P Information Technology	0.161	0.310	0.064	0.242
S&P Materials	0.105	0.193	0.066	0.276
S&P Real Estate	0.165	0.127	0.016	0.367
S&P Retailing	0.162	0.212	0.038	0.262
S&P Telecom	0.089	0.224	0.002	0.196
S&P Transportation	0.113	0.181	0.084	0.237
S&P Utilities	0.114	0.157	0.020	0.162
Real Estate AZ-Phoenix	0.066	0.029	-0.194	0.068
Real Estate CA-Los Angeles	0.076	0.036	-0.117	0.055
Real Estate CA-San Diego	0.074	0.034	-0.102	0.055
Real Estate CA-San Francisco	0.076	0.036	-0.108	0.077
Real Estate CO-Denver	0.050	0.019	-0.018	0.042
Real Estate DC-Washington	0.066	0.028	-0.067	0.049
Real Estate FL-Miami	0.071	0.025	-0.176	0.052
Real Estate FL-Tampa	0.055	0.024	-0.141	0.044
Real Estate GA-Atlanta	0.041	0.011	-0.056	0.047
Real Estate IL-Chicago	0.057	0.022	-0.076	0.054
Real Estate MA-Boston	0.045	0.028	-0.020	0.038
Real Estate MI-Detroit	0.045	0.017	-0.140	0.063
Real Estate MN-Minneapolis	0.055	0.019	-0.079	0.079
Real Estate NC-Charlotte	0.036	0.015	-0.027	0.031
Real Estate NV-Las Vegas	0.063	0.035	-0.226	0.054
Real Estate NY-New York	0.053	0.024	-0.054	0.028
Real Estate OH-Cleveland	0.040	0.017	-0.030	0.058
Real Estate OR-Portland	0.074	0.022	-0.056	0.040
Real Estate TX-Dallas	0.031	0.017	-0.010	0.043
Real Estate WA-Seattle	0.068	0.027	-0.063	0.039
Average for 12 Equity Sectors	0.131	0.182	0.021	0.238
Average for 20 Real Estate Regions	0.057	0.024	-0.088	0.051

Modeling Steps

3. Credit risk analysis on borrowers (individuals, firms, Sovereigns, etc.) in various sectors and regions in the simulated financial and economic environment.

   - Simulated credit quality including default,
   - Simulated recovery rate in the event of default.

10 Bank Balance Sheets

It is crucial to know where the loans are concentrated.

Table 5. Two Small Bank Balance Sheet (less10 billion dollars).
- California
- Florida Georgia
- Three Sectors

Table 6. Three Medium Bank Balance Sheet (10 to 100 billion dollars).
- West Coast
- Mid-America
- East Coast
- Four Sectors

Table 7. Three Large Bank Balance Sheets (100 to 500 billion dollars).
- 20 regions
- 14 sectors

Table 8. Two Mega Banks Balance Sheets (over 500 billion dollars).
- 20 regions
- 14 sectors
- 62% of total banking system assets

Sources: SNL Financial, Staff estimates.

Table 7. Large Banks Balance Sheet (percent assets)

	Large 1	Large 2	Large 3
ASSETS			
Non Interest Bearing Assets	1.34	1.26	1.63
of which:			
Cash & Non Int-Bearing Deps	1.3	1.3	1.6
Gold	0.0	0.0	0.0
Fed Funds Sold	0.1	0.0	0.0
Interest Bearing Deposits	14.1	4.4	5.4
Securities	26.76	17.65	36.90
of which:			
US Govt	2.3	3.9	2.2
State & local	0.2	1.4	2.4
MBS (GSE)	14.3	5.8	10.2
MBS (Other)	3.4	3.0	2.9
ABS	2.2	1.3	8.4
Other	3.5	2.0	9.9
Repos	0.9	0.4	1.0
Loans	43.00	61.75	43.61
of which:			
Construction and Development 1-4 family	0.5	0.3	0.3
Construction and Development-Other	1.2	0.7	2.1
Other Real Estate Loans	15.8	18.2	20.6
Non Real Estate Loans	25.6	42.5	20.5
Reserves	1.7	2.1	1.0
Investment in Real Estate	1.30	1.07	1.28
of which:			
Premises & Fixed Assets	1.2	0.9	1.0
Total Other Real Estate Owned	0.1	0.2	0.3
Invest in Unconsol Subs	0.4	1.1	0.2
Intangible Assets	7.6	3.0	5.4
Other Assets	6.9	11.8	6.1
Adjustment	0.0	0.1	0.5
Total Assets	100.00	100.00	100.00
LIABILITIES			
Core Deposits	40.4	38.5	48.7
Negotiable CDs	7.9	3.4	4.6
Fed Funds Purchased	0.1	0.1	1.2
Repurchase Agreements	1.1	0.7	3.1
Foreign Deposits	13.8	1.2	14.7
Other Borrowed Money	10.9	31.7	10.6
Subordinated Notes&Debentures	2.2	1.7	1.8
Sub Debt - Trust Pref Sec	1.1	1.0	0.9
Trading Liabilities	4.3	0.3	1.2
Other Liabilities	5.3	9.5	2.9
Equity Capital incl Minority Interest	13.1	12.0	10.5

