Experimental Evidence of Bank Runs as Pure Coordination Failures

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Introduction

- Classic model of bank runs: Diamond and Dybvig (1983)
  - Banks provide liquidity insurance through investment in illiquid long-term project and issuance of short-term debt (demand deposit)
  - The demand deposit contract exhibits payoff externality
  - Two symmetric pure strategy Nash eqa: run & non-run
  - Bank runs may occur as pure coordination failures
- The theory does not provide good explanation about which eqm is selected
- Competing view: bank runs are caused by deterioration of the quality of the bank's assets (Allen and Gale, 1998)

Introduction

- Empirical testing of the bank-run models is difficult
  - Real world bank runs tend to involve various factors: hard to determine whether bank runs are due to miscoordination, or weakening assets
  - Empirical investigation gives mixed results
    - Gorton (1988), Allen and Gale (1998) and Schumacher (2000): bank runs have historically been strongly correlated with deteriorating economic fundamentals
    - Boyd et al. (2001): bank runs are often the outcome of coordination failures
- Advantage of an experimental study: control the different factors that may induce bank runs

Introduction

We study whether bank runs can occur as pure coordination failures (and if yes, under what conditions)

- Fix ROR of the bank's long-term asset: rule out deterioration of bank's asset as source of bank runs
- Fix the short-term rate for some time before changing it: subjects interact in an environment with minimal change so that they can focus on coordination decision
- The short-term rate affects the "coordination requirement parameter":
    - With payoff externality, payoff to withdrawing late increasers with the number of late withdrawers
    - Coordination requirement parameter: minimum fraction of depositors choosing to withdraw late so that the strategy gives higher payoff than withdrawing early

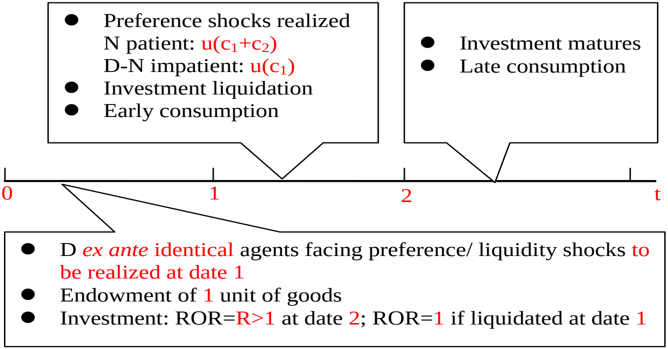
Main results

- Bank runs can occur as pure coordination failures, but only when coordination requirement is high
- A version of evolutionary learning algorithm captures experimental data

Literature–Experimental Studies of Bank Runs

- Madiès (2006): suspension of payments combined with "narrow banking" solution, or full deposit coverage can eliminate bank runs
- Garrat and Keister (2009): bank runs occur more frequently when there is aggregate liquidity risk, or when depositors have multiple withdrawing opportunities
- Schotter and Yorulmazer (2009)
  - Depositors are willing to wait to find out what other depositors have done
  - The presence of insiders slows down runs
  - Deposit insurance, even of a limited type, mitigates severity of bank runs.
- Klos and Sträter (2010): global game theory of bank runs

Theory: DD Model of Bank Runs



Optimal risk sharing:
Impatient consume c_i^* at date 1, patient consume c_p^* at date 2, with $1 < c_i^* < c_p^* < R$.

Theory: DD Model of Bank Runs

Demand Deposit Contract

$$
\begin{aligned}
c_e &= \begin{cases} r, \text{ if } z \geq \hat{z}, \\ r \text{ w.p. } \frac{D-\hat{z}}{D-z} \text{ and } 0 \text{ w.p.} \frac{\hat{z}-z}{D-z}, \text{ if } z \leq \hat{z}; \end{cases} \\
c_\ell &= \begin{cases} \frac{D-r(D-z)}{z} R, \text{ if } z \geq \hat{z}, \\ 0, \text{ if } z \leq \hat{z} \end{cases}
\end{aligned}
$$

$r = c_\ell^*$
z :number of late withdrawers
$c_e(c_\ell)$:payoff to early (late) withdrawers
$\hat{z} = D/r$:min # of late withdrawals to prevent bankruptcy at date 1.

