Measuring the Systemic Risk in Interfirm Transaction Networks

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Introduction

- How do shocks to firms propagate through interfirm networks and affect the entire economy?

- Input-output linkage of goods and services for the co-movement of industries

  Long and Plosser (1983), Horvath (2000), and Shea (2002)
- Knowledge spillover for facilitating innovation in the economy

  Jaffe, Trajtenberg, and Henderson (1993)

- Yet, there exists another important transmission mechanism as documented in Kiyotaki and Moore (1997) and Boissay (2006): **Trade credit channel**

Trade credit channel

- An intuition for the trade credit channel

  A firm whose customers default may run into liquidity shortage and default on its own suppliers

  Default sequence transmits shocks through the supply chain and amplify them to damage the entire system

  Kiyotaki and Moore label this as “systemic risk”

Abundant anecdotes and scarcity of direct empirical evidence

- “A bankruptcy filing by even one of the Big Three would probably set in motion a cascade of smaller bankruptcies by suppliers of car parts, as the money the company owed them could not be paid” (New York Times)
- After the Great East Japan Earthquake in March 2011, more than 100 firms went bankrupt due to the bankruptcies or financial distress of customer firms (Report by Teikoku Data Bank)

- However, mainly due to data availability, no direct and systematic evidence for the default propagation through trade credit channel

- Raddatz (2010) provides indirect evidence

What we do

- Provide direct and systematic evidence on the existence and relevance of the default propagation in interfirm networks

- With information on 300,000+ firms and their interfirm transaction relationships, (1) simulate the extent of default propagation in interfirm networks, and (2) estimate the actual default probabilities

Summary of the results

- A sizable number of firms are predicted to fail when their customers default on their trade credit
- In some cases, the shock really "propagates" to the entire economy

- These prospective defaulters are more likely to actually default than other firms

- Banks play a role of "deep pockets" to alleviate the propagation

Empirical approach

1. Simulate the extent of default propagation in interfirm networks
   - Construct a matrix of bilateral trade credit relationships
     - Principle of maximum entropy to calculate bilateral credit amount
   - Identify initial defaulting firms
     - Three alternative variables for revenue sources
     - Detect firms with negative trade credit balance + other revenue sources
   - Examine the extent of propagation in the network
     - Two different assumptions on the extent of repaying trade debt

2. Estimate the probabilities of actual firm defaults and compare with the predicted defaults
   - H1: A firm whose customer goes bankrupt, and which is therefore exposed to a payment default by that customer, is more likely to default
   - H2: A firm that transacts with the same bank as its customer firms is more likely to obtain liquidity from the bank and is less likely to default

A matrix of trade credit relationships

- For 300,000+ firms produce a matrix of trade credit relationships
- We know the existence of interfirm transaction relationships between firm *i* and firm *j* , but not the amount (L_{ij})
- We also know the amount of trade credit and trade debt for each firm: TP_i and TR_i
- Therefore, we need to estimate L_{ij} in the matrix using the principle of maximum entropy
- We have about 2.8 million unknown elements, which is large but significantly smaller than 90 billion (=0.3 million^2) !

Table 1: Composition of trade credit/debt relationship matrix

	$\mathcal{N}_1$	$\mathcal{N}_2$	$\mathcal{N}_3$	Node 0	
$\mathcal{N}_1$	O	O	O	L^{10}	$[TP_i]_{i\in\mathcal{N}_1}$
$\mathcal{N}_2$	L^{21}	O	L^{23}	L^{20}	$[TP_i]_{i\in\mathcal{N}_2}$
$\mathcal{N}_3$	L^{31}	O	L^{33}	L^{30}	$[TP_i]_{i\in\mathcal{N}_3}$
node 0	L^{01}	L^{02}	L^{03}	O	$TP_0 + \tilde{TP}_0$
	$[TR_j]^T_{j\in\mathcal{N}_1}$	$[TR_j]^T_{j\in\mathcal{N}_2}$	$[TR_j]^T_{j\in\mathcal{N}_3}$	$TR_0 + \tilde{TR}_0$	S

Caveats about the matrix

- Most of the firms report their suppliers and customers
- But for some firms we cannot identify suppliers (N_1) and for some other firms we cannot identify customers (N_2)
- Also, $\sum_{i=1}^{N} TP_i < \sum_{i=1}^{N} TR_i$ because firms tend to extend trade credit to households more than they receive trade credit from them
- In order to address these issues, we introduce Node 0
- Transactions that involve Node 0 turn out to be relatively minor

Table 4(c): Decomposition of network matrix

Amount of trade credit (unit: thousand yen)

