Modeling Failure in Bank Networks

Preventing a Crisis

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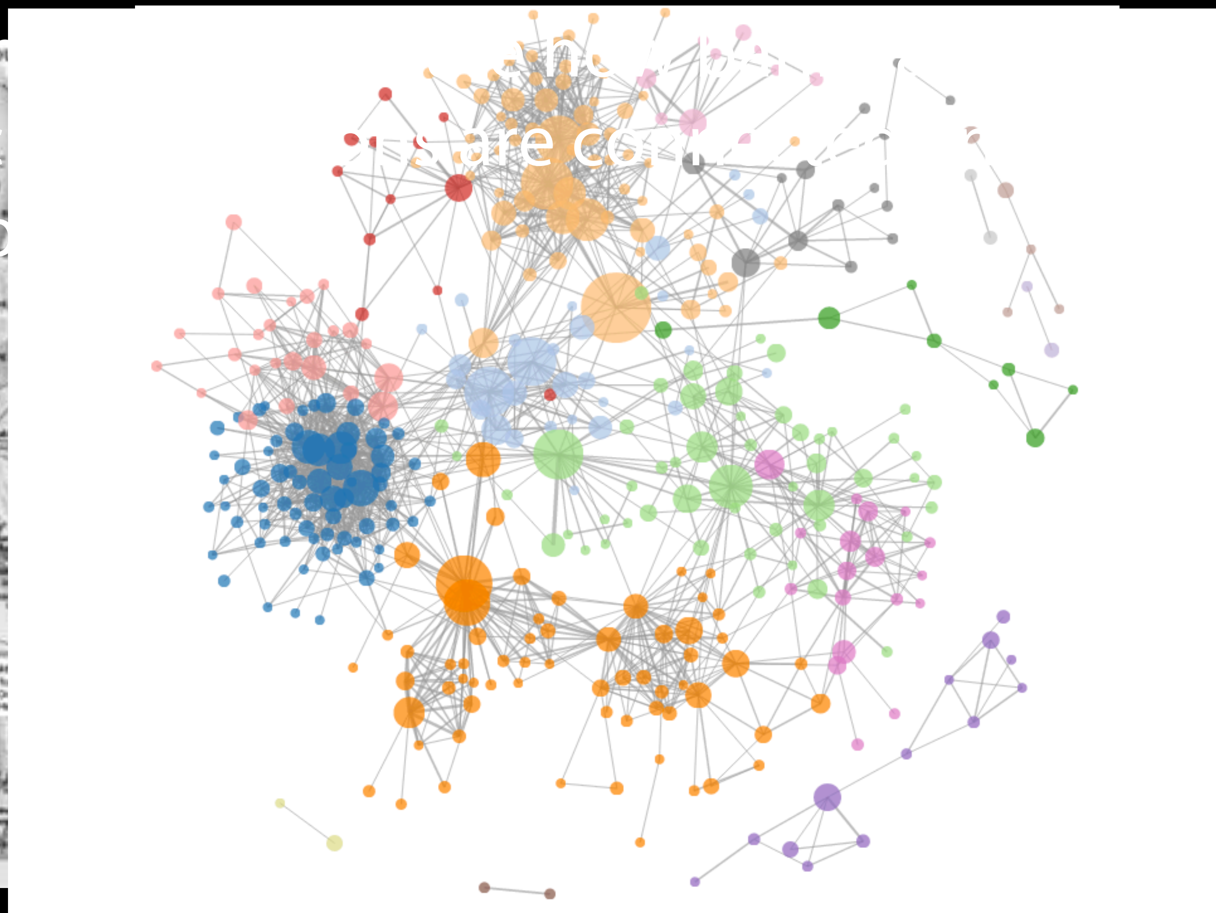
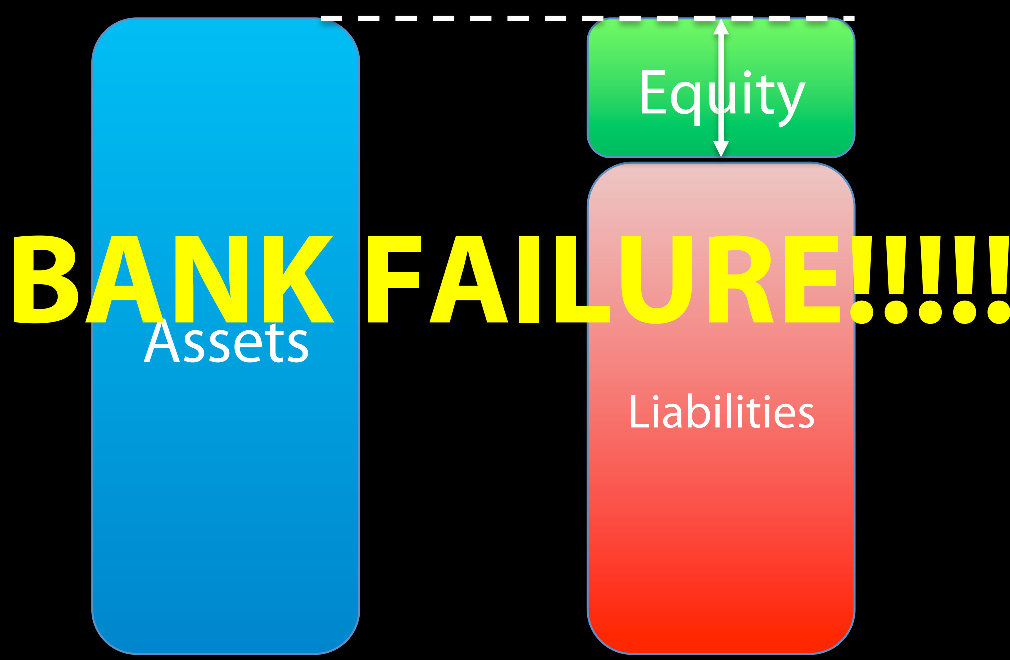
What is a (bank) network?

- Elements (nodes) that interact with each other (links)
- Bank n
  financ ... s are co ... ffect
  each o



What do we mean by failure?

- Banks have Assets & Liabilities
- Assets – Liabilities = Equity



Why is this important?

- Can the connections between banks change the risk of bank failure?
- How could the whole financial system fail?
  - What causes cascading failures?

SYSTEMIC RISK

- Can we add value to current policy making?

Why should physicists study bank networks?

- Bank network structures are complex, time-dependent and not well understood
  - Many interacting elements
  - Complex rules of interaction
  - Driven by stochastic processes

- Many banks rely on “quants” with physics/mathematics/computer science backgrounds

- Applying physics to the study of bank networks will help us understand cascading failures and may help us avoid economic disaster

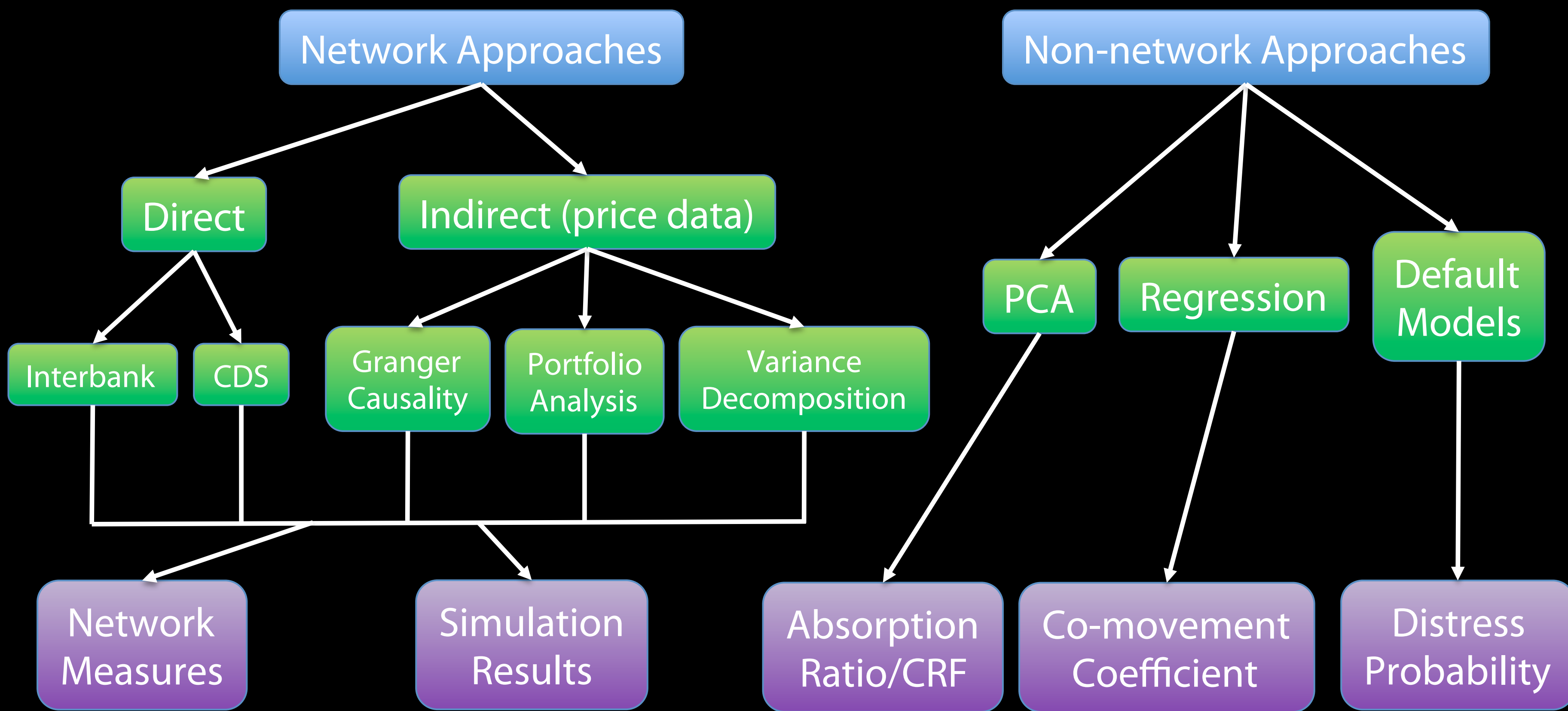
Presentation Overview

- Summary of network models in banking
- Direct exposure network model
  - Federal Reserve Y-15 report case study
- Bipartite cascading failure network model
  - Venezuelan banking case study
- What have we learned from these models?

What kind of network model?!

- Type of network structure
  - Direct bank-to-bank network
  - Bipartite bank-asset network
- Type of nodes
  - All financial institutions
  - Only the biggest banks
- Type of links
  - Credit obligations
  - Asset similarity
- Other factors
  - Market liquidity, leverage ratios, etc.
  - Endogenous vs. exogenous shocks

What kind of network model?!



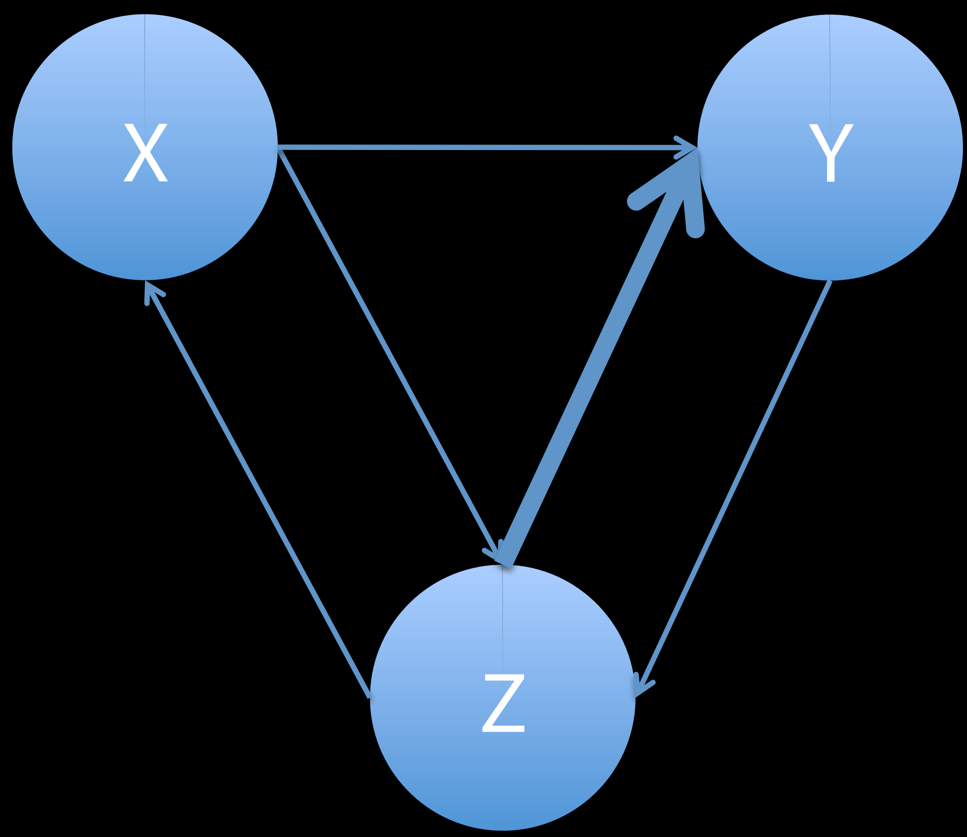
Gazi Kara, Mary Tian and Margaret Yellen
Taxonomy of Studies on Interconnectedness,
Board of Governors of the Federal Reserve System, July 31, 2015.