$\rightarrow$Two symmetric pure strategy Nash eqa: $z = 0$ and $z = N$.

Experimental Design

- $D = N = 10$: focus on strategic players
- $R = 2$
- Abstract from sequential service constraint, the payoff function is

$$c_e = \min\left\{r, \frac{N}{N-z}\right\}; \quad (1)$$

$$c_\ell = \max\left\{0, \frac{N - r(N-z)}{z} R\right\}. \quad (2)$$

  Payoff externality exists if $r > 1$.
- Two symmetric pure strategy Nash eqa: $z = 0, c = 1$(run eqm); $z = N, c = R$ (non-run eqm)

Experimental Design

- r changes every 10 periods: agents interact in a stable environment with minimal change
- r determines the coordination requirement η
  $r = \frac{N-(N-z)r}{z} R \rightarrow z^*, \;\; \eta = z^*/N = \frac{R(r-1)}{r(R-1)}$
- Each session has 7 phases, each phase has 10 periods

Phase	0	1	2	3	4	5	6	7
r	1.43	1.05	1.11	1.18	1.33	1.54	1.67	1.82
η	0.60	0.10	0.20	0.30	0.50	0.70	0.80	0.90
Period ($\uparrow \eta$)	-9-0	1-10	11-20	21-30	31-40	41-50	51-60	61-70
Period ($\downarrow \eta$)	-9-0	61-70	51-60	41-50	31-40	21-30	11-20	1-10

Experimental Design

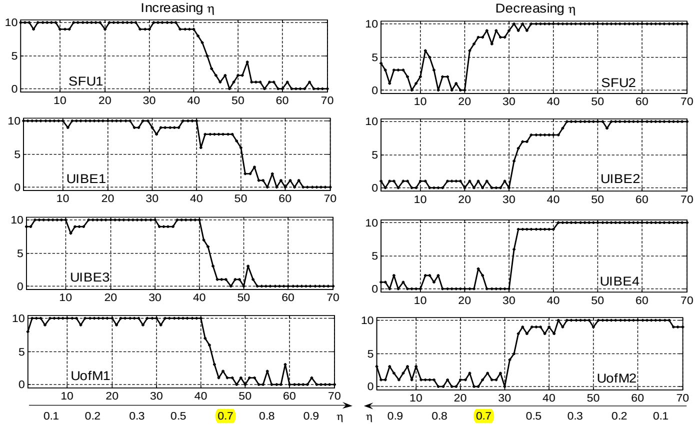
- 8 sessions (4 with $\uparrow \eta$, 4 with $\downarrow \eta$)
- Location: SFU (Burnaby), UofM (Winnipeg), UIBE (Beijing).
- 10 subjects from upper level and grad econ and business classes
- Each subject begins each period with 1 experimental dollar in the bank and makes withdrawing decision
- Each subject is assigned a computer terminal; communication is prohibited
- Payoff tables provided so that players focus on playing the coordination game

Table 0 (for practice): payoff if n of other 9 subjects withdraw
$r = 1.43$

n	payoff if withdraw	payoff if leave money in the bank
0	1.43	2.00
1	1.43	1.90
2	1.43	1.79
3	1.43	1.63
4	1.43	1.43
5	1.43	1.14
6	1.43	0.71
7	1.25	0.00
8	1.11	0.00
9	1.00	0.00

Experimental Design

- After all subjects make decisions, z and payoff are calculated
- History of own actions, payoffs, and cumulative payoffs shown at the end of each period
- Experimental dollars converted to cash; average pay $\approx$1.5 x what can be earned as tutors



Increasing η
Decreasing η
SFU1
SFU2
UIBE1
UIBE2
UIBE3
UIBE4
UofM1
UofM2
10
5
0
10 20 30 40 50 60 70
0.1 0.2 0.3 0.5 0.7 0.8 0.9 η
η 0.9 0.8 0.7 0.5 0.3 0.2 0.1

Experimental Results

- Finding 1.
  More coordination at late withdrawal when coordination requirement is lower.
- Finding 2.
  - When coordination is low ($\eta = 0.1, 0.2, 0.3, 0.5$), all experimental economies stay close to or converge to the non-run equilibrium
  - When coordination is high ($\eta = 0.8, 0.9$), all experimental economies stay close to or converge to the run equilibrium
  - When $\eta = 0.7$, experimental economies perform very differently.
- Finding 3.
  There is a stronger learning effect for intermediate values of η.