	N_1	N_2	N_3	Node 0	Total
N_1	0	0	0	2.21E+09	2.21E+09
N_2	4.74E+07	0	3.89E+09	0	3.94E+09
N_3	3.95E+08	0	1.06E+11	0	1.07E+11
Node 0	2.74E+09	3.35E+09	2.60E+10	0	3.21E+10
Total	3.18E+09	3.35E+09	1.36E+11	2.21E+09	1.45E+11

Extent of propagation in the network

- Propagation depends on how much defaulting firms use trade credit and other revenues for repaying trade debt
- Two polar cases: full utilization and no utilization

- In "full utilization" case, the payment amount for firm i is

$$p_i = \min\left(\sum_{j=1}^{N} \Pi_{ji} p_j + e_i, \bar{p}_i\right), \forall i \in N$$

- In "no utilization" case, the payment amount for firm i is

$$p_i = \lambda_i \min\left(\sum_{j=1}^{N} \lambda_j \Pi_{ji} p_j + e_i, \bar{p}_i\right), \forall i \in N$$

where p_i is firm i's payment amount, $\bar{p}_i$ is its payment obligation, λ_i is 1 if non-defaulting and 0 if defaulting, and $\Pi_{ij} = L_{ij} / \bar{p}_i$ if $\bar{p}_i = 0$ and 0 otherwise

- See the difference in the next few slides

Full-Utilization

$$N = \{1,2,3\}$$

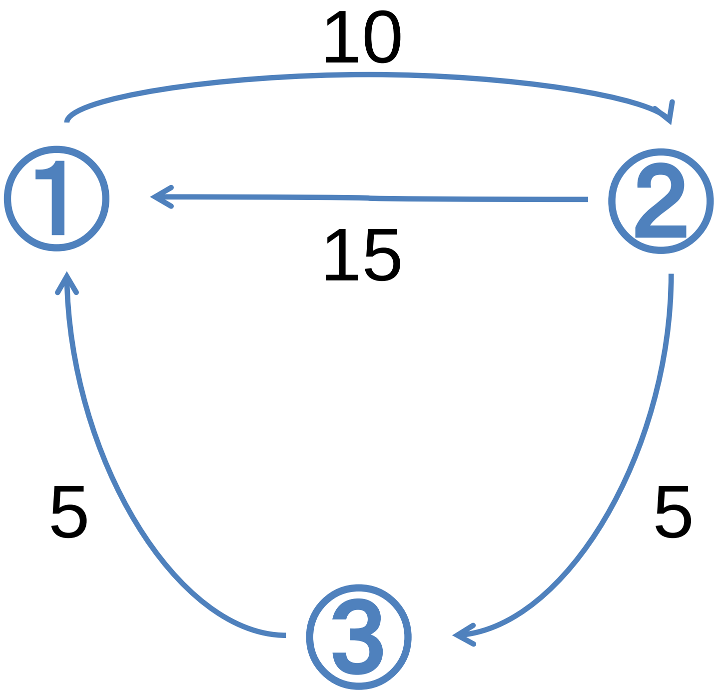
$$L = \begin{bmatrix} 0 & 10 & 0 \\ 15 & 0 & 5 \\ 5 & 0 & 0 \end{bmatrix}$$

$$e = \begin{pmatrix} 0 & 0 & 1 \end{pmatrix}^T$$

$$\Pi = \begin{bmatrix} 0 & 1 & 0 \\ 3/4 & 0 & 1/4 \\ 1 & 0 & 0 \end{bmatrix}$$

$$\overline{p} = \begin{pmatrix} 10 & 20 & 5 \end{pmatrix}^T$$

(Step1)



NV1 = (15 + 5) + 0 – 10 = 10 ≧ 0
NV2 = 10 + 0 – (15 + 5) = – 10 < 0
NV3 = 5 + 1 – 5 = 1 ≧ 0

1st-stage defaulter: firm 2

Full-Utilization

(Step2)