Direct Interbank Network

- Nodes = Banks
- Links = credit obligations between banks
  - Banks borrow funds from each other on a regular basis, mostly overnight lending
  - Banks also buy forms of insurance from other banks
  - If banks become distressed, they may not be able to fulfill their obligations to other banks

"Exposures" are the inverse of "obligations"

Direct Interbank Network



Direct Interbank Network

	Bank X	Bank Y	Bank Z
Bank X	0	?	?
Bank Y	?	0	?
Bank Z	?	?	0

= obligation of
bank to bank

= exposure of
bank to bank

Estimating Bank Obligations

- We used data from Federal Reserve FR Y-15 report
  - This data set includes total assets and liabilities as well as total <u>interbank</u> obligations and exposures for the 33 largest US financial institutions

- Interbank obligations are the sums of the rows

- Interbank exposures are the sums of the columns of our network matrix

Estimating Bank Obligations

	Bank X	Bank Y	Bank Z	
Bank X	0	?	?	8
Bank Y	?	0	?	5
Bank Z	?	?	0	7
				$= o$
	10	6	4	$= e$

Estimating Bank Obligations

- Start with prior matrix
- Find L that minimizes Kullback-Leibler divergence (aka cross-entropy) within the constraints
  - This results in the most interconnected network possible

$$D^*_{KL}(L, U) = \sum_{i=1}^{n} \sum_{j=1}^{n} l_{ij} log \left(\frac{l_{ij}}{u_{ij}} \right)$$

- We impose further constraints to alter the network structure

Estimating Bank Obligations

	Bank X	Bank Y	Bank Z	
Bank X	0	?	?	8
Bank Y	?	0	?	5
Bank Z	?	?	0	7
	10	6	4	

Estimating Bank Obligations

	Bank X	Bank Y	Bank Z	
Bank X	0	2.4	1.6	8
Bank Y	2.5	0	1	5
Bank Z	3.5	2.1	0	7
	10	6	4	

Estimating Bank Obligations

	Bank X	Bank Y	Bank Z	
Bank X	0	4.69	3.31	8
Bank Y	4.31	0	0.69	5
Bank Z	5.69	1.31	0	7
	10	6	4	

Can the banks cover their obligations?

- If payments are made on all interbank obligations, will any banks fail?

  then the bank fails

- If a bank fails then it can't completely fulfill it's obligations
- Banks "exposed" to that bank won't receive full payments
- Now those banks may fail,
  even if $equity_i + \sum_j L_{ij} - \sum_j L_{ij} > 0$,
  and we will have cascading failures

Measuring systemic risk

- How many banks fail? How many cascading failures?
  - For the FR Y-15 US bank data, we find that
    - 3 of the 33 banks would fail initially (BNY MELLON, AMEX, STATE STREET)
    - 1 due to a cascading failure (DEUTSCHE BANK)
- How much money is lost in the system due to bankruptcies?
  - \$292.4M out of \$2.38B (12.3%) in total interbank obligations

- How do these values change with our assumptions about interconnectedness?

- What if we shock the system?
  - What if asset values drop across the system?
  - What if a bank unexpectedly fails? How does that affect the rest of the system?

Changing the Network Structure

	Bank W	Bank X	Bank Y	Bank Z	
Bank W	0	3.15	2.25	2.60	8
Bank X	3.06	0	0.90	1.04	5
Bank Y	4.00	1.64	0	1.36	7
Bank Z	2.94	1.21	0.86	0	5
	10	6	4	5	

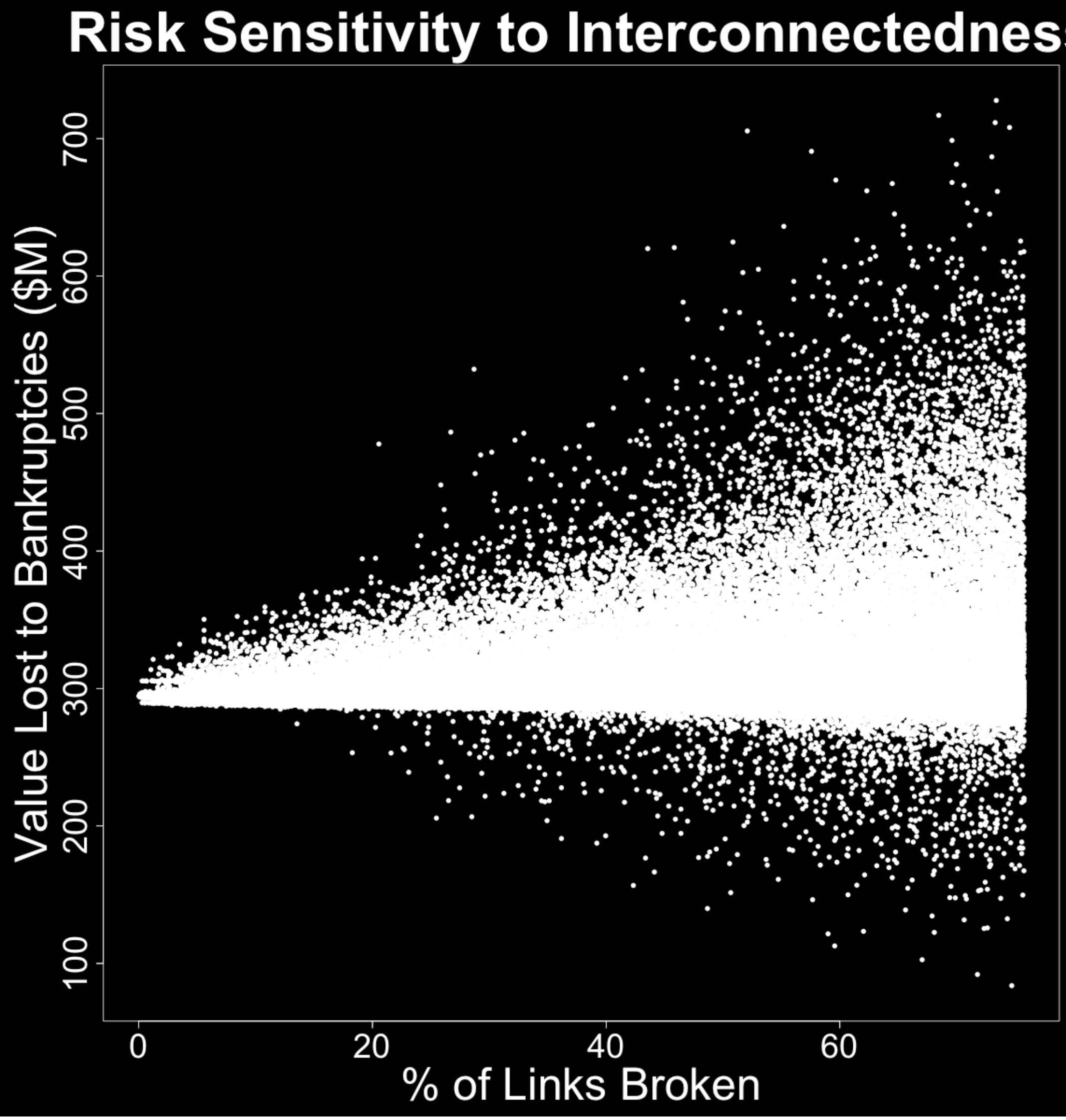
Changing the Network Structure

	Bank W	Bank X	Bank Y	Bank Z	
Bank W	0	3.15	2.25	0	8
Bank X	3.06	0	0.90	1.04	5
Bank Y	4.00	1.64	0	1.36	7
Bank Z	2.94	1.21	0.86	0	5
	10	6	4	5	

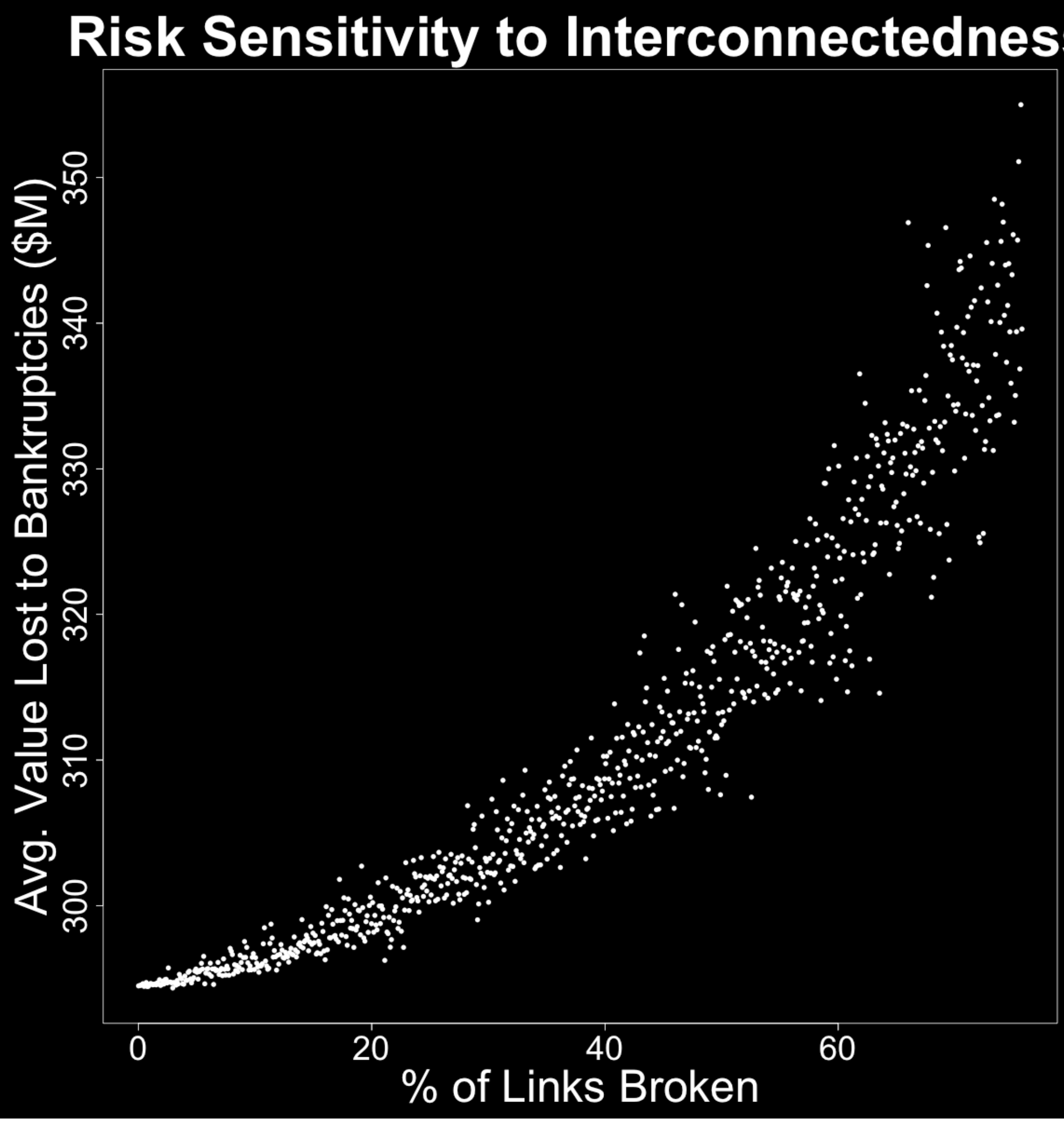
Changing the Network Structure

	Bank W	Bank X	Bank Y	Bank Z	
Bank W	0	4.75	3.25	0	8
Bank X	2.58	0	0.30	2.12	5
Bank Y	3.52	0.60	0	2.88	7
Bank Z	3.89	0.66	0.45	0	5
	10	6	4	5	

