Liquidity risk and contagion in interbank markets: a presentation of Allen and Gale Model

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Abstract

The paper analyzes liquidity risk and contagion in interbank markets. The aim of the research is to define the different structures of interbank markets and structures that allow the better allocation of liquidity and thus avoid the spread of crisis in the whole system. For this purpose, this paper examines Allen and Gale model. This model is the pioneer model in the management of liquidity risk in the interbank market. We will then analyze the mechanisms that explain the spread of liquidity risk in the banking system both at national and international level.

Introduction:

Interbank markets play a key role in the functioning of financial systems. Reserved to financial institutions, the interbank market is an interbank network where banks borrow and lend in short term and thus allows channel bank liquidity surplus cash to banks in deficit[1]. Indeed, it avoids the liquidation of long term assets when the demand for liquidity exceeds liquid assets (liquidation of investments - long term assets - causes a bank assets value's decrease). However, the interbank market facilitates the spread of the crisis from one bank to the entire banking system.

According to FREIXAS[2], there are *two mechanisms that can spread the failure of one bank into others: the similarity of their assets and the pure speculation*[3]. The first type of contagion occurs when banks invest in similar assets (which was the case during the subprime crisis). The second type, speculative contagion is explained by the fact that withdrawals of some depositors affect the others depositor's behavior of the bank and of the others bank: these depositors withdraw also their deposits. Even being solvent but illiquid, and not having the opportunity to obtain liquidity, the bank is forced to liquidate long-term assets resulting bankruptcy. Thus, the precipitation of depositors rush to withdraw their deposit is the element that triggers rushes withdrawals in other banks in the system. The first type of contagion is thus considered ineffective because it leads to bankruptcy illiquid and

[1] COSTISOR M., «Comment appréhender le risque d'illiquidité dans le système bancaire? », E.R.U.D.I.T.E., octobre 2006, Université PARIS
[2] FREIXAS X., « The Lender of Last Resort in Today's Financial Environment», C.R.E.I, 1999, n°10, Universitat POMPEU FABRA, Barcelone
[3] Ibid. p. 4

solvent banks while the second type is considered effective because the affected banks are only the insolvent ones.

The contagion of liquidity risk can also be done via the interbank market. The questions that arise are: What are the different structures of the interbank market? what structure of the interbank market allows the better allocation of liquidity? And which one allows to avoid the spread of crisis due to liquidity shocks?

To answer these questions, we will examine the work done by Allen and Gale. Indeed, these authors were the first to analyze the mechanisms of propagation of the crisis in the interbank market. In their model composed of four banks, they model the demand for liquidity in the interbank complete market and the incomplete one. This paper analyzes the Allen and Gale model. Thus, we will present this pioneer model in the management of liquidity risk in the interbank market and analyze the mechanisms that explain the spread of liquidity risk in the banking system both at national and international level.

This paper is organized as follows. In a first part, we present the main works that focused on the study of interbank market structures and the management of liquidity in these markets. In a second part, we present Allen and Gale model that studied the effect of the interbank market structure on liquidity and contagion risk. We will see what structure allows the better allocation of liquidity. The third and last part is reserved to the conclusions and recommendations.

Related literature:

The study of the interbank market has a major interest to both researchers and practitioners in finance. In their article, ALLEN and GALE[4] presented three types of interbank structures: the complete structure where each bank is connected reciprocally to other banks in the system, the incomplete structure where banks are connected only to their neighbors and the incomplete and disconnected structure where exists two unconnected interbank markets. If the interbank market is complete, the effect caused by an unexpected shock in a bank can be absorbed by other banks which reduces the intensity of the shock. However, if the interbank market is incomplete, a shock in a bank can be transmitted to its neighbors. The incomplete market seems to be more sensitive to shocks.

FREIXAS, PARIGI and ROCHET[5] have defined a fourth structure of interbank markets: the money center in which exists a center of money connected to all the others banks disconnected. In case of a bank's failure, there is no effect on the money center. But if the failure is at the money center, this crisis is transmitted to all existing banks. ESTRADA and MORALES[6] presented these different structures of interbank markets as follows:

[4] ALLEN F and GALE D., « Financial Contagion », Journal of Political Economy, University of Chicago Press, vol. 108(1), pp. 1-33, Février 2001

[5] FREIXAS X., PARIGI B. and ROCHET J.C., « Systemic risk, interbank relations and liquidity provision by the Central Bank», Journal of Money, Credit and Banking, n° 32, pp. 611–638