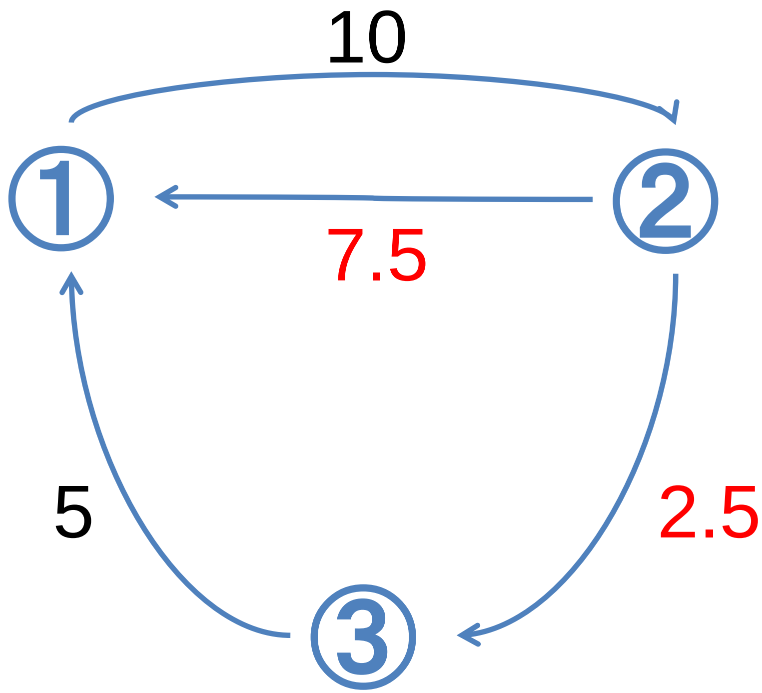
$$N = \{1,2,3\}$$

$$L = \begin{bmatrix} 0 & 10 & 0 \\ 15 & 0 & 5 \\ 5 & 0 & 0 \end{bmatrix}$$

$$e = (0 \quad 0 \quad 1)^T$$

$$\Pi = \begin{bmatrix} 0 & 1 & 0 \\ 3/4 & 0 & 1/4 \\ 1 & 0 & 0 \end{bmatrix}$$

$$p = (10 \quad 10 \quad 5)^T$$



NV1 = (7.5 + 5) + 0 – 10 = 2.5 ≧ 0

NV2 = 10 + 0 – (7.5 + 2.5) = 0

NV3 = 2.5 + 1 – 5 = – 1.5 < 0

1st-stage defaulter: firm 2

2nd-stage defaulter: firm 3

Full-Utilization

(Step3)