Evolutionary Algorithm

Young (1993), Kandori et. al (1993)

- Two components:
  - Myopic best response with inertia
  - Experimentation: random strategy change with prob δ.
- Standard Algorithm
  - Prob of playing best response and experimentation is exogenous.
  - Temzelides (1997): as $\delta \to 0$, stay in non-run (run) eqm with prob 1 if $\eta < 0.5$ (if $\eta > 0.5$).

Modified Evolutionary Algorithm

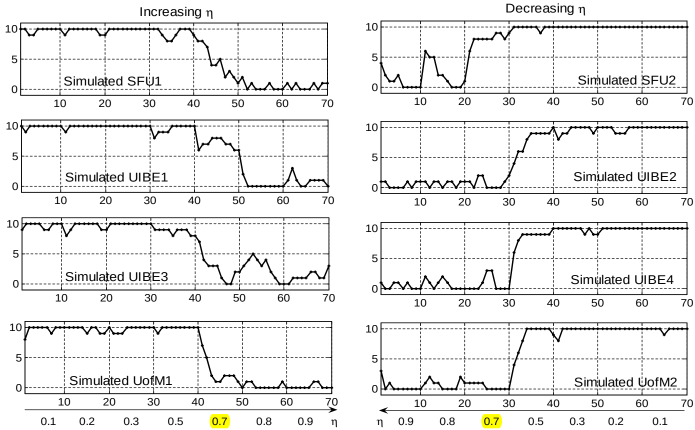
Algorithm depends on agents' information sets: η and possibly z_{t-1}.

- Myopic best response with inertia:
  Played only when subjects can infer whether $z_{t-1} > z^*$.
- Experimentation:
  Prob depends on η; and also on z_{t-1} if subjects can infer z_{t-1}.

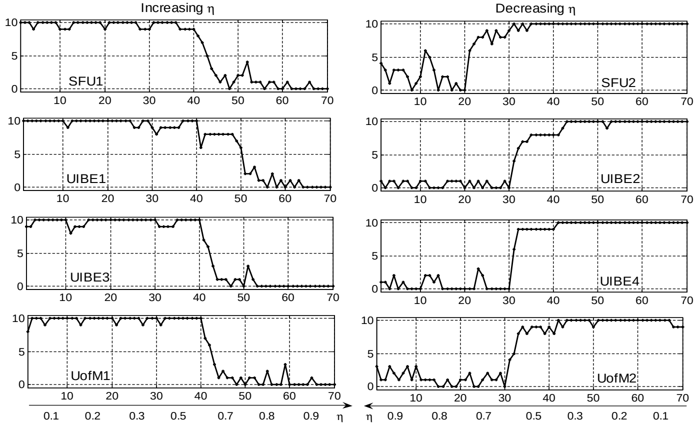
Simulation with Modified Algorithm

- Estimate probability of experimentation using experimental data
- Same parameters as in the experiments: 10 players, 7 phases, each phase has 10 rounds
- Use z_0 for each of the 8 sessions
- Apply the modified algorithm using estimated prob of experimentation

A Sample Simulated Path of z



Experimental Results



Conclusion

- Bank runs can happen as the result of pure coordination failures when coordination is difficult.
- A critical value of the coordination parameter serves as the watershed for coordination.
  - When coordination is easy (hard), subjects tend to coordinate at the non-run (run) equilibrium.
  - The consensus breaks down when η is equal to 0.7.
- The endogenous evolutionary algorithm can capture the behavior of human subjects in the laboratory.