Measuring systemic risk
Network Structure



Measuring systemic risk
Network Structure

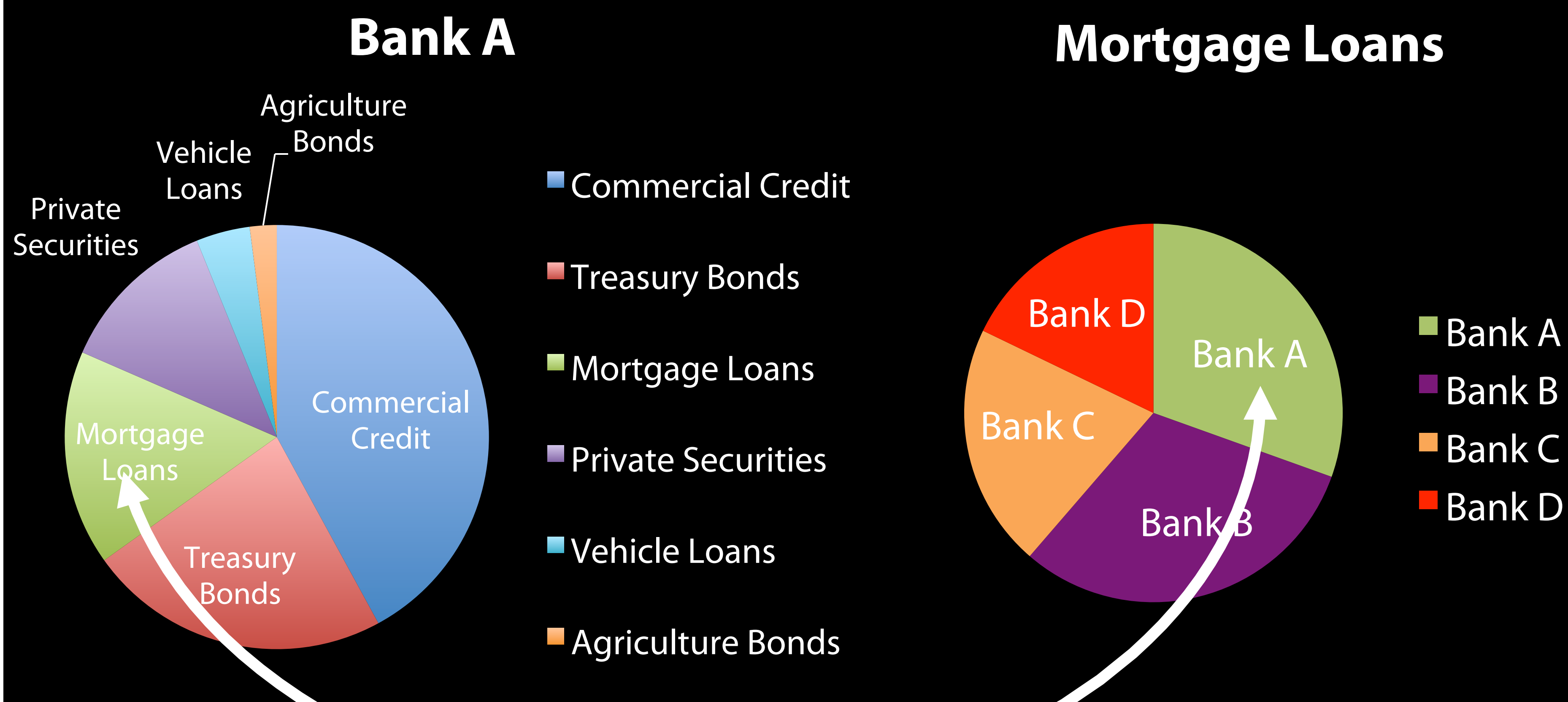


Bipartite Bank-Asset Network

- Nodes = Banks & Assets Classes
  - Two types of nodes
- Link = asset type is owned by a bank
  - Links are only between bank nodes & asset nodes

BIPARTITE

Bipartite Bank-Asset Network



B_i = total asset value of bank i

A_m = total value of asset m in system

$B_{i,m}$ = value of asset m owned by bank i

Cascading Failure Model

B_i = total asset value of bank i

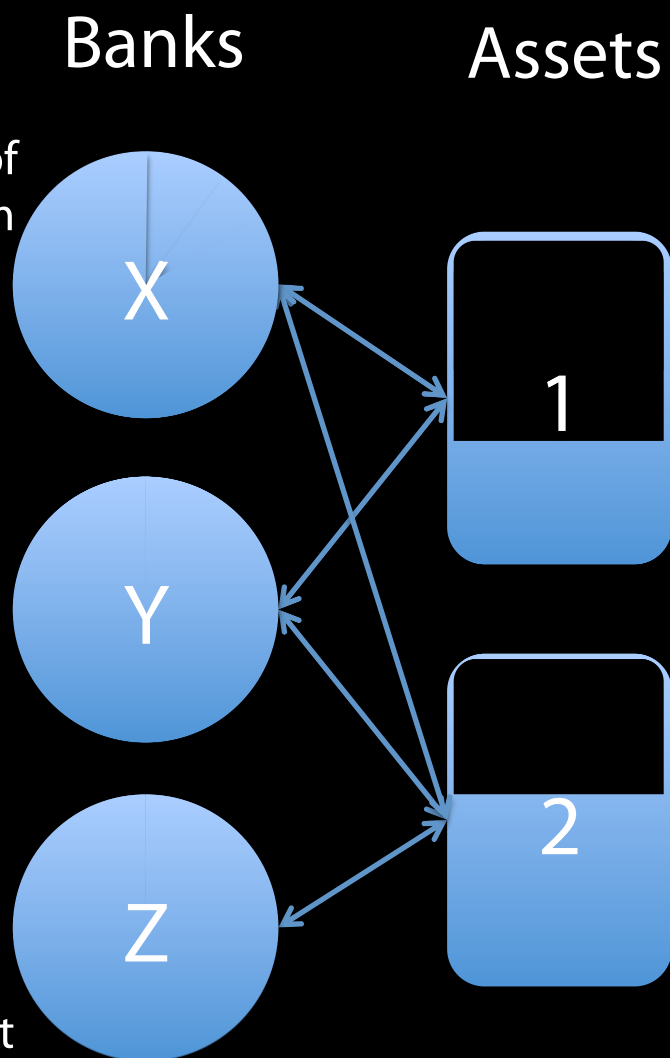
A_m = total value of asset m in system

$B_{i,m}$ = value of asset m owned by bank i

m* – shocked asset

p – fraction of shocked asset remaining

α – liquidity parameter, aka fire-sale effect



1. Initial shock to chosen asset class
2. Devalue bank assets correspondingly
3. Check for bankruptcies
   If none, then we're done
4. Devalue assets owned by failed banks
5. Return to step 2