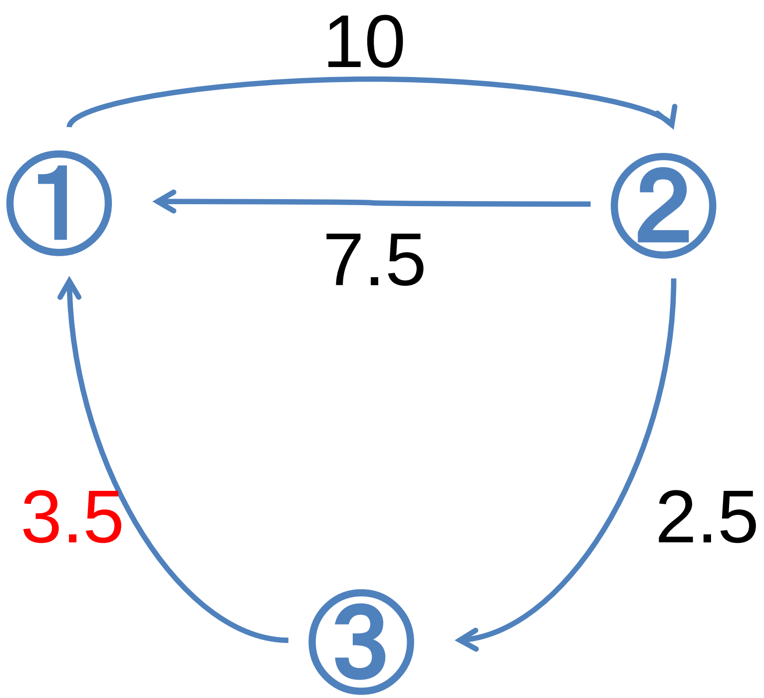
$$N = \{1,2,3\}$$

$$L = \begin{bmatrix} 0 & 10 & 0 \\ 15 & 0 & 5 \\ 5 & 0 & 0 \end{bmatrix}$$

$$e = (0 \quad 0 \quad 1)^T$$

$$\Pi = \begin{bmatrix} 0 & 1 & 0 \\ 3/4 & 0 & 1/4 \\ 1 & 0 & 0 \end{bmatrix}$$

$$p^* = (10 \quad 10 \quad 3.5)^T$$



NV1 = (7.5 + 3.5) + 0 – 10 = 1 ≧ 0

NV2 = 10 + 0 – (7.5 + 2.5) = 0

NV3 = 2.5 + 1 – 3.5 = 0

1st-stage defaulter : firm 2

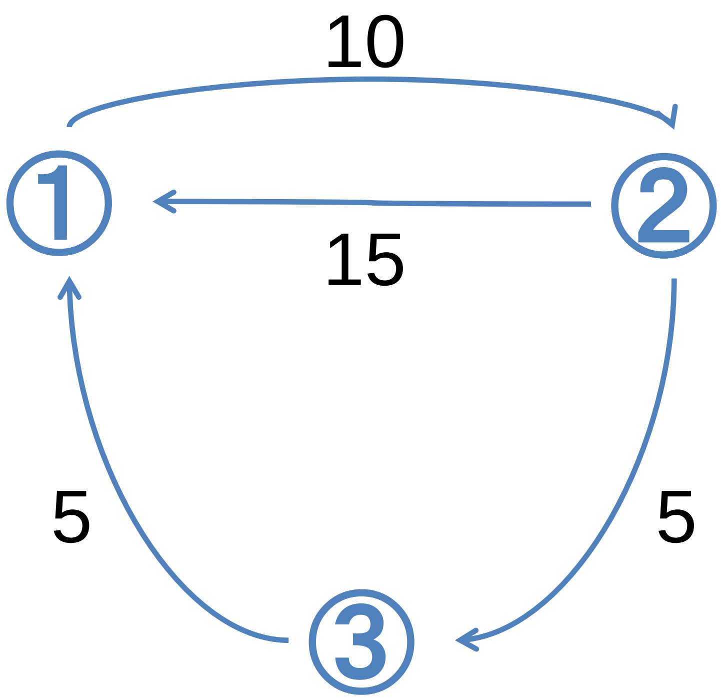
2nd-stage defaulter : firm 3

Non-defaulter : firm 1

No-Utilization

(Step1)

$$N = \{1,2,3\}$$



$$L = \begin{bmatrix} 0 & 10 & 0 \\ 15 & 0 & 5 \\ 5 & 0 & 0 \end{bmatrix}$$

$$e = \begin{pmatrix} 0 & 0 & 1 \end{pmatrix}^T$$

$$\Pi = \begin{bmatrix} 0 & 1 & 0 \\ 3/4 & 0 & 1/4 \\ 1 & 0 & 0 \end{bmatrix}$$

$$\bar{p} = \begin{pmatrix} 10 & 20 & 5 \end{pmatrix}^T$$

NV1 = (15 + 5) + 0 – 10 = 10 $\geqq$ 0

NV2 = 10 + 0 – (15 + 5) = – 10 < 0

NV3 = 5 + 1 – 5 = 1 $\geqq$ 0

1st-stage defaulter : firm 2

No-Utilization

(Step2)

