Modeling systemic risk with ΔCoVaR:

a comparison of linear and neural network approaches

Master of Science in Applied Data Science for Banking and Finance

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Research Overview

Context

- Measuring systemic risk (banking sector)

Goals

- Exploring a neural network quantile regression (NNQR) approach to calculate the systemic risk metric ΔCoVaR
- Computing a predictive model on ΔCoVaR using lagged financial variables
- Providing practical interpretation of findings (keeping in mind possible applications)

Results

- NNQR shows slightly better performance than LQR for ΔCoVaR calculations
- Contradicting results for the predictive model



Before the Great Financial Crisis of 2007 and 2008

Preventing each bank from taking large risks would prevent a build-up risk in the entire financial system.



After the the Great Financial Crisis

Systemic Risk

A phenomenon of financial interconnectedness that could start with a single event (initial shock) which then spreads regionally or globally.



Systemic risk can arise from:

- a single "too big-to-fail" institution
- a group of smaller institutions exhibiting similar behaviors, which can create a lack of diversification

VaR = Value at Risk

VaR

a measure of risk for financial institutions that quantifies the potential maximum loss for an institution within a specified confidence interval

- for a given probability q (e.g., 5%), a VaR of -12% means that an institution's market-valued assets are expected to fall by at least 12% over a specific time period (e.g., a week)



CoVaR = Co-Value at Risk

CoVaR

a systemic risk measure defined as the VaR of the financial system conditional on some event of institution *i*

- the prefix "Co" in CoVaR stands for conditional, contagion, or comovement
- introduced by Adrian and Brunnermeier in 2011[1]
- CoVaR answers the question: "what is the VaR of the entire financial system if a specific institution is in distress?"

[1] Tobias Adrian and Markus K. Brunnermeier. **Covar**. National Bureau of Economic Research Working Paper Series, No. 17454, October 2011



ΔCoVaR

ΔCoVaR

the difference between the system's CoVaR when a firm is in distress and the system's CoVaR when that same firm is in its normal, median state

$$\Delta CoVaR_t^i(q) = CoVaR_t^i(q) - CoVaR_t^i(50\%)$$

- This difference isolates and quantifies the marginal contribution of a single institution to overall systemic risk
- A ΔCoVaR of -1.16 means that when a particular institution is in distress, the financial system's VaR is expected to change by -1.16 percentage points
- It is not a measure of direct causality: it rather captures the idea that the distress of one firm signals that others are likely also struggling, increasing system-wide risk

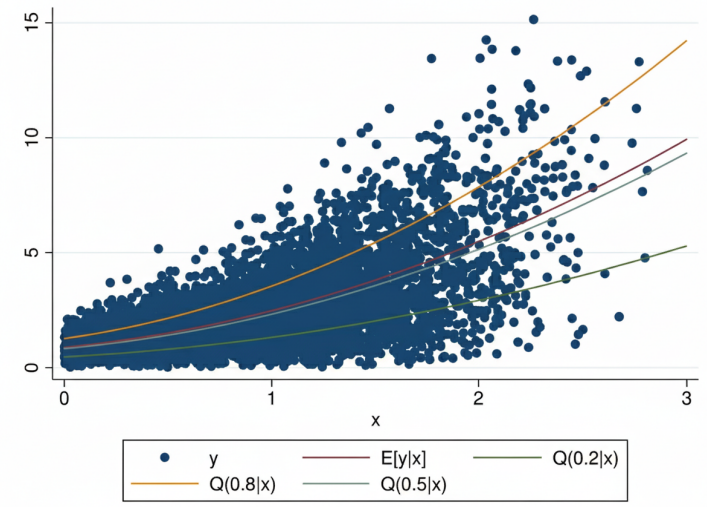


Adrian and Brunnermeier's CoVaR Limitations

Use of linear quantile regression (LQR)

LQR

Estimates the impacts of the independent variables in different regions of the conditional distribution of y (e.g. lower tail for a small q)