Source: SNL Financial, Staff estimates

Table 9. Credit Quality of Committed and Outstanding Commercial and Industrial Loans (In Billions of Dollars per Year)

Year	Special Mention	Sub-Standard	Doubtful	Loss	Total Classified	Total Criticized	Total Committed	Total Outstanding
1989	24.0	18.5	3.5	0.9	22.9	46.9	692.0	245.0
1990	43.1	50.8	5.8	1.8	58.4	101.5	769.0	321.0
1991	49.2	65.5	10.8	3.5	79.8	129.0	806.0	361.0
1992	50.4	56.4	12.8	3.3	72.5	122.9	798.0	357.0
1993	31.7	50.4	6.7	3.5	60.6	92.3	806.0	332.0
1994	31.4	31.1	2.7	2.3	36.1	67.5	893.0	298.0
1995	18.8	25.0	1.7	1.5	28.2	47.0	1063.0	343.0
1996	16.8	23.1	2.6	1.4	27.1	43.9	1200.0	372.0
1997	19.6	19.4	1.9	0.9	22.2	41.8	1435.0	423.0
1998	22.7	17.6	3.5	0.9	22.0	44.7	1759.0	562.0
1999	30.8	31.0	4.9	1.5	37.4	68.2	1829.0	628.0
2000	36.0	47.9	10.7	4.7	63.3	99.3	1951.0	705.0
2001	75.4	87.0	22.5	8.0	117.5	192.8	2049.0	769.0
2002	79.0	112.0	26.1	19.1	157.1	236.1	1871.0	692.0
2003	55.2	112.1	29.3	10.7	152.2	207.4	1644.0	600.0
2004	32.8	55.1	12.5	6.4	74.0	106.8	1545.0	500.0
2005	25.9	44.2	5.6	2.7	52.5	78.3	1627.0	522.0
2006	33.4	58.1	2.5	1.2	61.8	95.2	1874.0	626.0
2007	42.5	69.6	1.2	0.8	71.6	114.1	2275.0	835.0
2008	210.4	154.9	5.5	2.6	163.1	373.4	2789.0	1208.0
2009	195.3	337.1	56.4	53.3	446.8	642.1	2881.0	1563.0
2010	142.7	256.4	32.6	15.4	304.5	447.2	2519.0	1210.0

Note: Sources Shared National Credit Report 2010. Figures may not add to totals due to rounding