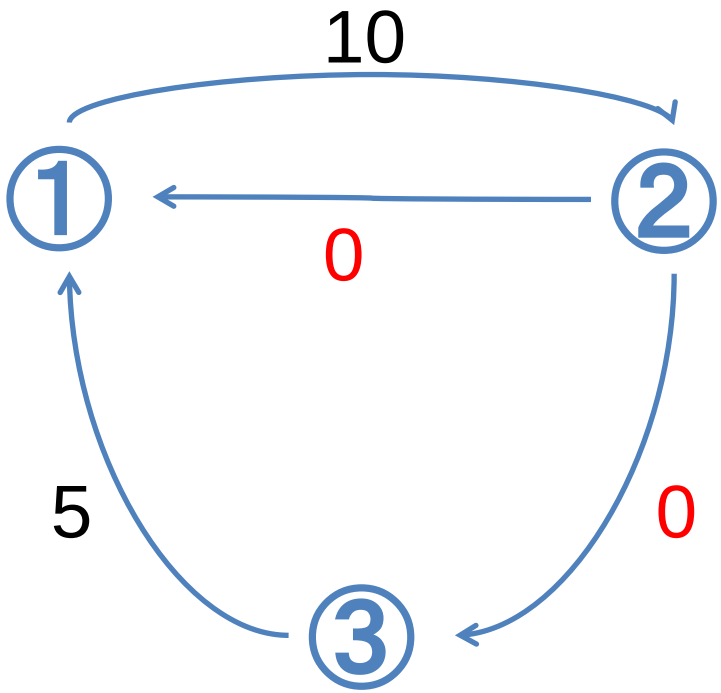
$$N = \{1,2,3\}$$

$$L = \begin{bmatrix} 0 & 10 & 0 \\ 15 & 0 & 5 \\ 5 & 0 & 0 \end{bmatrix}$$

$$e = \begin{pmatrix} 0 & 0 & 1 \end{pmatrix}^T$$

$$\Pi = \begin{bmatrix} 0 & 1 & 0 \\ 3/4 & 0 & 1/4 \\ 1 & 0 & 0 \end{bmatrix}$$

$$p = \begin{pmatrix} 10 & 0 & 5 \end{pmatrix}^T$$



NV1 = (0 + 5) + 0 – 10 = – 5 < 0

NV2 : -

NV3 = 0 + 1 – 5 = – 4 < 0

1st-stage defaulter: firm 2

2nd-stage defaulter: firm 1 & 3

Summary statistics

Table 2(a): Summary statistics on firm attributes

	Employees	Assets	Sales	TR	TP	e^1	e^2	e^3
N	300853	300853	300853	300853	300853	300853	300853	300853
mean	49.5	3569450.0	3146691.0	474765.0	374450.8	618469.4	286949.6	335640.7
sd	390.4167	8.43E+07	5.35E+07	8397273	6355149	9627521	3869213	7392605
min	0	2	3	0	0	0	0	0
p1	0	8248	19181.2	0	0	3085	556	0
p5	1	20607.5	46102	0	0	10699	2258.5	0
p25	4	79093.33	144420	1037.5	0	31198.75	11692.14	1046.422
p50	10	216699.6	336403.5	14313.36	12023.1	70958.63	36065.17	26527.67
p75	25	687022.8	930994.8	84924.4	70091.63	197091	112376.2	97565.72
p95	154	5239213	6564422	914555.3	782390.3	1373942	704531.6	647698.9
p99	647	3.20E+07	3.79E+07	6257431	5121712	7003500	3377703	3504424
max	69125	1.32E+10	1.00E+10	1.43E+09	1.04E+09	2.07E+09	6.60E+08	1.56E+09

Summary statistics

Table 2(b): Summary statistics on firm industry

Sector	Freq.	Percent
Agriculture and fishery	682	0.23%
Mining	613	0.20%
Construction	133580	44.40%
Manufacturing	40645	13.51%
Wholesale	49981	16.61%
Retail and restaurants	14099	4.69%
Finance and insurance	1147	0.38%
Real estate	12187	4.05%
Transportation and communication	9718	3.23%
Electricity, gas, water, and heat supply	228	0.08%
Services	37961	12.62%
N.A.	12	0.00%
Total	300853	100.00%

Table 2(c): Summary statistics on firm location

Region	Freq.	Percent
Hokkaido	16822	5.59%
Tohoku	20242	6.73%
Hokuriku	14741	4.90%
Kanto	103542	34.42%
Chubu and Tokai	38701	12.86%
Kinki	50958	16.94%
Chugoku and Shikoku	26839	8.92%
Kyushu and Okinawa	28311	9.41%
N.A.	697	0.23%
Total	300853	100.00%

Simulation results (number of defaulters)

- First-stage defaulters (we expect them to fail as a result of their own financial distress)

  9,392, 25,352, and 29,365 among 300,853 firms for Model 1 (sales profits), 2 (cash holdings), and 3 (net liquid assets)

- Smaller but sizable number of second- and later-stage defaulters (we expect them to default because they fail to receive trade credit extended to earlier-stage defaulters)

- Larger numbers of second- and later-stage defaulters in no utilization case
- LGD ratio is very small among second- and later-stage defaulters

- # of second- and later stage defaulters/ # of first-stage defaulters always less than unity

Simulation results (number of defaulters)

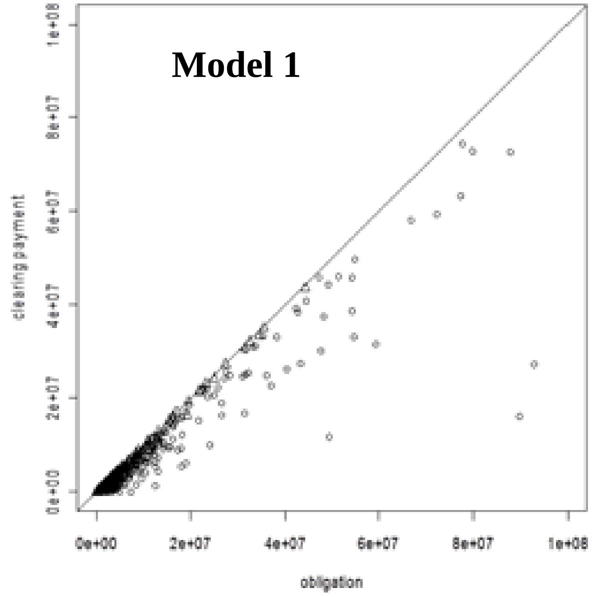
Table 5(a): Default propagation (full utilization)