Shock = 1-p

$B_{i,m^*} \leftarrow pB_{i,m^*}$

$A_{m^*} \leftarrow pA_{m^*}$

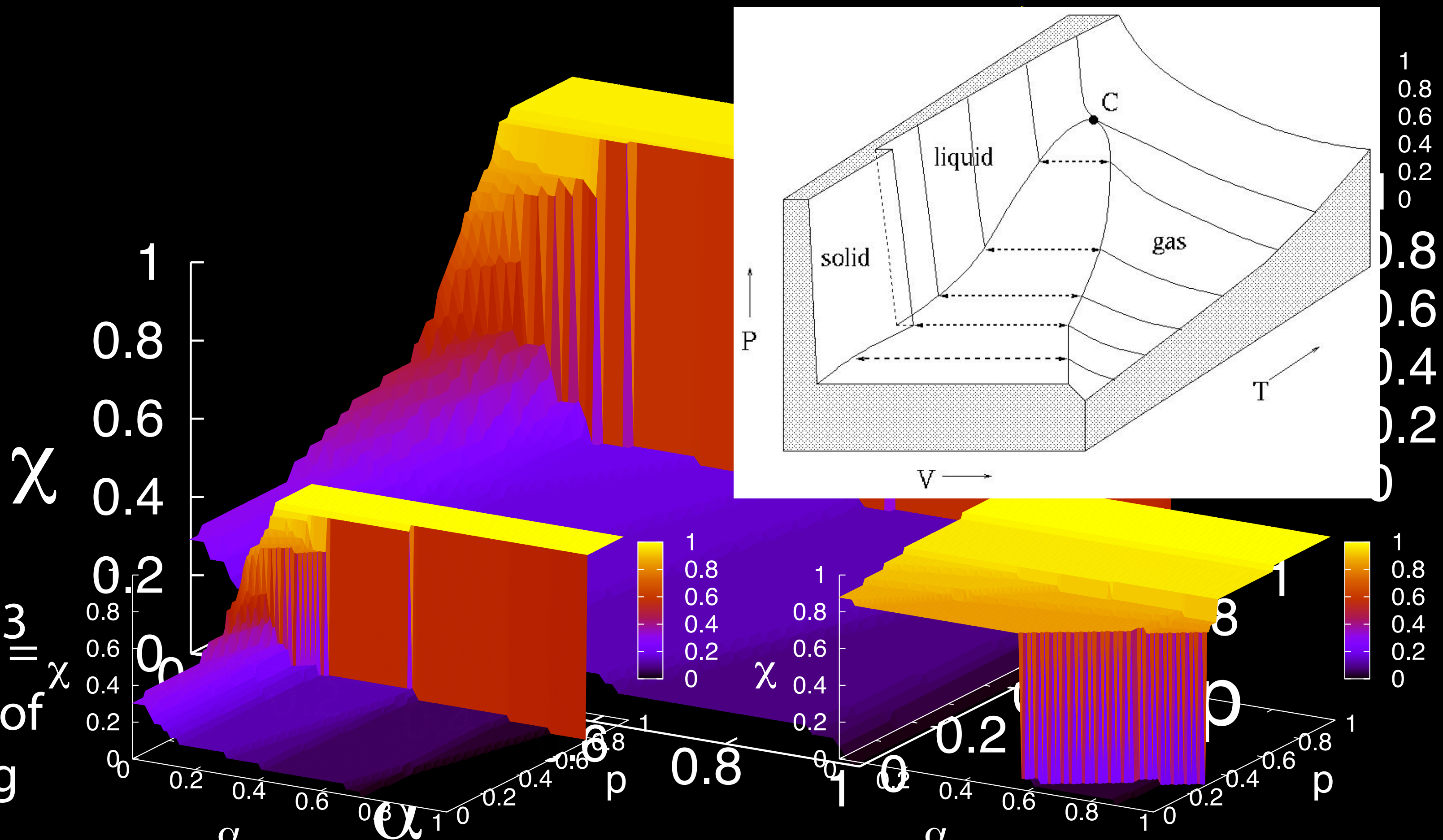
$B_i \leftarrow B_i - (1-p)B_{i,m^*}$

If assets < liabilities then the bank fails

$A_m \leftarrow A_m - \alpha B_{i,m}$

Sensitivity to α & p

12/2005

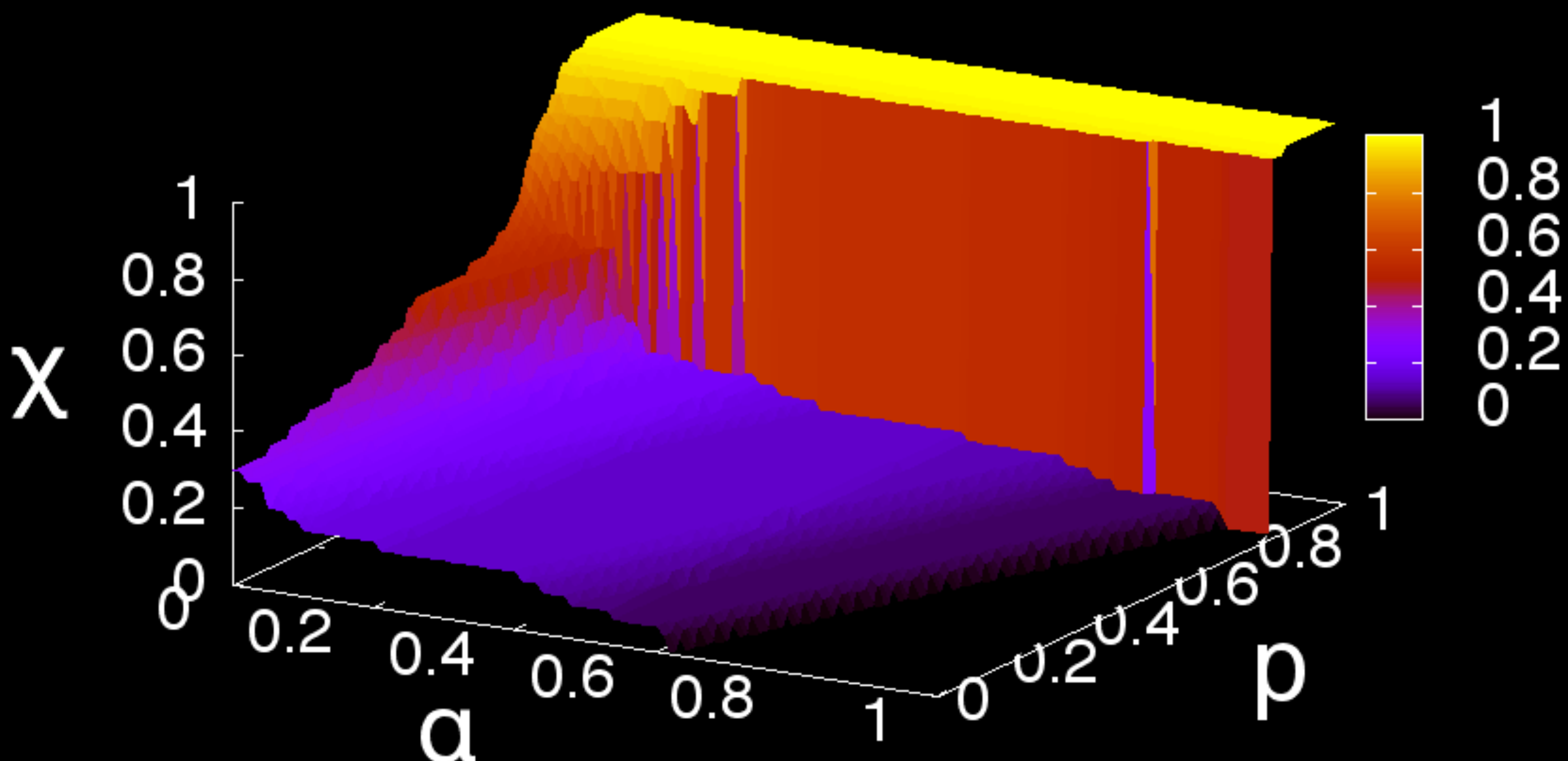


12/2013

$\chi(\alpha,p,m)$ = fraction of surviving banks

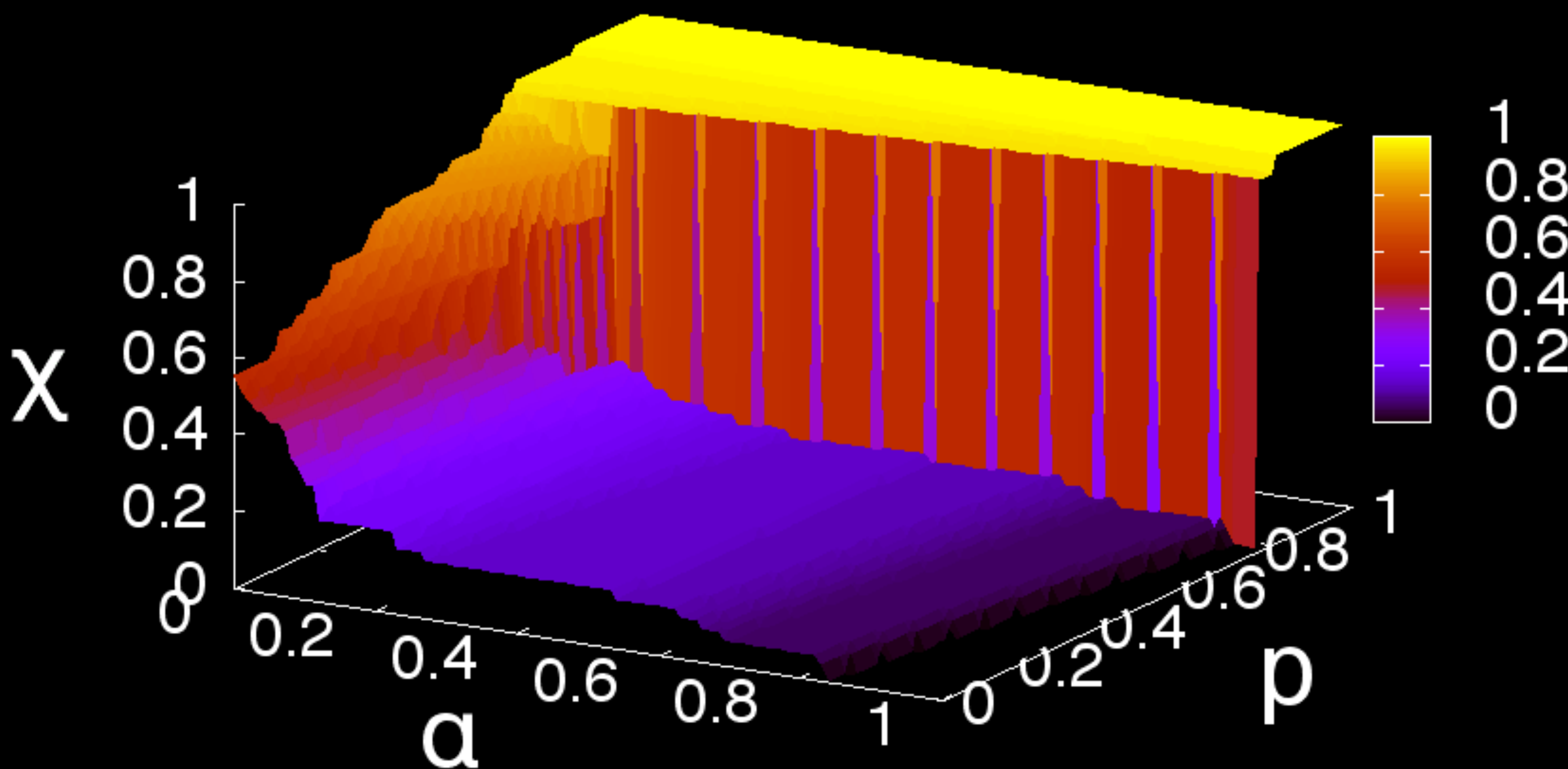
Commercial Credit BCV Bonds

Stable sensitivity
Commercial Credits



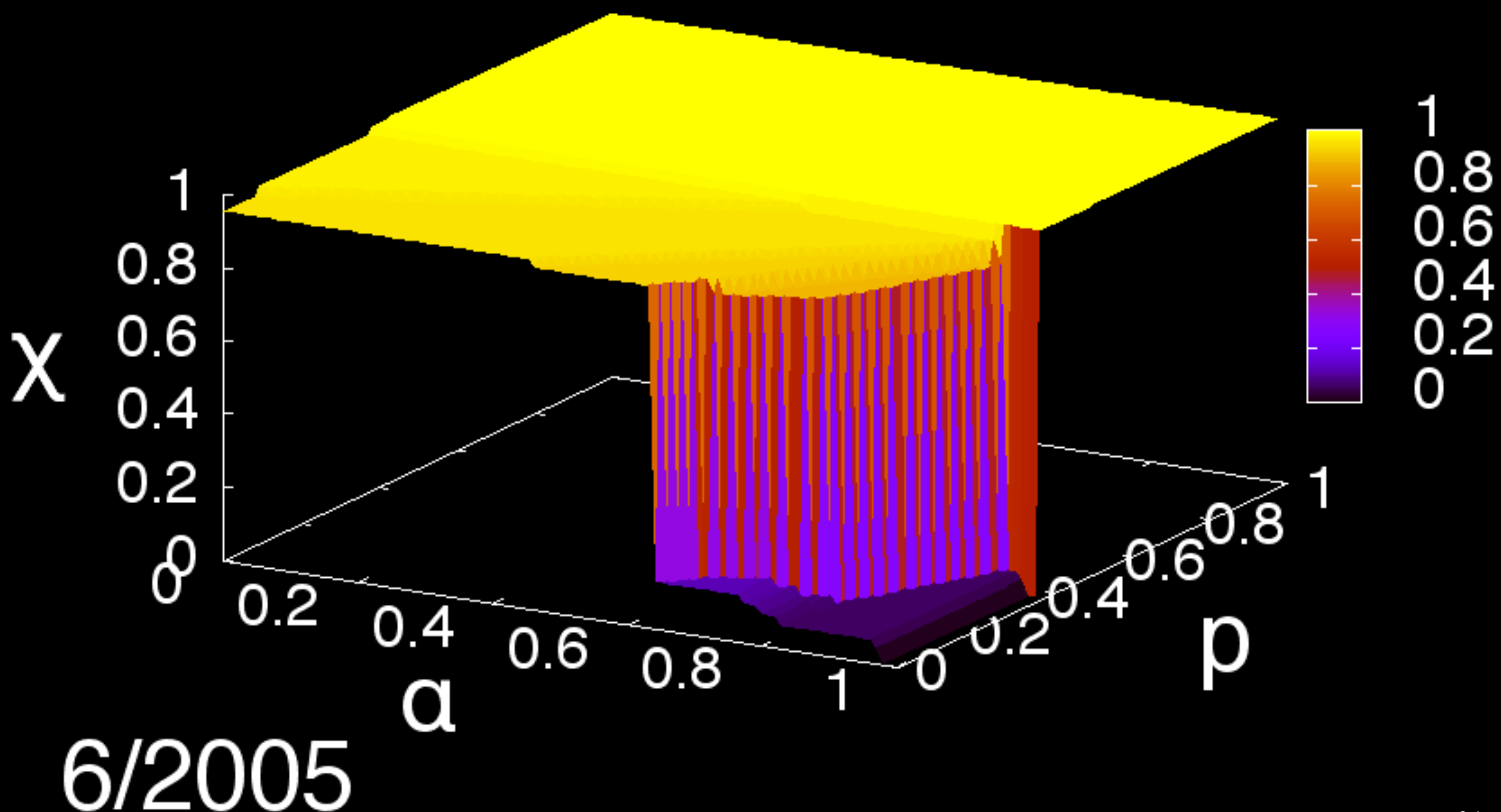
6/2005

Unstable sensitivity
BCV Bonds

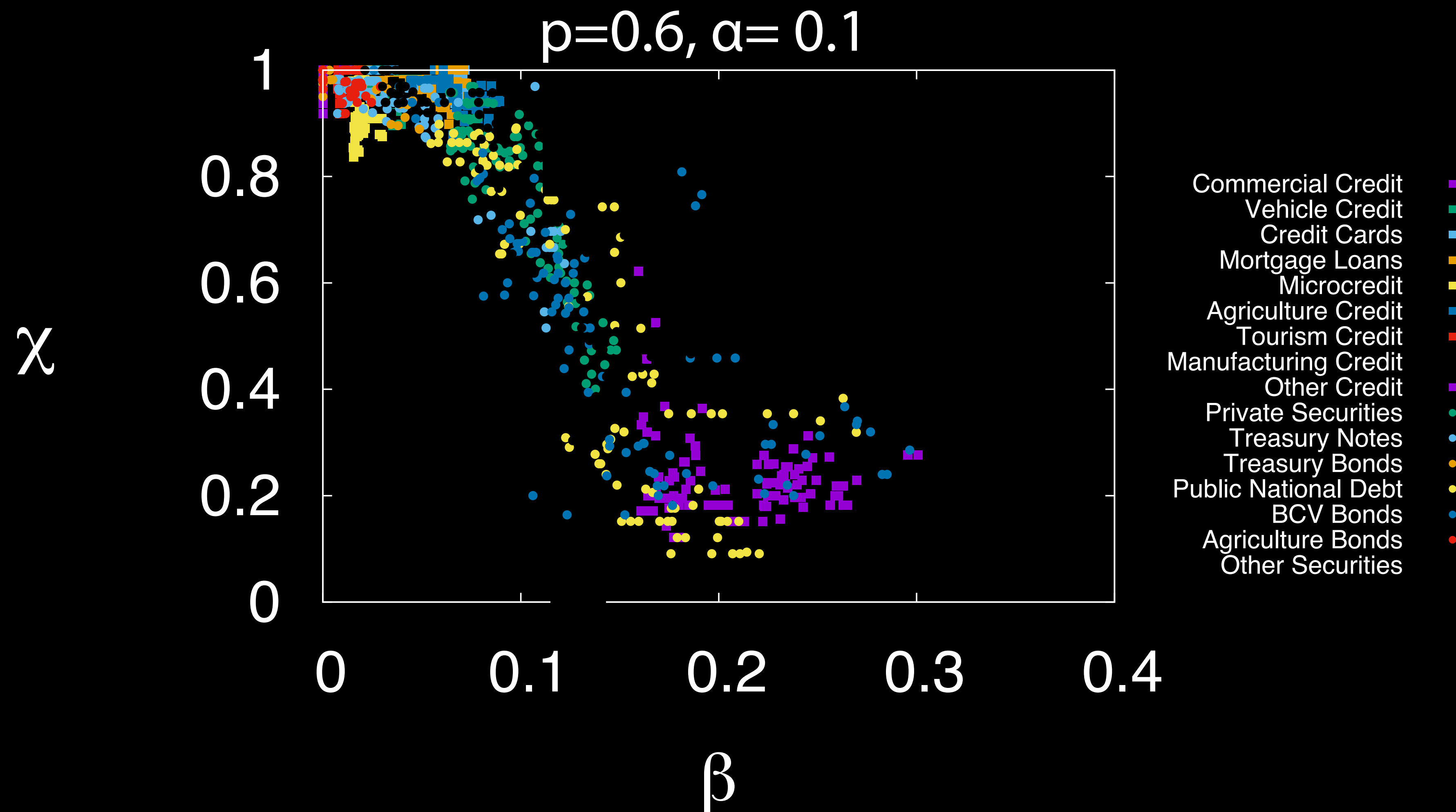


6/2005

Very unstable sensitivity
Treasury Notes

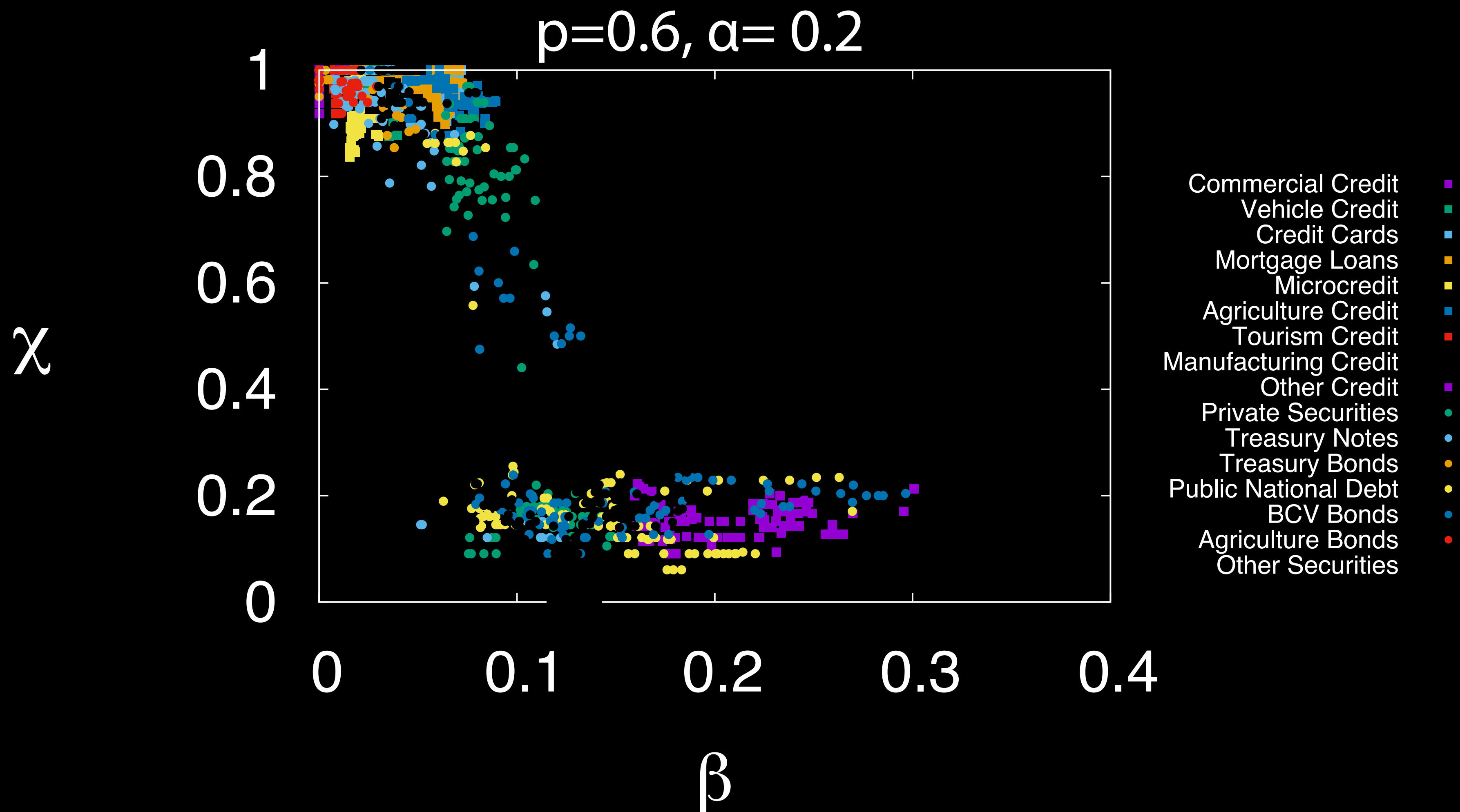


Failure by asset size



β = relative size of shocked asset

Failure by asset size



β = relative size of shocked asset

What should you take away?

- Greater interconnectedness tends to result in a more resilient system
- Risk of systemic failure is sensitive to small changes in shock size and the fire-sale effect
- The size of a shock and level of liquidity that will cause systemic failure can change abruptly month-to-month and needs to be monitored

Why is this important?

- How do the connections between banks change the risk of bank failure?
  – More interconnectedness tends to mean less systemic risk, but not always so
- How could the whole financial system fail?
  – Shocks in prices of widely held assets, i.e. mortgages, bonds, etc.
- Can we add value to current policy making?
  – We have tools help monitor systemic sensitivity to adverse scenarios, i.e. a new mortgage crisis