Table 10. Assumed Distribution of Initial Mortgage Loan to Value Ratios

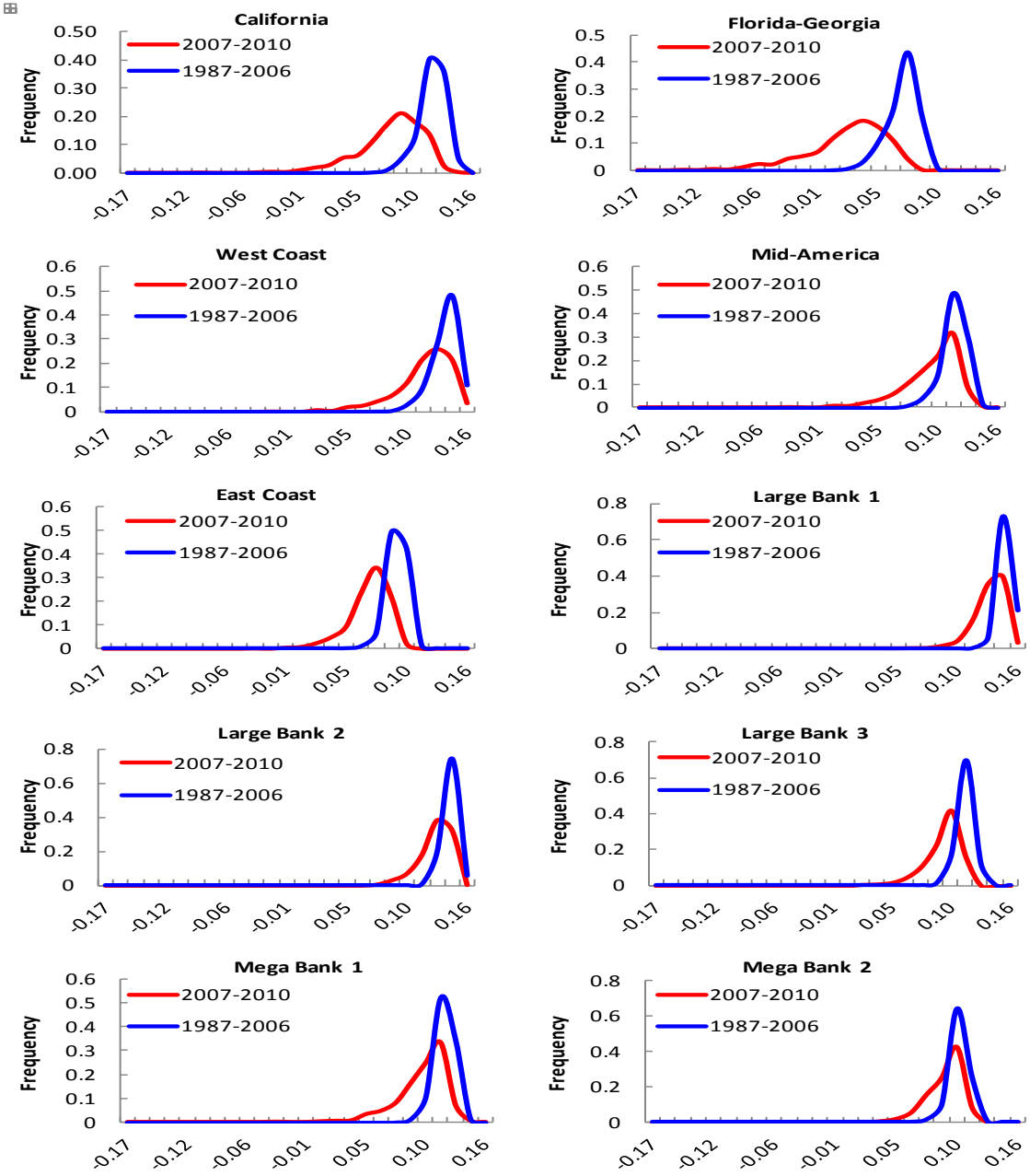
Assumed Initial LTV	Percentage of Mortgage Loans
0.355	0.090
0.710	0.110
0.800	0.350
0.900	0.120
1.000	0.080
1.055	0.150
1.300	0.100

Sources: Fannie Mae, Freddie Mac, author estimates.

Modeling Steps

4. Revaluation of all 10 bank's defaulted and non-defaulted assets and liabilities (5,000 different loans and securities):
   - calculation of bank capital ratios, and
   - identification of banks that failed at T1 *due to solvency problems*.

Figure 3. Capital Ratios, 1987–2006 and 2007–2010; Before Interbank Failures



Source: ValueCalc estimates.

Table 12. Simulated Capital Ratios for Banks using the 1987–2006 Financial Environment with No Inter-Bank Default Losses