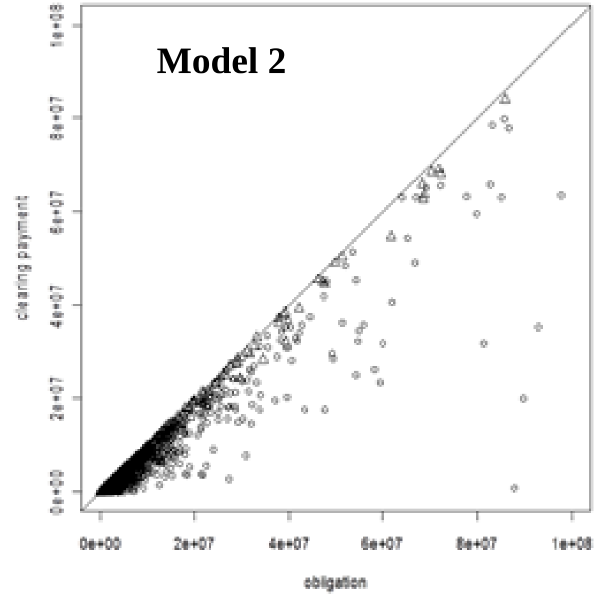
Stage	Model 1		Model 2		Model 3	
-	290,612	96.6	273,563	90.9	260,732	86.7
1	9,392	3.1	25,352	8.4	29,365	9.8
2	837	0.3	1,756	0.6	10,432	3.5
3	11	0	161	0.1	289	0.1
4	1	0	19	0	31	0
5		0	2	0	4	0
Total	300,853	100	300,853	100	300,853	100

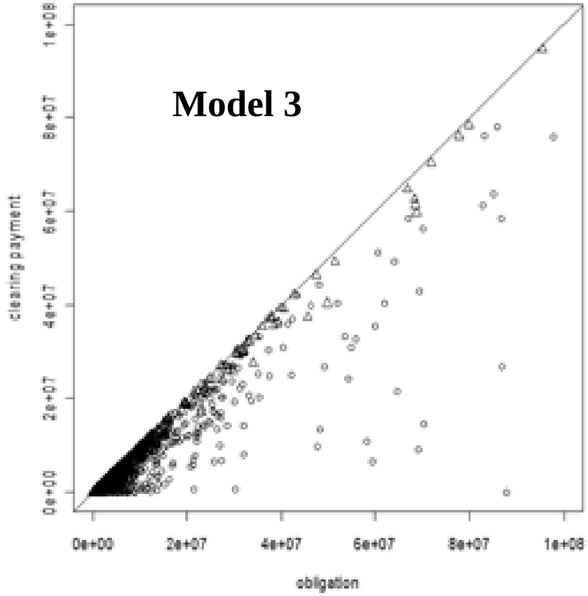
Table 5(b): Default propagation (no utilization)

Stage	Model 1		Model 2		Model 3	
-	288,722	95.97	260,843	86.7	245,951	81.75
1	9,392	3.12	25,352	8.43	29,365	9.76
2	2,031	0.68	5,618	1.87	14,607	4.86
3	351	0.12	2,739	0.91	3,801	1.26
4	203	0.07	1,836	0.61	2,898	0.96
5	84	0.03	1,394	0.46	1,923	0.64
6	61	0.02	915	0.3	1,267	0.42
7	9	0	1,095	0.36	593	0.2
8			591	0.2	348	0.12
9			470	0.16	100	0.03
Total	300,853	100	300,853	100	300,853	100

Simulation results (number of defaulters)







- $p_i(bar)$ along the x-axis and p_i along the y-axis
- Circle markers for first-stage defaulters and triangular markers for second- and later-stage defaulters
- Vertical distance from the 45 degree lines represent the ratio of loss given default

Simulation results (economic significance)

- Simply counting the number of firms may not be appropriate since firms are heterogeneous in their size
- To gauge economic significance, we calculate
  (average sales amount of firms in default stage i) * (# of firms in the stage)
- Aggregate sales of second- and later-stage defaulters/ those of first-stage defaulters are sometimes larger than 1
- Economic impact of second- and later-stage defaults is sometimes more sizable than that of first-stage defaults

Simulation results (economic significance)

Table 6(a): Sum of sales amount for each default stage (full utilization)

Stage	Model 1 Number of firms	Total Sales	Model 2 Number of firms	Total Sales	Model 3 Number of firms	Total sales
-	290612	8.84E+11	273563	7.81E+11	260732	7.64E+11
1	9392	4.32E+10	25352	1.25E+11	29365	1.28E+11
2	837	4.44E+09	1756	2.30E+10	10432	3.65E+10
3	11	6.67E+07	161	2.61E+09	289	3.38E+09
4	1	1.49E+08	19	1.03E+08	31	3.91E+08
5			2	5.53E+05	4	9.52E+07
First-stage defaulters	9392	4.32E+10	25352	1.25E+11	29365	1.28E+11
Second+ defaulters	849	4.66E+09	1938	2.57E+10	10756	4.03E+10
Second+/first	9.0%	10.8%	7.6%	20.6%	36.6%	31.6%