Limitations:

1. assumes linearity
2. requires manual specification of nonlinear terms
3. oversimplifies complex relationships between y and $\mathbf{x}$

$\longrightarrow$ Motivation for a different approach

BankFocus - Groups

Total banks: 1284

Flag	**Status Group: # entities**
Active companies: • Active	(1) Active: 632
Active companies: • Active (administratively non-compliant) • Active (rescue plan) • Active (default payment) • Active (insolvency proceedings) • Active (reorganization) • Active (dormant)	(2) Rest: 30



BankFocus - Groups

Flag	**Status Group: # entities**
Inactive companies (since 2006): • Administratively suspended • In liquidation • Bankruptcy • Dissolved (demerger) • Dissolved (liquidation) • Dissolved (bankruptcy) • Dissolved • Inactive (no precision)	(3) Inactive: 622



BankFocus - Entities Specifics

Geographical areas

- United States
- Euro Area

Other Characteristics:

- Not minor branches or subsidiaries (GUOs)
- Publicly listed companies
- Formerly publicly listed companies



Bloomberg

Date: 26/12/2003 - 29/12/2023 (1045 weeks)

Weekly

Macro/Market Indicators (US):

- Yield on 10-year US Treasury bond
- Yield on 3-month US Treasury bill
- Average yield of US high-yield corporate bonds
- S&P500 Total Return Index
- Chicago Board Options Exchange Volatility Index (VIX)

Stock Metrics :

- Market Capitalization
- Stock Price
- Beta

Quarterly

Financials:

- Total Assets
- Total Equity
- Leverage Risk Ratio

  (risk-weighted assets / equity)
- Maturity Mismatch

  (total loans / total deposits)
- Tier 1 ratio

  (tier 1 capital / risk-weighted assets)



Growth of Market Valued Total Assets: X_t^i

Market valued total assets

$$A_t^i = ME_t^i \cdot LEV_t^i$$

where:

- ME_t^i is the market capitalization
- LEV_t^i is the leverage ratio as $\frac{TotAssets}{TotEquity}$ (quarterly $\rightarrow$ weekly)

Growth market valued total assets

$$X_t^i = \frac{A_t^i - A_{t-1}^i}{A_{t-1}^i}$$



Market Variables: M^i_{t-1}

Market variables M^i_{t-1}

Change in Credit Spread

US Corporate Risky Bond - 10Y Gov bond [2]

Change in Yield Curve Slope

10Y Gov bond - 3M Gov bond [2]

Historical Equity Risk Premium

Weekly equity return - 10Y Gov bond [3]

VIX

as it is



[2] Change: Value_t - Value_{t-1}

[3] Equity return: $(S\&P500_t - S\&P500_{t-1})/(S\&P500_{t-1})$

VaR

Quantile regression ($\mathbf{q = 5\%}$ & $\mathbf{q = 50\%}$):

- Linear
- Neural networks

Over expanding windows - 260 weeks

$$X_t^i = \alpha^i + \gamma^i M_{t-1} + \epsilon_t^i$$

$$VaRt^i(q) = \hat{\alpha}_q^i + \hat{\gamma}_q^i M_{t-1}$$



Financial system returns: X_t^{system}

$$X_t^{system} = \sum_i w_{t-1}^i \cdot X_t^i \quad \forall t$$

where $w_{t-1}^i = \dfrac{TotAssets_{t-1}^i}{\sum_i TotAssets_{t-1}} \quad \forall t$



CoVaR and ΔCoVaR

Quantile regression (**q** = **5%** & **q** = **50%**):