	Capital Ratio Bank 1	Capital Ratio Bank 2	Capital Ratio Bank 3	Capital Ratio Bank 4	Capital Ratio Bank 5	Capital Ratio Bank 6	Capital Ratio Bank 7	Capital Ratio Bank 8	Capital Ratio Bank 9	Capital Ratio Bank 10	Number of Failed Banks
Average	0.112	0.062	0.130	0.110	0.086	0.139	0.134	0.108	0.112	0.097	0.010
Std. Dev.	0.013	0.014	0.012	0.011	0.008	0.006	0.006	0.007	0.009	0.008	0.101
Max	0.141	0.093	0.155	0.136	0.106	0.154	0.149	0.127	0.133	0.118	1
Min	0.056	-0.005	0.072	0.061	0.050	0.110	0.103	0.075	0.074	0.066	0
Percentile											
0.25	0.106	0.055	0.124	0.105	0.082	0.136	0.130	0.104	0.107	0.093	0
0.10	0.094	0.042	0.113	0.095	0.076	0.132	0.126	0.099	0.101	0.088	0
0.09	0.093	0.041	0.111	0.094	0.075	0.131	0.126	0.098	0.100	0.087	0
0.08	0.091	0.040	0.110	0.092	0.075	0.131	0.125	0.098	0.099	0.087	0
0.07	0.090	0.038	0.109	0.090	0.074	0.130	0.125	0.097	0.098	0.086	0
0.06	0.088	0.036	0.107	0.089	0.073	0.129	0.125	0.096	0.096	0.085	0
0.05	0.086	0.035	0.105	0.088	0.072	0.128	0.123	0.096	0.094	0.085	0
0.04	0.084	0.033	0.103	0.086	0.069	0.128	0.122	0.095	0.093	0.083	0
0.03	0.082	0.030	0.101	0.084	0.068	0.126	0.121	0.093	0.092	0.081	0
0.02	0.079	0.026	0.098	0.080	0.065	0.124	0.119	0.091	0.089	0.078	0
0.01	0.073	0.020	0.093	0.075	0.062	0.121	0.117	0.088	0.086	0.074	0
0.001	0.057	0.004	0.076	0.068	0.053	0.114	0.108	0.077	0.075	0.066	1

Source: ValueCalc Estimates.

Table 13. Simulated Capital Ratios for Banks using the 2007–2010 Financial Environment Calibration with No Inter-Bank Default Losses (percent)

	Capital Ratio Bank 1	Capital Ratio Bank 2	Capital Ratio Bank 3	Capital Ratio Bank 4	Capital Ratio Bank 5	Capital Ratio Bank 6	Capital Ratio Bank 7	Capital Ratio Bank 8	Capital Ratio Bank 9	Capital Ratio Bank 10	Number of Failed Banks
Average	0.072	0.012	0.110	0.090	0.061	0.124	0.120	0.087	0.092	0.084	0.655
Std. Dev.	0.031	0.036	0.026	0.024	0.018	0.014	0.015	0.018	0.022	0.017	0.914
Max	0.130	0.088	0.157	0.134	0.099	0.151	0.147	0.124	0.133	0.116	8
Min	-0.105	-0.173	-0.025	-0.038	-0.036	0.054	0.037	-0.009	-0.038	0.001	0
Percentile											
0.25	0.057	-0.005	0.097	0.078	0.051	0.117	0.113	0.078	0.082	0.075	1
0.10	0.029	-0.039	0.075	0.058	0.037	0.106	0.100	0.063	0.061	0.062	1
0.09	0.026	-0.042	0.072	0.054	0.034	0.105	0.098	0.061	0.060	0.061	1
0.08	0.024	-0.044	0.070	0.051	0.033	0.103	0.097	0.060	0.059	0.059	1
0.07	0.022	-0.048	0.067	0.048	0.031	0.103	0.095	0.057	0.056	0.057	1
0.06	0.017	-0.051	0.063	0.046	0.029	0.101	0.093	0.054	0.052	0.055	2
0.05	0.014	-0.057	0.058	0.044	0.026	0.099	0.091	0.051	0.048	0.053	2
0.04	0.008	-0.066	0.054	0.039	0.022	0.096	0.088	0.048	0.042	0.050	2
0.03	0.000	-0.071	0.047	0.033	0.018	0.092	0.084	0.043	0.040	0.046	3
0.02	-0.008	-0.081	0.043	0.025	0.014	0.089	0.080	0.038	0.036	0.042	3
0.01	-0.021	-0.092	0.032	0.016	0.002	0.081	0.075	0.023	0.026	0.033	4
0.005	-0.036	-0.114	0.012	0.001	-0.008	0.076	0.068	0.015	0.014	0.025	7

Source: ValueCalc Estimates.

Modeling Steps

5. Implementation of network model to assess inter-bank credit losses and potential additional bank solvency failures at T1 (systemic solvency risk).