Econophysics publications

1. S. Levy-Carciente, D.Y. Kenett, **A. Avakian**, H. E. Stanley and S. Havlin. *Dynamical macro-prudential stress testing using network theory.* Journal of Banking and Finance, Vol. 59 (164-181), 2015.

2. **A. Avakian**, I. Vodenska, and H.E. Stanley. *Interconnectedness in bank networks of direct credit exposure.* (2017, in preparation)

3. **A. Avakian**, B. Podobnik, M. Piskor and H.E. Stanley. *Capital death in the world market* Phys. Rev. E. 89, 032805, 2014.

4. H.S. Moat, C. Curme, **A. Avakian**, D.Y. Kenett, H.E. Stanley, T. Preis. *Quantifying Wikipedia usage patterns before stock market moves.* Scientific Reports, Vol. 3, pp. 1801, 2013.

Thank you!

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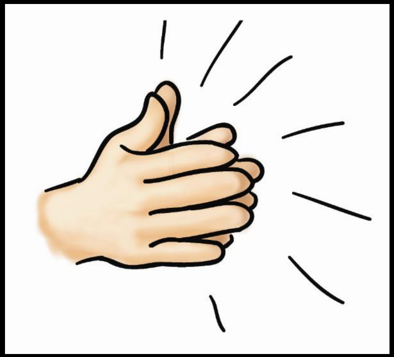
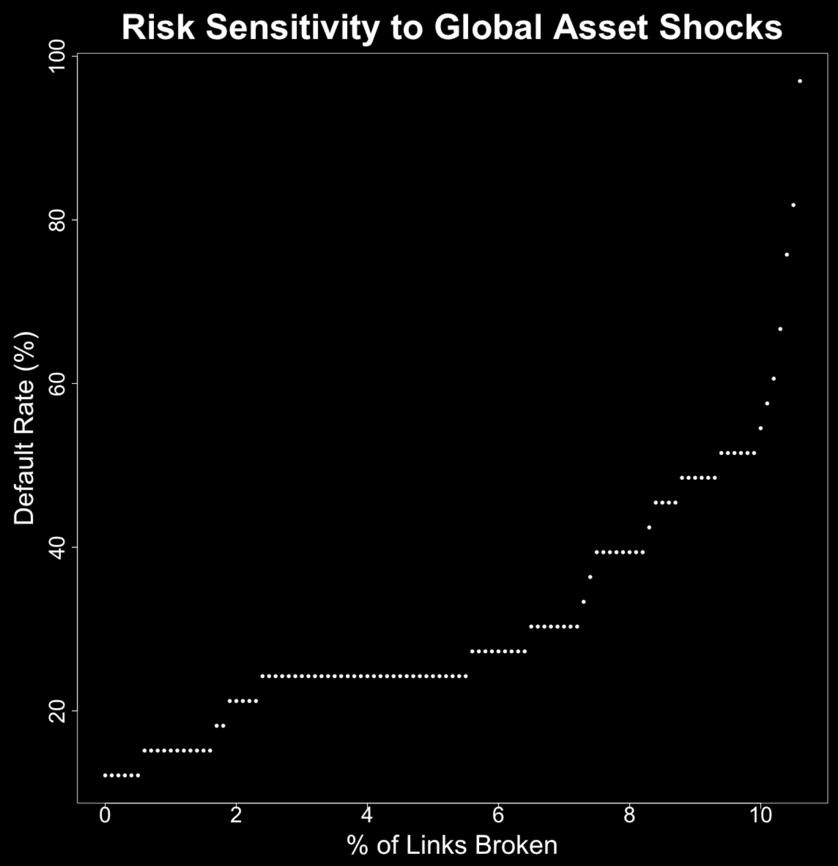
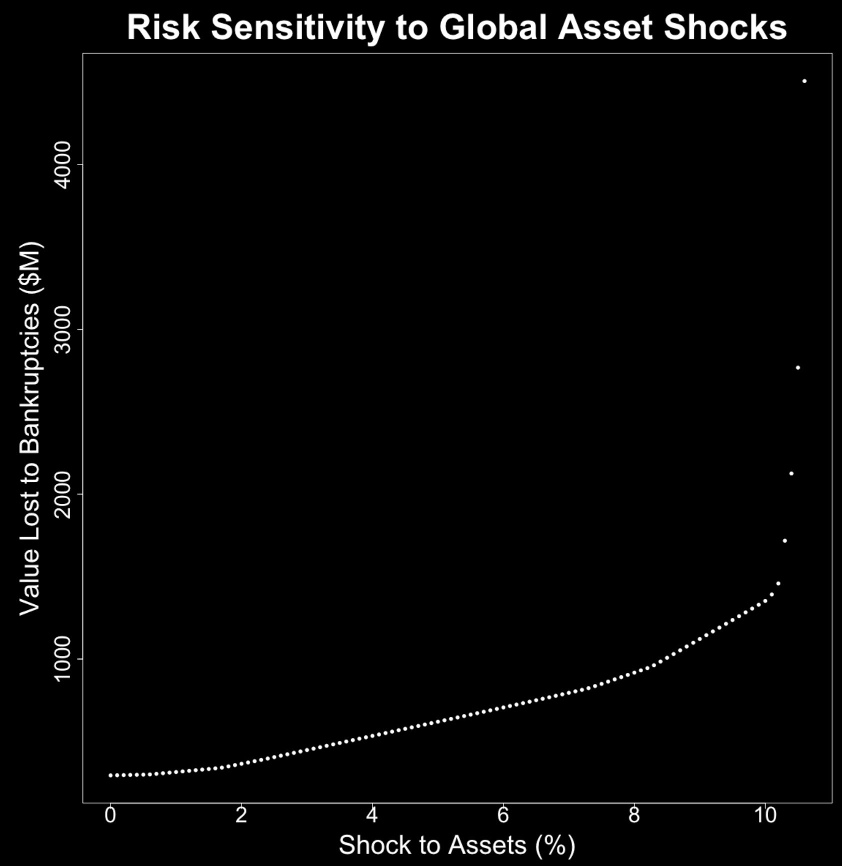
- Thanks to my committee members
- Thanks to all who listened to my practice talks
- Thanks to Mirtha Cabello!!!!!



Measuring systemic risk
Asset Shocks

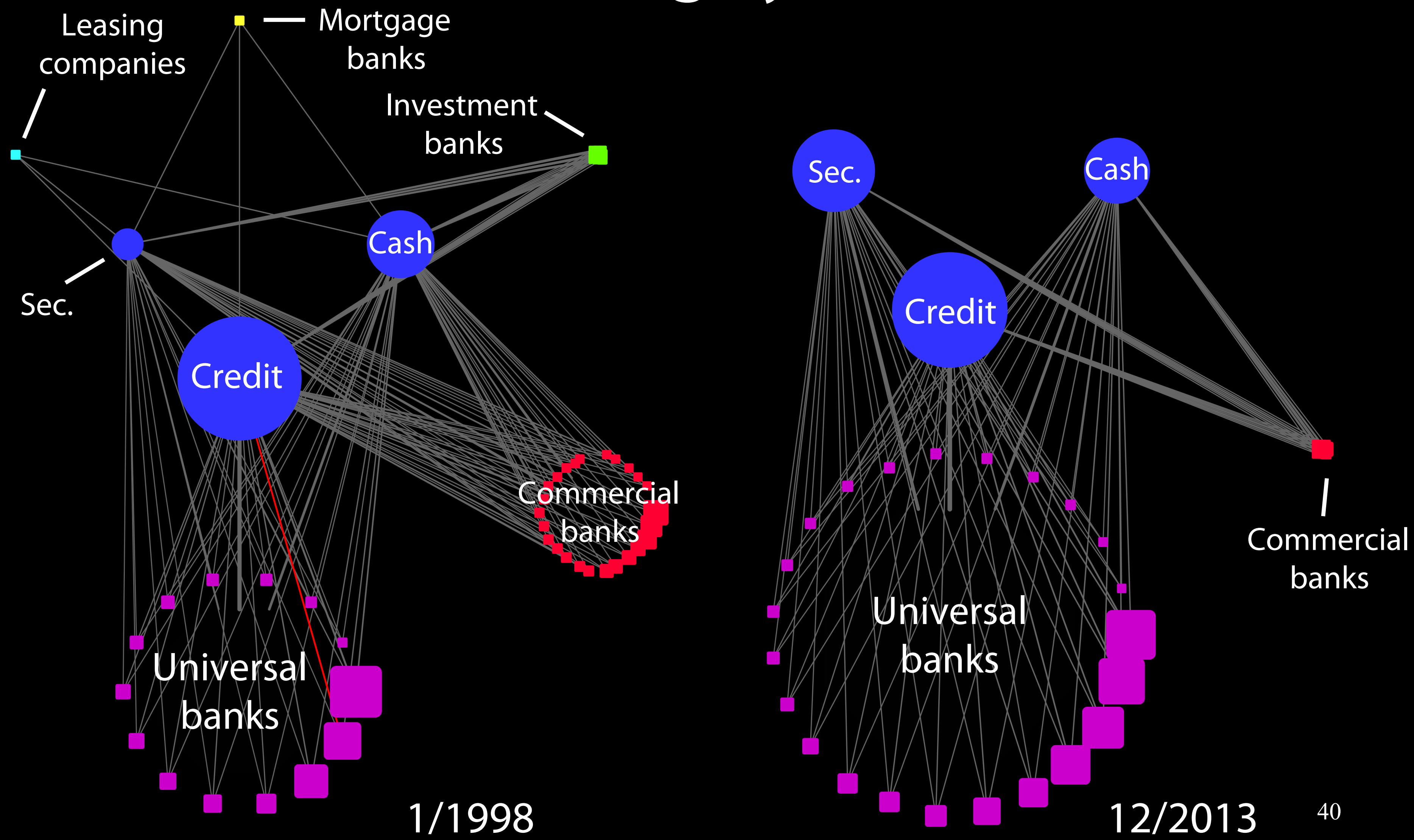




Asset & Bank Types

Asset Types	Bank Types
Cash & Cash Equivalents	Commercial banking
Credit	Universal banking
Commercial credit	Investment banking
Vehicle credit	Savings and loan institutions
Credit cards	Mortgage banking
Mortgage loans	Leasing institutions
Microcredit	Money market funds
Agriculture credit	Micro-finance banking
Tourism credit	Development banking
Manufacturing credit	
Securities	
Private securities	
Treasury notes	
Treasury bonds	
Public national debt	
BCV bonds	
Agriculture bonds	