- Linear
- Neural networks

Over expanding windows - 260 weeks

$$X_t^{system} = \alpha^{system|i} + \beta^{system|i} X_t^i + \gamma^{system|i} M_{t-1} + \epsilon_t^{system|i}$$

$$CoVaR_t^i(q) = \hat{\alpha}^{system|i} + \hat{\beta}^{system|i} VaR_t(q)^i + \hat{\gamma}^{system|i} M_{t-1}$$

$$\Delta CoVaR_t^i(q) = CoVaR_t^i(q) - CoVaR_t^i(50\%)$$

negative values: institution i distress $\uparrow$ risk for entire system



Quantitative Comparison

Negative residuals

$y - \hat{y} < 0 \Rightarrow \hat{y} > y$

Negative residuals percentage of 5% CoVaR

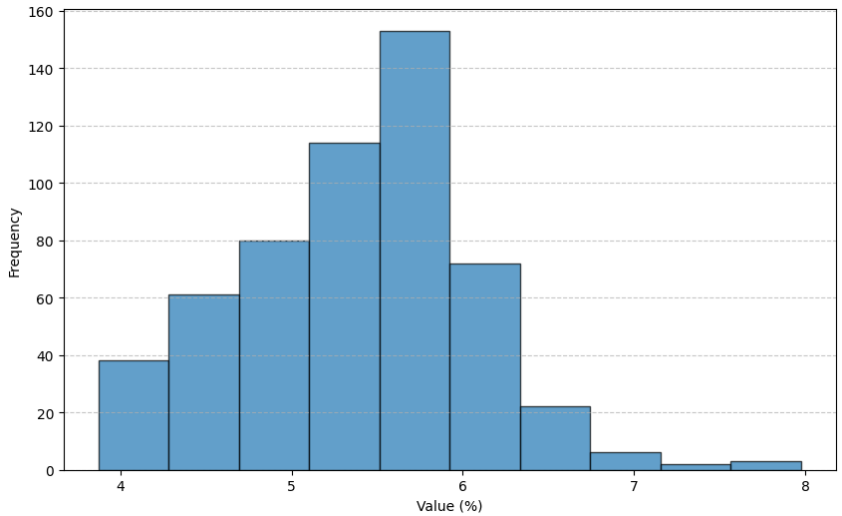


Figure 1: For LQR

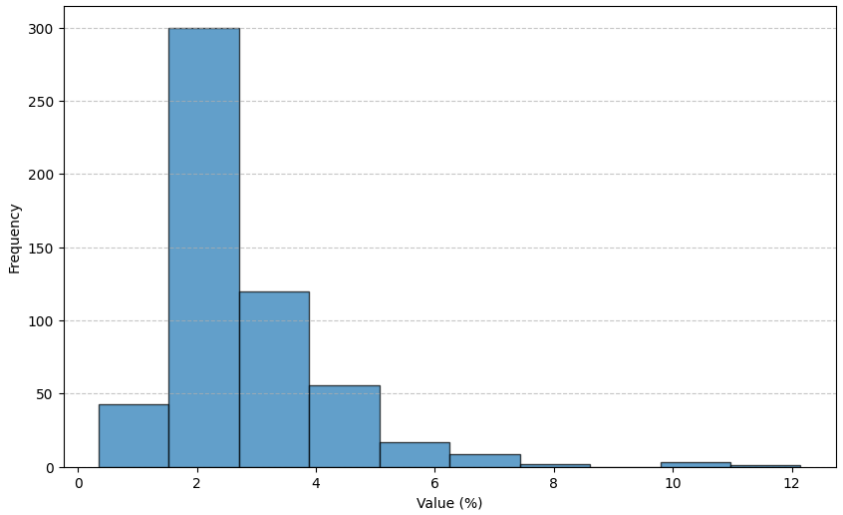


Figure 2: For NNQR

Graphical Comparison - Commercial Banks during GFC

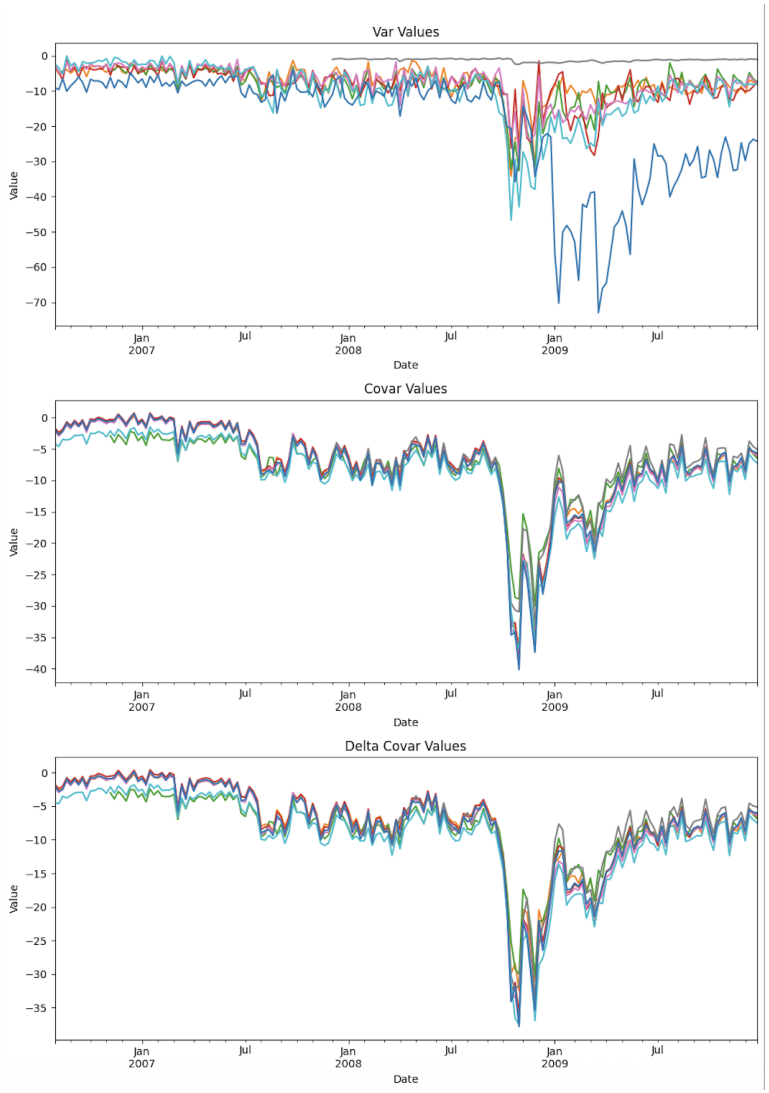


Figure 3: With LQR

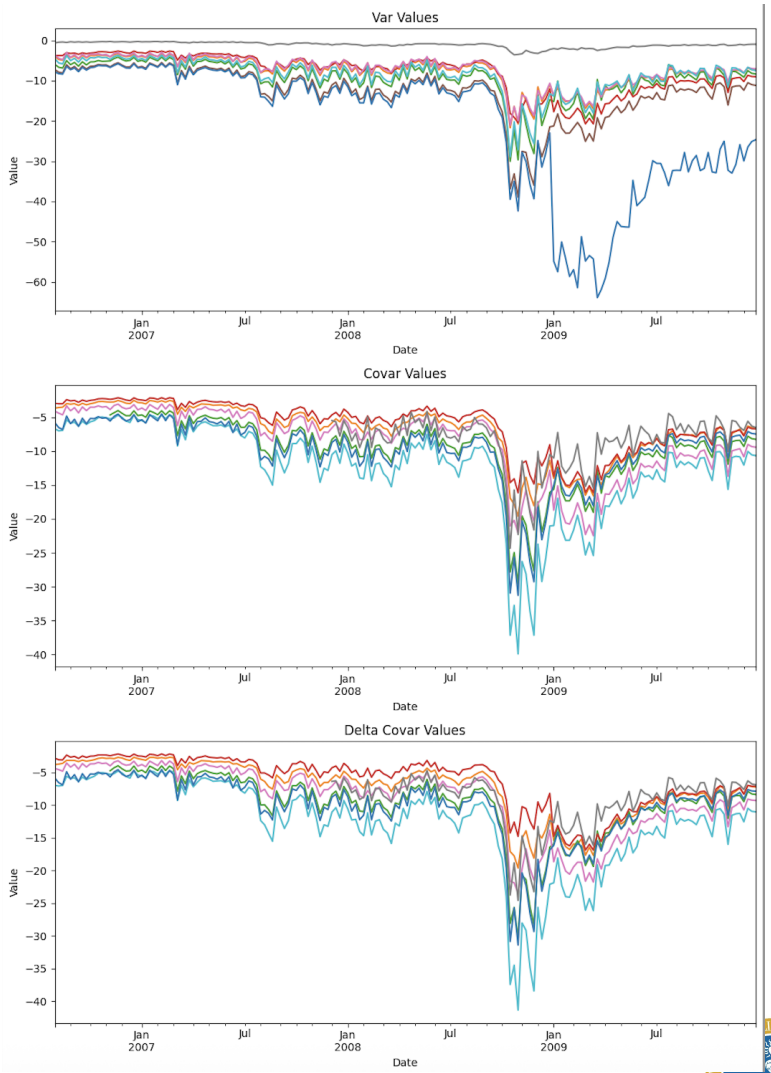


Figure 4: With NNQR

Forward ΔCoVaR

Procyclicality

Current metrics move in the same direction as the overall economy