Table 14. Simulated Capital Ratios for Banks using the 2007–2010 Financial Environment Calibration with First and Second Round of Inter-bank Default Losses

	Capital Ratio Bank 1	Capital Ratio Bank 2	Capital Ratio Bank 3	Capital Ratio Bank 4	Capital Ratio Bank 5	Capital Ratio Bank 6	Capital Ratio Bank 7	Capital Ratio Bank 8	Capital Ratio Bank 9	Capital Ratio Bank 10	Number of Failed Banks
Average	0.072	0.012	0.110	0.090	0.059	0.122	0.120	0.086	0.091	0.083	1
Std. Dev.	0.033	0.039	0.027	0.025	0.024	0.019	0.016	0.020	0.023	0.018	
Max	0.129	0.088	0.157	0.133	0.099	0.151	0.146	0.124	0.132	0.116	10
Min	-0.145	-0.236	-0.058	-0.061	-0.145	-0.042	0.008	-0.048	-0.069	-0.030	0
Percentile											
0.25	0.057	-0.005	0.097	0.078	0.049	0.116	0.112	0.078	0.081	0.074	1
0.10	0.028	-0.040	0.075	0.058	0.035	0.104	0.099	0.063	0.060	0.061	1
0.09	0.026	-0.042	0.071	0.054	0.032	0.103	0.098	0.061	0.059	0.060	1
0.08	0.023	-0.045	0.069	0.051	0.031	0.101	0.096	0.059	0.058	0.058	1
0.07	0.021	-0.048	0.066	0.048	0.029	0.100	0.094	0.056	0.055	0.056	1
0.06	0.016	-0.051	0.063	0.046	0.027	0.099	0.092	0.053	0.050	0.053	2
0.05	0.013	-0.058	0.057	0.043	0.024	0.097	0.090	0.049	0.046	0.051	2
0.04	0.008	-0.068	0.052	0.038	0.019	0.094	0.087	0.046	0.040	0.048	3
0.03	-0.001	-0.074	0.046	0.031	0.015	0.087	0.083	0.041	0.038	0.043	3
0.02	-0.009	-0.083	0.041	0.024	0.009	0.083	0.079	0.035	0.034	0.035	3
0.01	-0.032	-0.104	0.024	0.005	-0.027	0.055	0.060	0.005	0.022	0.019	6
0.001	-0.092	-0.193	-0.024	-0.024	-0.113	-0.026	0.034	-0.024	-0.027	-0.010	9
0.0001	-0.139	-0.231	-0.054	-0.057	-0.141	-0.041	0.011	-0.045	-0.064	-0.028	10

Source: ValueCalc Estimates.

Modeling Steps

6. Begin Liquidity Risk Analysis.

   Estimate probability of banks solvency failures at T2 as measured at T1.

Table 16. Distributional Analysis of Bank Probabilities of Solvency Default at T2 as Measured at T1 (2007–2010 Financial Environment Calibration)

	Bank 1	Bank 2	Bank 3	Bank 4	Bank 5	Bank 6	Bank 7	Bank 8	Bank 9	Bank 10	Wtd Avg for Banking System
Average	0.287	0.866	0.042	0.073	0.202	0.020	0.003	0.039	0.047	0.030	0.091
Std. Dev.	0.270	0.177	0.113	0.147	0.236	0.100	0.034	0.116	0.116	0.107	0.106
Max	1	1	1	1	1	1	1	1	1	1	1
Min	0.024	0.213	0.006	0.007	0.012	0.009	0.000	0.009	0.007	0.003	0.016
Percentile											
0.99	1.000	1.000	0.706	1.000	1.000	0.430	0.041	1.000	0.693	0.681	0.633
0.95	1.000	1.000	0.162	0.282	0.799	0.010	0.009	0.124	0.195	0.075	0.227
0.90	0.754	1.000	0.083	0.151	0.510	0.010	0.005	0.058	0.103	0.035	0.154
0.75	0.366	1.000	0.032	0.061	0.264	0.009	0.000	0.022	0.037	0.018	0.093
0.50	0.176	1.000	0.010	0.027	0.102	0.009	0.000	0.011	0.010	0.010	0.065
0.25	0.100	0.769	0.009	0.012	0.058	0.009	0.000	0.010	0.009	0.007	0.050
0.10	0.062	0.575	0.009	0.010	0.037	0.009	0.000	0.010	0.009	0.006	0.038
0.09	0.058	0.552	0.009	0.010	0.036	0.009	0.000	0.010	0.009	0.006	0.037
0.08	0.057	0.538	0.009	0.010	0.036	0.009	0.000	0.010	0.009	0.005	0.036
0.07	0.054	0.520	0.009	0.010	0.034	0.009	0.000	0.010	0.009	0.005	0.034
0.06	0.053	0.501	0.008	0.010	0.034	0.009	0.000	0.010	0.009	0.005	0.033
0.05	0.045	0.491	0.008	0.010	0.032	0.009	0.000	0.010	0.009	0.005	0.032
0.04	0.044	0.471	0.008	0.009	0.030	0.009	0.000	0.010	0.009	0.005	0.032
0.03	0.040	0.458	0.008	0.009	0.024	0.009	0.000	0.010	0.009	0.004	0.031
0.02	0.038	0.420	0.007	0.009	0.021	0.009	0.000	0.010	0.009	0.004	0.029
0.01	0.033	0.368	0.007	0.008	0.020	0.009	0.000	0.010	0.008	0.004	0.025
0.001	0.024	0.287	0.006	0.008	0.012	0.009	0.000	0.009	0.007	0.004	0.021