Table 6(b): Sum of sales amount for each default stage (no utilization)

Stage	Model 1 Number of firms	Total Sales	Model 2 Number of firms	Total Sales	Model 3 Number of firms	Total sales
-	288722	8.64E+11	260843	5.50E+11	245951	5.15E+11
1	9392	4.32E+10	25352	1.25E+11	29365	1.28E+11
2	2031	1.21E+10	5618	7.81E+10	14607	9.58E+10
3	351	5.58E+09	2739	4.77E+10	3801	7.98E+10
4	203	4.04E+09	1836	3.47E+10	2898	5.27E+10
5	84	1.76E+09	1394	2.79E+10	1923	2.81E+10
6	61	1.04E+09	915	3.91E+10	1267	1.89E+10
7	9	5.61E+07	1095	1.38E+10	593	8.30E+09
8			591	1.24E+10	348	2.83E+09
9			470	3.17E+09	100	3.72E+09
First-stage defaulters	9392	4.32E+10	25352	1.25E+11	29365	1.28E+11
Second+ defaulters	2739	2.45E+10	14658	2.57E+11	25537	2.90E+11
Second+/first	29.2%	56.7%	57.8%	205.6%	87.0%	227.4%

Simulation results (geographical distribution)

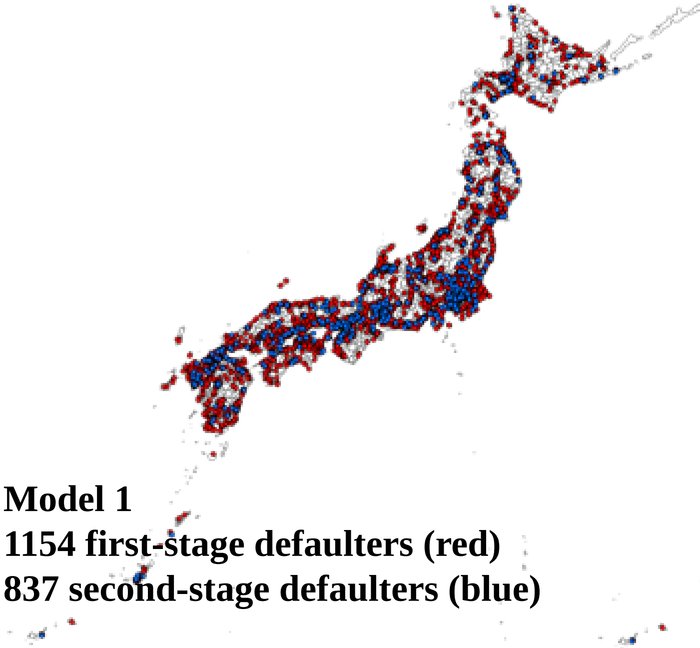
- Examine the geographical pattern of default propagation

- If second- and later-stage defaulters are located in close proximity to first-stage defaulters, propagation may cause regional adverse shocks

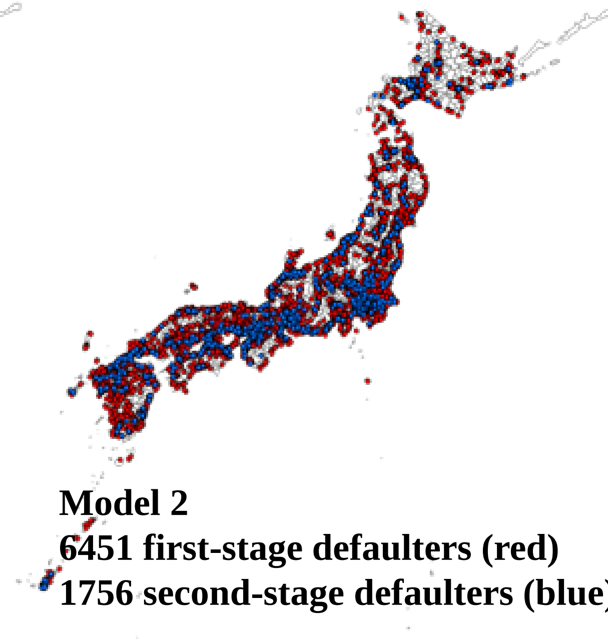
- Blue dots (second-stage defaulters) appear to be more concentrated in metropolitan areas than red dots (first-stage defaulters) do, indicating that the propagation may cause regional shocks in these areas