Future Work

- DD originally attribute banks runs to sunspot
- In this paper, we study whether bank runs in the absence of a sunspot variable.
- Sunspot behavior, especially in the context of a model with equilibria that can be Pareto ranked, is rarely observed in the lab.
- Duffy and Fisher (2005) and Fehr et al. (2011): direct evidence of sunspots in the laboratory with non-Pareto-rankable or Pareto-equivalent eqa.
- Arifovic et al. (2011): some initial experimental evidence of sunspot behavior with Pareto rankable eqa.
- The experimental results in this paper suggest that the level of coordination requirement may affect the occurrence of sunspot behavior.

Table 3: Performance Classification

Category	Label	Criterion
Very close to the non-run equilibrium	NN	$M \geq 9$
Fairly close to the non-run equilibrium	FN	$8 \leq M < 9$
Converging to the non-run equilibrium	CN	$5 < M < 8$ and $T \geq 8$
Moderate high coordination	H	$5 < M < 8$ and $T < 8$
Very close to the run equilibrium	RR	$M \leq 1$
Fairly close to the run equilibrium	FR	$1 < M \leq 2$
Converging to the run equilibrium	CR	$2 < M < 5$ and $T \leq 2$
Moderate low coordination	L	$2 < M < 5$ and $T > 2$

Table 4: Performance of Experimental Economies

η	0.1	0.2	0.3	0.5	0.7	0.8	0.9
SFU1	NN	NN	NN	NN	CR	CR	RR
UIBE1	NN	NN	NN	NN	H	CR	RR
UIBE3	NN	NN	NN	NN	CR	RR	RR
UofM1	NN	NN	NN	NN	CR	RR	RR
SFU2	*NN*	*NN*	*NN*	*NN*	*CN*	*CR*	*CR*
UIBE2	*NN*	*NN*	*NN*	*CN*	*RR*	*RR*	*RR*
UIBE4	*NN*	*NN*	*NN*	*FN*	*RR*	*RR*	*RR*
UofM2	*NN*	*NN*	*NN*	*CN*	*RR*	*RR*	*FR*

Modified Evolutionary Algorithm – Information

Table 0 **(for practice): payoff if n of other** 9 **subjects withdraw**

$r = 1.43$

n	payoff if withdraw	payoff if leave money in the bank
0	1.43	*2.00*
1	1.43	*1.90*
2	1.43	*1.79*
3	1.43	*1.63*
4	1.43	*1.43*
5	1.43	*1.14*
6	1.43	*0.71*
7	*1.25*	0.00
8	*1.11*	0.00
9	*1.00*	0.00

Modified Evolutionary Algorithm

Best response with inertia

- If withdraw early and receive 1.43, not know whether $z_{t-1} > z^*$, $\rightarrow$ inertia (withdraw early)
- If withdraw early and receive < 1.43, know $z_{t-1} < z^*$, $\rightarrow$ best response (withdraw early)
- If withdraw late, know whether $z_{t-1} > z^*$, $\rightarrow$ best response (withdraw late iff $z_{t-1} > z^*$)

Modified Evolutionary Algorithm

Prob of experimentation

- If withdraw early & receive < 1.43, or withdraw late & receive > 0, $\rightarrow$ know z_{t-1}, prob depends on (η, z_{t-1})
- Otherwise, prob depends on η
- Estimate three probabilities
  - Prob of changing from early to late withdrawal
    $\begin{cases} \delta^{i}_{el}(z_{t-1}, \eta) \text{ if informed of } z_{t-1}; \\ \delta^{u}_{el}(\eta) \text{ otherwise.} \end{cases}$
  - Prob of changing from late to early withdrawal: $\delta_{le}(z_{t-1}, \eta)$.