Source: ValueCalc Estimates

Modeling Steps

7. Estimation of T1 funding withdrawals based on probability of failure at T2.

Table 11. Withdrawal Rate Assumptions for Decline in Total Liabilities (percent)

Default Probability	Withdrawal Rate	
	Case 1	Case 2
	(BHC)	(IB)
10-20	5	7-10
20-35	10	14-21
>35	25	42

Sources: SNL Financial; and author estimates.

Modeling Steps

8. Estimation of fire sale of assets and/or reductions in lending and bank liquidity failures.

Banks that face a liquidity run are assumed to follow one of two strategies:

• In the first strategy banks stop lending in the interbank and repo markets, liquidate interest bearing bank deposits, sell government securities, and sell other securities (at fire sale prices). **If these steps do not produce adequate liquidity, they ultimately default on their obligations**. This case may be illustrative of a **very rapidly developing liquidity crisis** where *banks that do not have deposit insurance* have little opportunity to adjust their loan portfolios.

• In the second strategy banks **sell their liquid securities and reduce their loan portfolios** in proportions similar to that observed in U.S. bank holding companies having elevated failure probabilities.
This case may be illustrative of *banks with deposit insurance* that face liquidity outflows over time and have an opportunity to adjust their entire asset and liability structure.

Table 19. Simulated Percentage Reduction in Bank Loans after Liquidity Shock (Case 1 for BHC's) (2007–2010 Financial Environment Calibration)

	Bank 1	Bank 2	Bank 3	Bank 4	Bank 5	Bank 6	Bank 7	Bank 8	Bank 9	Bank 10	Total Banking System
Average	-12.05	-25.99	-1.03	-2.20	-8.43	-0.50	-0.18	-0.99	-0.83	-0.31	-2.84
Std. Dev.	10.49	1.63	4.21	5.85	10.54	4.86	1.86	4.30	3.46	2.15	2.94
Max	0.00	-19.08	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.08
Min	-33.58	-37.63	-28.17	-26.74	-41.04	-50.57	-32.92	-29.76	-24.52	-19.06	-27.19
Percentile											
0.99	0.00	-19.69	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.10
0.95	0.00	-24.44	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.36
0.90	0.00	-24.71	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.37
0.75	-4.21	-25.15	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	-1.60
0.50	-4.38	-25.81	0.00	0.00	-4.97	0.00	0.00	0.00	0.00	0.00	-1.80
0.25	-19.82	-26.57	0.00	0.00	-21.18	0.00	0.00	0.00	0.00	0.00	-3.06
0.10	-25.64	-27.60	0.00	-3.82	-25.44	0.00	0.00	0.00	-0.80	0.00	-3.97
0.09	-25.76	-27.70	-2.70	-13.25	-25.55	0.00	0.00	0.00	-0.80	0.00	-4.29
0.08	-25.79	-27.77	-2.72	-17.56	-25.69	0.00	0.00	0.00	-0.81	0.00	-4.47
0.07	-25.90	-27.86	-2.73	-17.64	-25.80	0.00	0.00	0.00	-0.93	0.00	-4.61
0.06	-26.02	-28.07	-2.80	-17.71	-25.88	0.00	0.00	-6.21	-0.95	0.00	-5.00
0.05	-26.07	-28.33	-2.86	-17.86	-26.00	0.00	0.00	-6.40	-11.41	0.00	-8.18
0.04	-26.34	-28.59	-17.55	-18.04	-26.17	0.00	0.00	-6.52	-11.60	0.00	-8.85
0.03	-26.46	-28.78	-17.67	-22.50	-26.46	0.00	0.00	-19.02	-11.68	0.00	-10.04
0.02	-26.85	-29.13	-17.80	-22.69	-26.60	0.00	0.00	-19.60	-11.78	-6.28	-11.98
0.01	-28.24	-30.66	-23.79	-23.51	-29.39	-16.58	-4.82	-25.30	-20.10	-16.16	-18.02
0.001	-31.80	-36.10	-27.07	-25.65	-39.58	-48.82	-20.06	-28.99	-23.44	-18.47	-25.07