- Admittedly, this is still a primitive observation and we need to quantify it

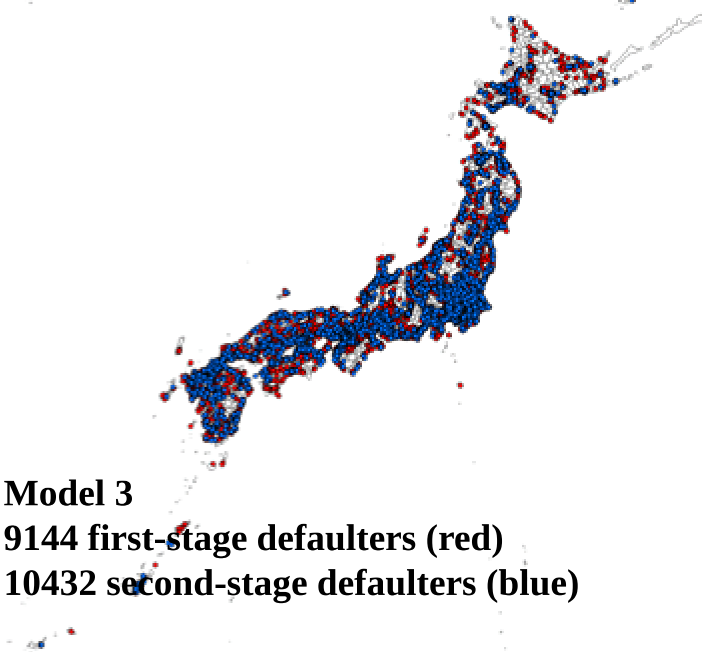
Simulation results (geographical distribution)



Model 1
1154 first-stage defaulters (red)
837 second-stage defaulters (blue)



Model 2
6451 first-stage defaulters (red)
1756 second-stage defaulters (blue)



Model 3
9144 first-stage defaulters (red)
10432 second-stage defaulters (blue)

Estimation results

- The purpose here is to compare simulated defaults and actual defaults and examine how much and why they differ from each other

- A probit model estimation of default probabilities
  - Dependent variable: Dummy for actual defaults in 2008-2011
  - Explanatory variable: Dummy for simulated first-stage defaulters, dummy for simulated second- and later-stage defaulters, firm-bank relationships, and other controls
  - For firm-bank relationships, (# of customer firms that transact with the same bank as the firm itself)/(# of all customer firms for the firm)

- In Models 1 and 2, positive coefficients on dummies for simulated first-stage and second&later-stage defaulters, and negative coefficients on firm-bank relationships

- Consistent with Hypotheses 1 and 2

Estimation results

Table 8: Probit model estimation results

Dependent variable: Actual default dummy in 2008-2011

	Model 1		Model 2		Model 3	
	dF/dx	P>|z|	dF/dx	P>|z|	dF/dx	P>|z|
Simulated_def1	0.075	0	0.06	0	0.027	0
Simulated_def2	0.029	0	0.022	0	-0.009	0
ln(Employees)	-0.011	0	-0.01	0	-0.01	0
Est_year	0	0.003	0	0.008	0	0.011
Cap_ratio	-0.002	0	-0.001	0	-0.002	0
ROA	-0.019	0	-0.015	0	-0.019	0
Rate	0	0.636	0	0.607	0	0.72
Liq_liab/Liq_asset	0	0.843	0	0.904	0	0.797
Relationship	-0.01	0	-0.01	0	-0.013	0.002
Ind_dum	Yes		Yes		Yes	
Bank_type_dum	Yes		Yes		Yes	
N	265949		265949		265949	
LR chi2	1769.23		2591.86		1178.04	
P>chi2	0		0		0	
Log likelihood	-37398.25		-36986.93		-35490.09	
Pseudo R2	0.023		0.034		0.0163	
Obs. P	0.033		0.033		0.033	
Pred. P (at x-bar)	0.03		0.029		0.029	

Summary

In the simulations

- A sizable number of firms are initially financially healthy but become short of liquidity and are predicted to default when their customer firms default
- The default propagation sometimes economically significant

In the estimation of actual defaults

- Firms that are predicted to fail as a result of defaults by their customers are more likely to go default themselves in practice
- A certain type of firm-bank relationship, in which a bank extends loans to many of the firms in the same supply chain, significantly reduce firms' default probability (banks as "deep pockets")

Possible extensions

- Alternative assumptions regarding the way shocks propagate in the network may be introduced and tested
  - netting trade credit and debt for bilateral transactions
  - relaxing the assumption of proportional repayment in case of default

- Current analysis focuses on “instantaneous” default propagation, taking firms’ debt structure and trade credit network structure as fixed

- If extended to a longer-time horizon, we may examine
  - how shocks propagate not only upward along the supply chain but also downward
  - how the structure of the network may change over time in response to firms’ prospective defaults