Modified Evolutionary Algorithm

Estimate the prob of experimentation using experimental data

Table 5: Observations for Logit Regression

		# of Obs.	# of Exp.	Exp. Rate (%)
$s_b = e$	Informed	1824	149	8.17
	Uninformed	336	108	32.1
$s_b = \ell$	Informed	2880	31	1.08

s_b :strategy choice resulting from best response

Total number of observations = 5040: 8 sessions x 10 subjects x 7 situations x 9 observations for each subject

Modified Evolutionary Algorithm

Table 6: Early to Late (informed): logit $(\delta^i_{el}) = \alpha_0 + \alpha_1(z_{t-1} - z^*)$

	Coefficient	Standard Error.	t-statistic	p-value
$z_{t-1} - z^*$	0.51	0.04	13.93	0.00
Constant	0.74	0.22	3.30	0.00

Table 7: Early to Late (uninformed): logit $(\delta^u_{el}) = \beta_0 + \beta_1 \eta$

	Coefficient	Standard Error.	t-statistic	p-value
η	-2.74	0.62	-4.43	0.00
Constant	1.03	0.41	2.49	0.01

Table 8: Late to Early: logit $(\delta_{le}) = \gamma_0 + \gamma_1(z_{t-1} - z^*)$

	Coefficient	Standard Error.	t-statistic	p-value
$z_{t-1} - z^*$	-0.24	0.07	-3.40	0.00
Constant	-3.04	0.04	-7.10	0.00

Modified Evolutionary Algorithm – Simulation

- Same parameters as in the experiments: 10 players, 7 phases, each phase has 10 rounds
- Adopt endogenous evolutionary algorithm, use estimated prob of experimentation
- Use z_0 for each of the 8 sessions
- Simulate for 100 times

		0.1	0.2	0.3	0.5	0.7	0.8	0.9
	NN	100	100	100	98	41		
	FN				2	26		
	CN							
SFU1	H					10		
	RR						75	99
	FR					1	21	1
	CR					19	4	
	L					3		

Modified Evolutionary Algorithm – Simulation

		0.1	0.2	0.3	0.5	0.7	0.8	0.9
	NN	100	100	100	70	1		
	FN				29	3		
	CN				1	2		
UIBE1	H					3		
	RR					1	75	99
	FR					25	21	1
	CR					53	4	
	L					12		

Modified Evolutionary Algorithm – Simulation

		0.1	0.2	0.3	0.5	0.7	0.8	0.9
	NN	100	99	100	90	3		
	FN		1		10	6		
	CN							
UIBE3	H					6		
	RR						63	100
	FR					11	30	
	CR					60	6	
	L					14	1	

Modified Evolutionary Algorithm – Simulation

		0.1	0.2	0.3	0.5	0.7	0.8	0.9
	NN	100	100	98	90	3		
	FN			2	10	6		
	CN							
UofM1	H					6		
	RR						85	100
	FR					11	13	
	CR					60	2	
	L					14		

Modified Evolutionary Algorithm – Simulation

		0.1	0.2	0.3	0.5	0.7	0.8	0.9
	NN	100	100	100	98	1		
	FN				2	3		
	CN					2		
SFU2	H					3		
	RR					1	85	100
	FR					25	13	
	CR					53	2	
	L					12		

Modified Evolutionary Algorithm – Simulation

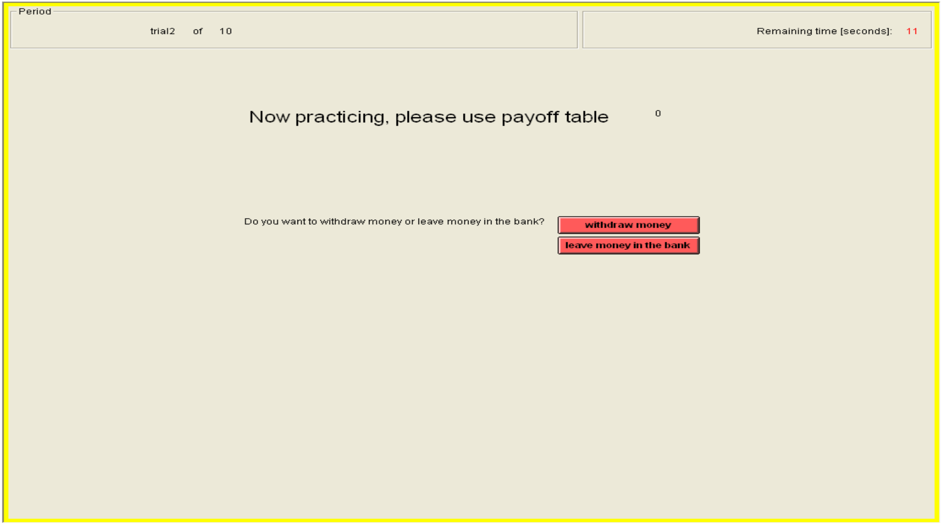
		0.1	0.2	0.3	0.5	0.7	0.8	0.9
	NN	100	100	97	3			
	FN			3	36			
	CN				59	1		
UIBE2	H				1			
	RR					42	85	99
	FR					42	13	1
	CR					6	2	
	L					9		