Source: ValueCalc Estimates.

Modeling Steps

9. Implementation of network model to assess inter-bank credit losses resulting from bank liquidity induced solvency failures at T1 (systemic liquidity risk).

Table 17. Simulated Distribution of Total Solvency plus Liquidity Induced Bank Failures (2007–2010 Financial Environment Calibration)

	Max Liquidity Run = 25% Total Assets	Max Liquidity Run = 42% Total Assets	No Liquidity Run
Average	1.33	1.43	
Std. Dev.	1.03	1.19	
Max	10.00	10.00	
Min	0.00	0.00	
Percentile			
0.99	0.00	0.00	
0.95	1.00	1.00	
0.90	1.00	1.00	
0.75	1.00	1.00	
0.50	1.00	1.00	
0.25	1.00	1.00	
0.10	2.00	3.00	
0.09	2.00	3.00	
0.08	2.00	3.00	
0.07	2.00	3.00	
0.06	2.00	3.00	
0.05	2.05	3.00	
0.04	3.00	3.00	
0.03	4.00	4.00	
0.02	4.00	4.00	
0.01	7.00	8.00	6.00
0.001	9.00	10.00	

Source: ValueCalc Estimates

Modeling Steps

10. Identify policy actions that can be taken in advance of crises to moderate risk levels:
    - financial and economic environment,
    - portfolio concentrations,
    - portfolio credit quality,
    - Deposit insurance,
    - liquidity buffers,
    - capital levels, etc.

Table 20. Additional equity capital required at T0 for banks to have a 99 percent confidence level that at T1 they would less than a 10 percent probability of failing by T2

	Capital Ratio Bank 1	Capital Ratio Bank 2	Capital Ratio Bank 3	Capital Ratio Bank 4	Capital Ratio Bank 5	Capital Ratio Bank 6	Capital Ratio Bank 7	Capital Ratio Bank 8	Capital Ratio Bank 9	Capital Ratio Bank 10
Initial Capital Ratios	0.104	0.057	0.124	0.104	0.080	0.134	0.124	0.095	0.101	0.088
Approximate Additional Equity Capital Required at T=0 to Have 1% Pprobability of a 10% Probability of Failure at T=1	0.111	0.216	0.045	0.056	0.123	0.031	-0.011	0.049	0.046	0.026

Source: ValueCalc Estimates.

Conclusions

- These are only illustrative risk assessments for the US.
- For a future environment similar to the 1987–2006 volatilities and correlations, we find only a small risk of U.S. bank failures focused on thinly capitalized and regionally concentrated smaller banks.
- For the 2007–2010 financial environment calibration we find substantially elevated solvency and liquidity risks for all banks and the banking system.

Important areas for **future research** include assessing:

- modeling potential economic regime shifts is also an exceptionally important risk assessment topic.
- the relationship between system wide stress levels and liquidity risk for individual banks,
- correlated changes in all liability accounts for banks with elevated solvency risk,
- how volatility in bank loan collateral values increase bank solvency and liquidity risk,

Important areas for **future research** include assessing:

- correlations between the volume of repossessed collateral (e.g., real estate) and subsequent price declines for that collateral type and subsequent default rates on related bank loans, and
- modeling correlated systemic solvency, liquidity, and sovereign risk.