A brief history of the Venezuelan banking system



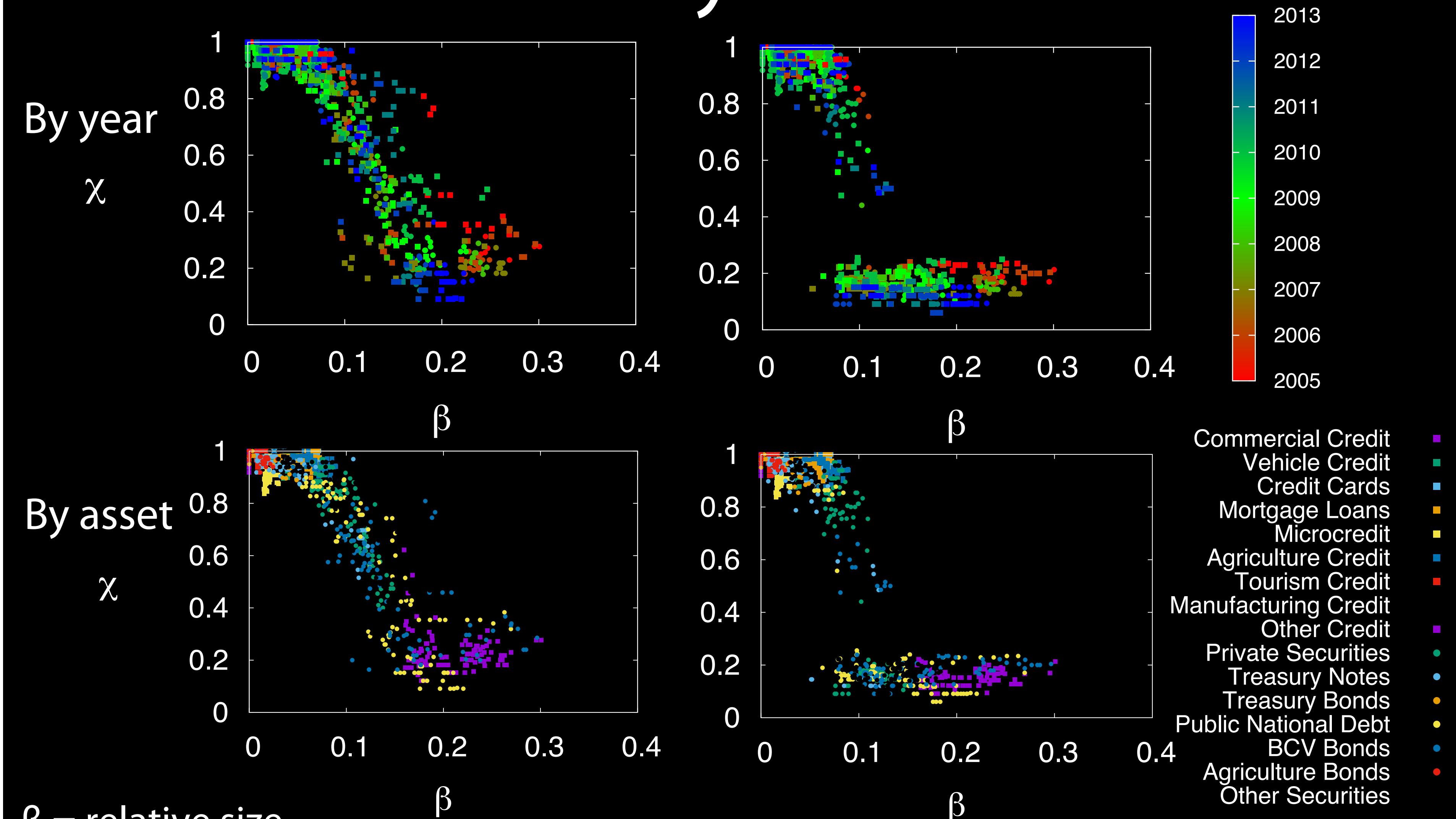
Results from Huang, et al. (2013)

- Was able to correctly identify many of the banks that failed following the 2008 crash
- Sensitivity to commercial (not residential as many people said) real estate asset values were primarily responsible for 2008 crash
- Can be used as a stress testing tool to prevent future crashes

Venezuelan case study

- Cons
  - No crash with which to tune parameters
  - Much smaller financial system
    - Less global impact
- Pros
  - Longitudinal data (monthly 1998-2013)
  - Much smaller financial system
    - We can easily look at a large parameter space

Failure by asset size



β = relative size of shocked asset

p=0.6, α= 0.1

p=0.6, α= 0.2

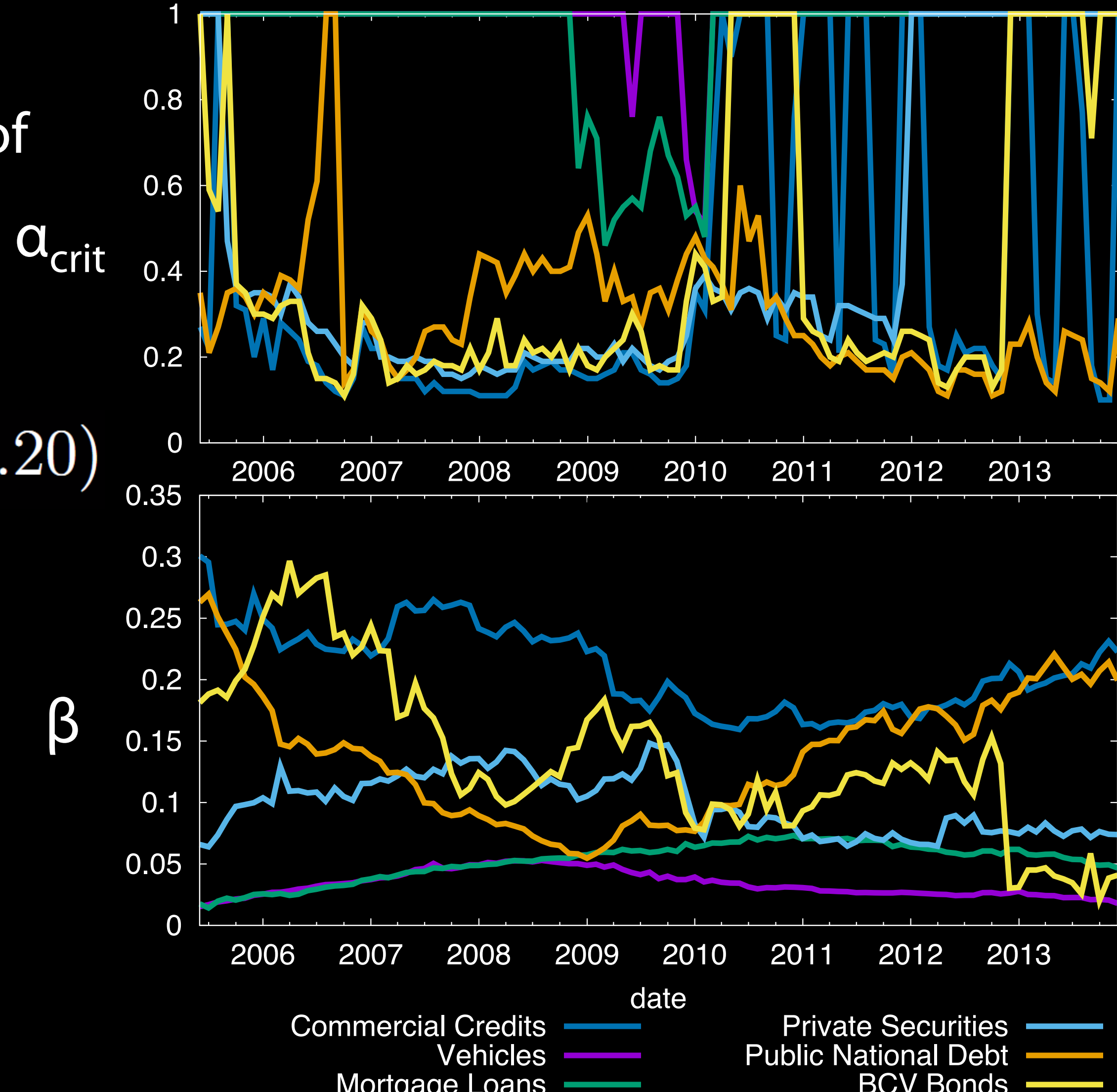
Sensitivity to liquidity and relative asset size

α_{crit} – smallest α such that fewer than 20% of banks survive

$$\alpha_{crit}(p) = \alpha | (\chi(p, \alpha) \leq 0.20 \ \& \ \chi(p + 0.01, \alpha) > 0.20)$$