Modified Evolutionary Algorithm – Simulation

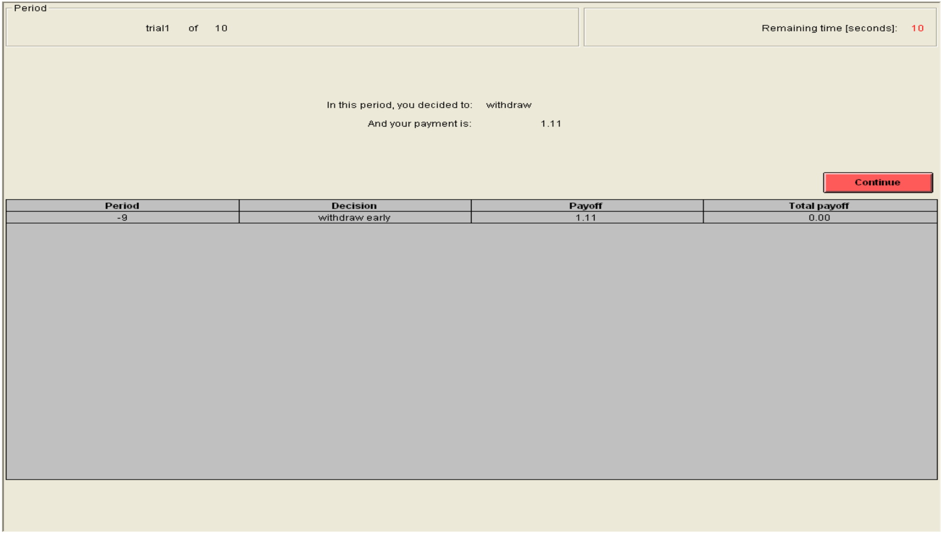
		0.1	0.2	0.3	0.5	0.7	0.8	0.9
	NN	100	100	100	29			
	FN				65			
	CN				5			
UIBE4	H				1			
	RR					61	75	99
	FR					29	21	1
	CR					6	4	
	L					4		

Modified Evolutionary Algorithm – Simulation

		0.1	0.2	0.3	0.5	0.7	0.8	0.9
	NN	100	100	97	3			
	FN			3	36			
	CN				59	1		
UofM2	H				1			
	RR					42	85	90
	FR					42	13	10
	CR					6	2	
	L					9		



The Decision Screen



The Payoff Screen

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9	1.00	0.00

- Van Huyck et al (1990, 1991): number of subjects.
- Battalio et al (2001): Cabrales et al (2007): payoff differential between eqa.
- Heinemann et al (2004), Duffy and Ochs (2010): how individual strategies respond to a continually changing payoff relevant variable that causes both the difficulty of coordination and the payoff differential to change.
- Heinemann et al (2009): how individual strategies change wrt payoff difference between eqa, and how the relationship is affected by coordination requirement.

Compare with Literature on Experimental Studies of Coordination Games

Our paper:

- Whether bank runs can occur as result of pure coordination failures: the experimental setup in our paper is more proper for the purpose
- Systematic study of how aggregate economy responds to coordination requirement
- Capture a stronger learning effect for intermediate coordination requirement