Risk measures should recognize that

- risk typically builds up in the background
- materializes only during a crisis

⟶ **Forward ΔCoVaR**

Forward ΔCoVaR Methodology

Panel regression of ΔCoVaR_t

- for each institution i
- for each quarter t
- on a set of institutional characteristics lagged:
  - 1 quarter
  - 1 year (**best**)
  - 2 years

Future contribution to systemic risk $\sim$ Firm's current characteristics

$$\Longrightarrow \quad \Delta\text{CoVaR}_t \sim \begin{bmatrix} x_{1,t-1} \\ \vdots \\ x_{n,t-1} \end{bmatrix}$$



Variables Included

- Log of Assets
- Log of Equity
- Stock Price Returns Volatility
- Risk Leverage [a]
- Market-to-Book Ratio [b]
- Tobin's Q [c]
- Matuirity Mismatch [d]
- Tier 1 Ratio [e]

[a] RWAs / Equity
[b] Market Cap / Book Equity
[c] (Market Cap + Liabilties) / Total Assets
[d] Total Loans / Total Deposits * 100
[e] Tier 1 Capital / RWAs



LQR ΔCoVaR for Active Group

Unexpected results:

- LQR better than NNQR
- Variables don't fully capture ΔCoVaR values
- "Too small to care" effect
- "Moral hazard" of banks with a strong balance sheet

Variable	Parameter	Std. Err.	P-value
const	-140.07	1.4471	0.0000
Tobin's Q	-0.878	1.0078	0.3836
MTB Ratio	0.0501	0.0803	0.5327
Log Assets	7.1801	0.1893	0.0000
Log Equity	-3.7215	0.1553	0.0000
Returns Volatility	-1.5316	0.3226	0.0000
Maturity Mismatch	0.0272	0.0011	0.0000
Risk Leverage	-0.2292	0.0105	0.0000
Tier1 Ratio	-0.2109	0.0099	0.0000

Table 1: Panel regression for LQR ΔCoVaR - 1 year lagged variables (Active)



Conclusions

Key Results

- **NNQR** shows slightly better performance for ΔCoVaR calculations than **LQR**
- F**orward** Δ**CoVaR** with panel regression better performance for:
  - 1 year lagged variables
  - LQR



Potential improvements

- Use of European market variables
- MICE interpolation
- X_t^i growth of market valued total assets split in < 0 and > 0
- XGBoost instead of panel regression
- Interconnectedness data