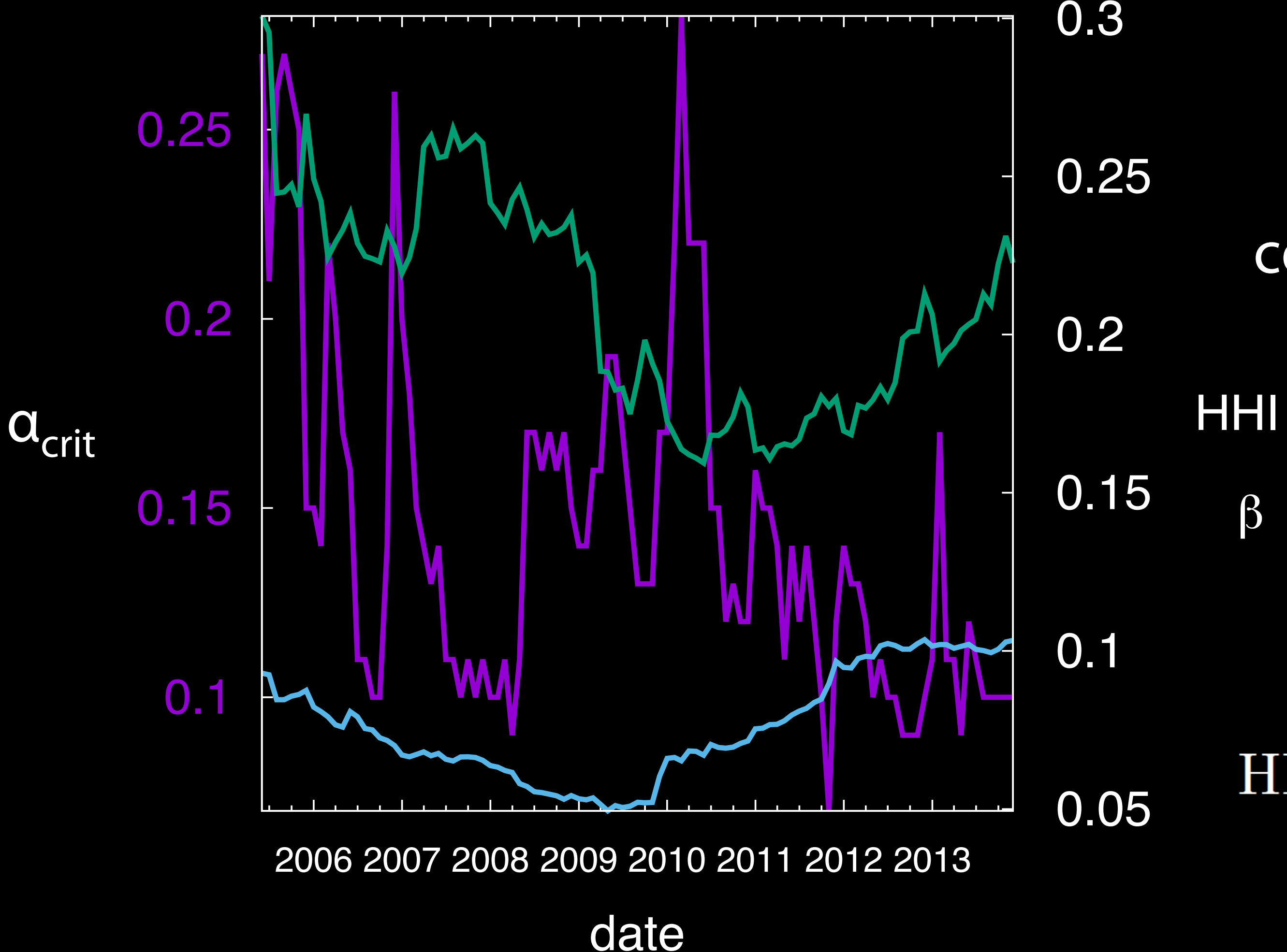
β – relative size of shocked asset

$$\beta_m = \frac{A_m}{\sum_i A_i}$$



p= 0.80

Asset size and concentration with sensitivity to liquidity

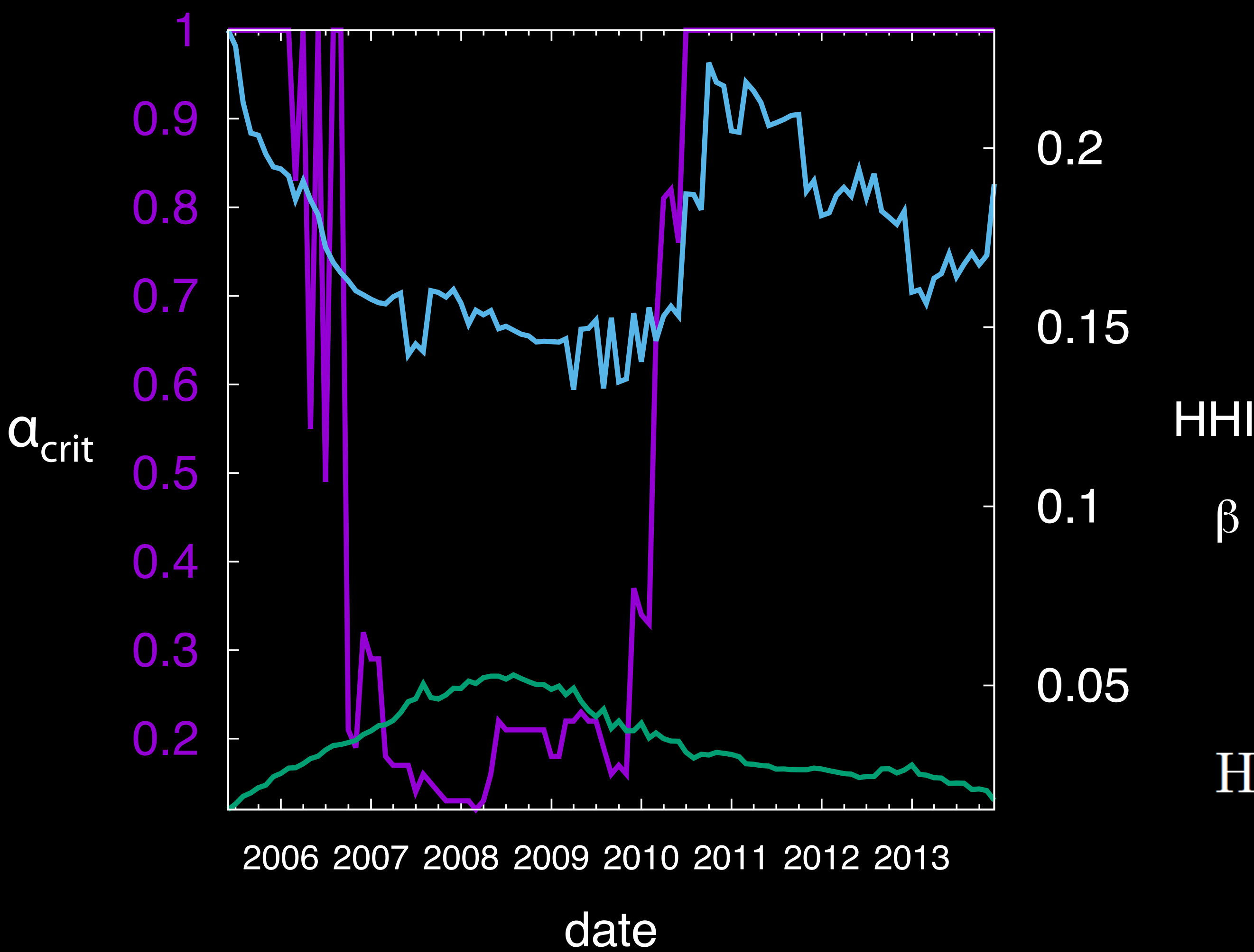


commercial credit, p=0.70

HHI – measure of concentration of shocked asset

$$\mathrm{HHI}_m = \sum_i \left(\frac{B_{i,m}}{A_m} \right)^2$$

Asset size and concentration with sensitivity to liquidity



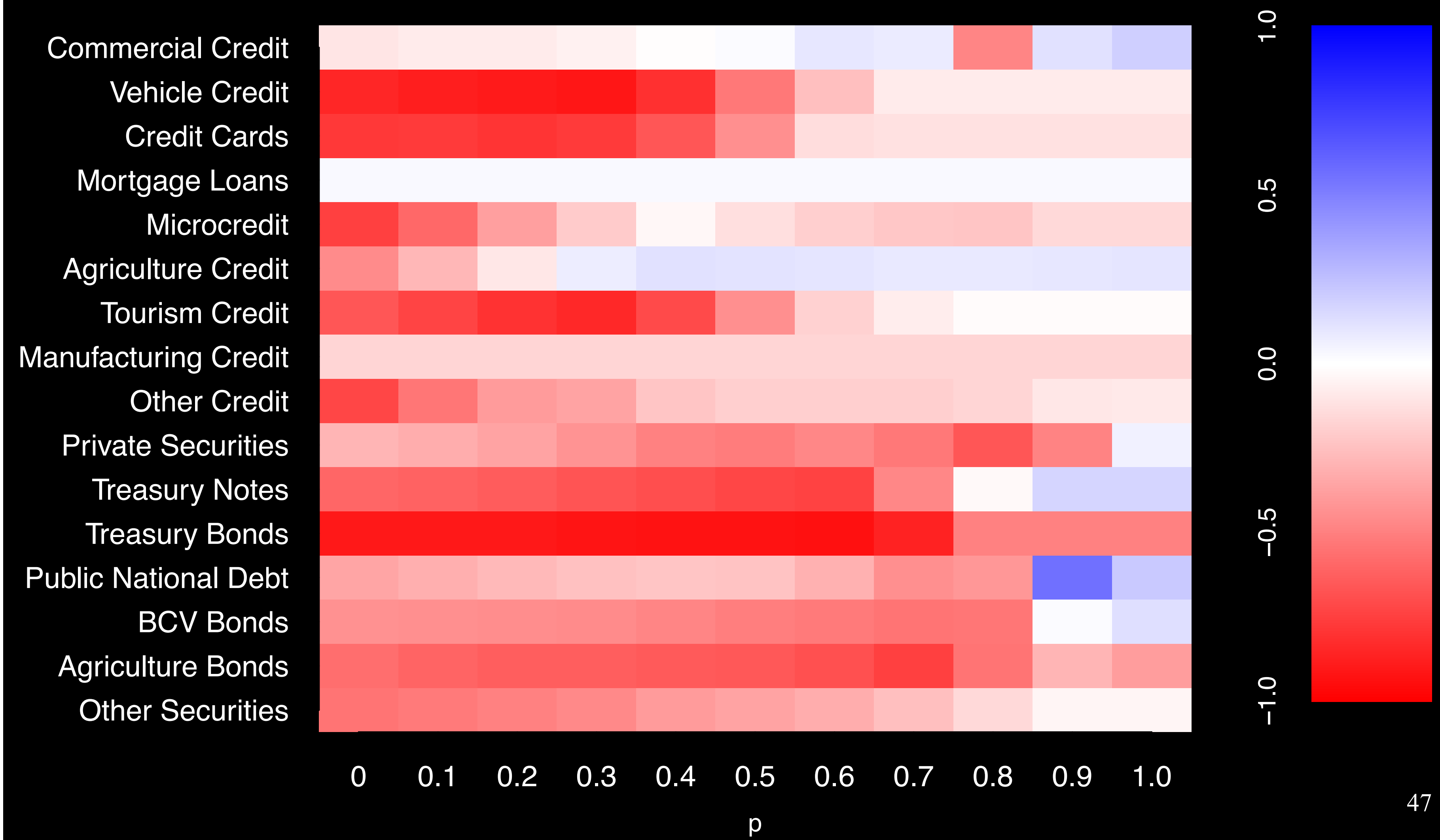
vehicles, p=0.20

HHI – measure of concentration of shocked asset

$$\mathrm{HHI}_m = \sum_i \left(\frac{B_{i,m}}{A_m} \right)^2$$

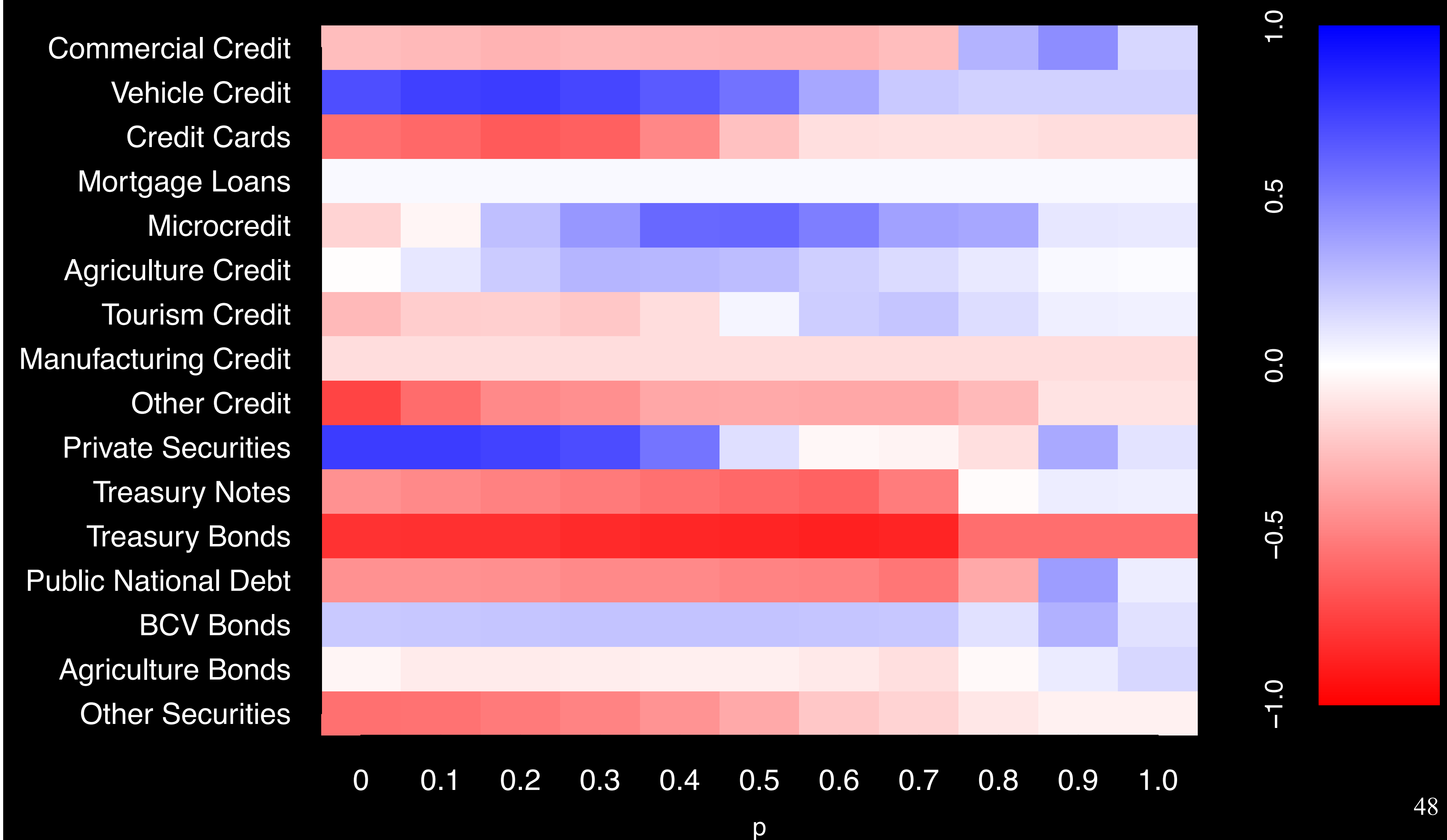
Asset size matters

Correlation of α_{crit} vs β



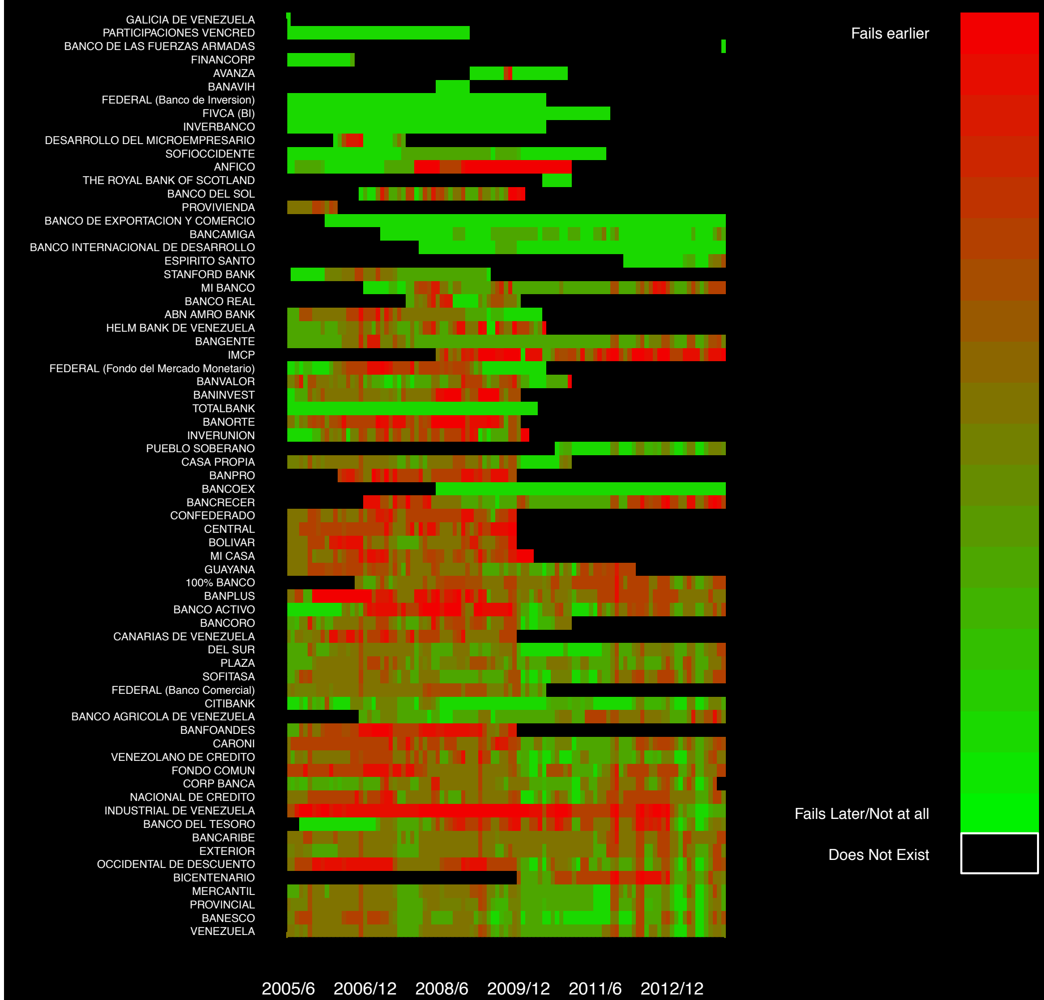
Asset distribution matters

Correlation of α_{crit} vs HHI

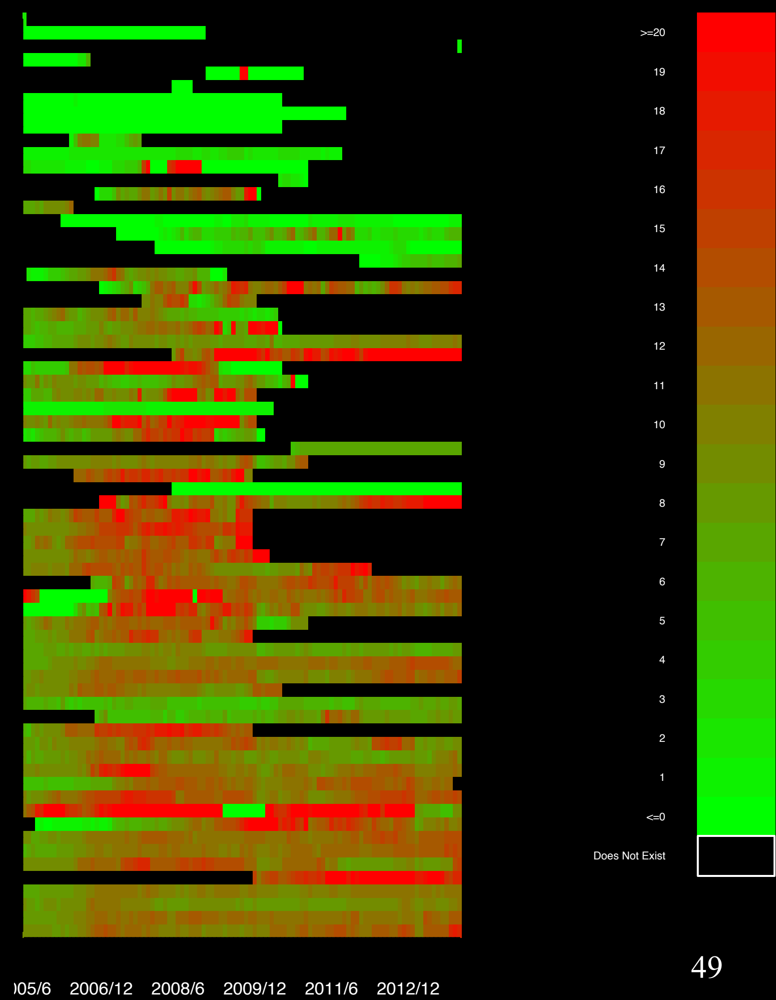


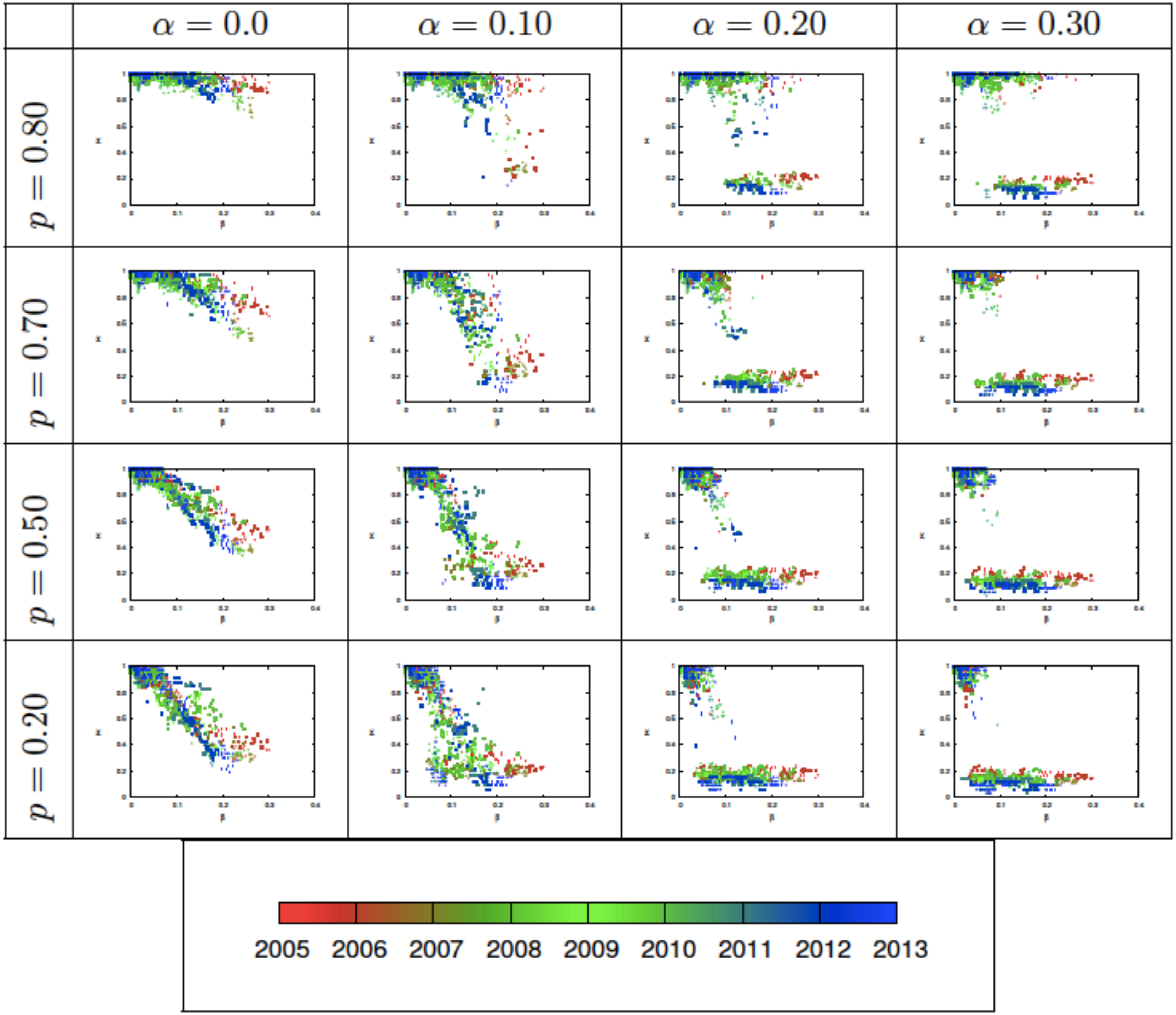
Comparing to traditional risk measures

Average fail order
α=0.10, p=0.70, all assets



Debt-to-equity ratio



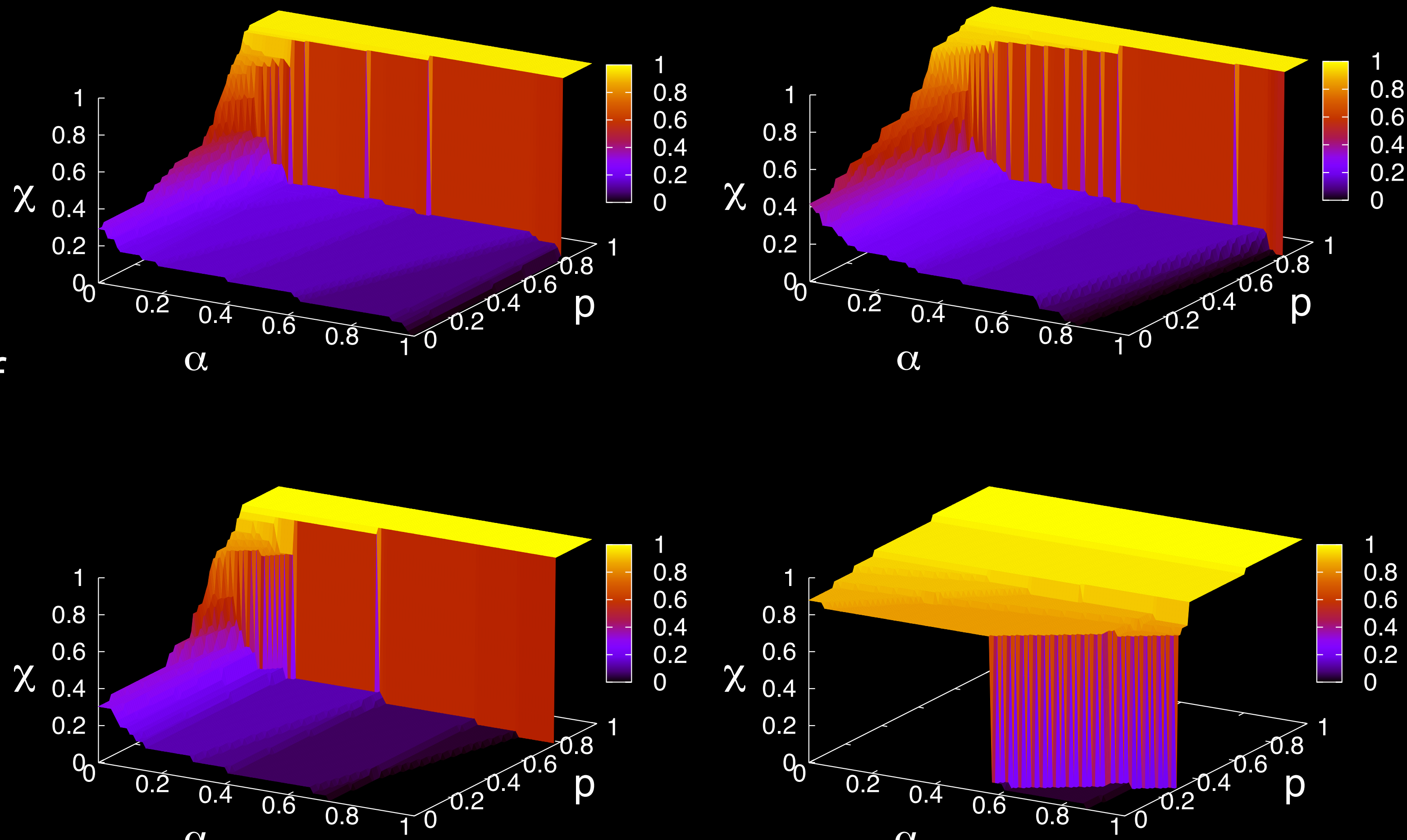

$\alpha = 0.0$
$\alpha = 0.10$
$\alpha = 0.20$
$\alpha = 0.30$
$p = 0.80$
$p = 0.70$
$p = 0.50$
$p = 0.20$
2005 2006 2007 2008 2009 2010 2011 2012 2013

Sensitivity to α & p

12/2005

$\chi(\alpha,p,m)$ = fraction of surviving banks

12/2013



Commercial Credit

BCV Bonds