[6] ESTRADAY D. and MORALES P., « The Structure of the Colombian Interbank Market and Contagion Risk», Banco de la Republica de Colombia, 2008

	Complete structure			
	Bank A	**Bank B**	**Bank C**	**Bank D**
Bank A	0	1	1	1
Bank B	1	0	1	1
Bank C	1	1	0	1
Bank D	1	1	1	0

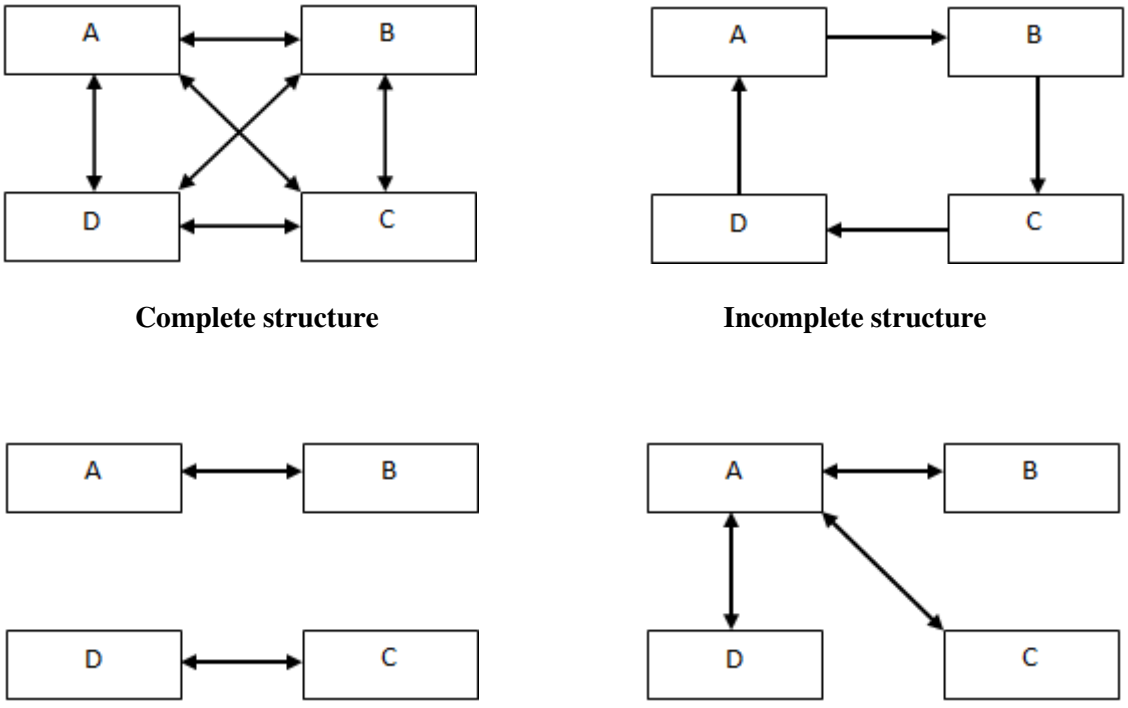
	Incomplete structure			
	Bank A	**Bank B**	**Bank C**	**Bank D**
Bank A	0	1	0	0
Bank B	0	0	1	0
Bank C	0	0	0	1
Bank D	1	0	0	0

	Disconnected structure			
	Bank A	**Bank B**	**Bank C**	**Bank D**
Bank A	0	1	0	0
Bank B	1	0	0	0
Bank C	0	0	0	1
Bank D	0	0	1	0

	Money center structure			
	Bank A	**Bank B**	**Bank C**	**Bank D**
Bank A	0	1	1	1
Bank B	1	0	0	0
Bank C	1	0	0	0
Bank D	1	0	0	0

Table 1 : Interbank markets structures[7]

[7] Ibid,. page 12



Complete structure **Incomplete structure**

Disconnected structure **Money center structure**

Figure 1: Interbank markets structures

The main works that studied the interbank market and liquidity risk were presented by BHATTAHCHARYA and GALE (1985), FLANNERY (1996), FREIXAS and JORGE (2007), ACHARYA, GROMB and YORULMAZER (2009), EIFELDT (2004), FREIXAS and HOLTHAUSEN (2001), HEIDER, HOEROVA and HOLTHAUSEN (2009), BRUNNERMEIR and PEDERSEN (2007) and ALLEN, CARLETTI AND GALE.

The paper of BHATTAHCHARYA and GALE[8] was the first that focused on the management of liquidity in the interbank market. This work is considered as the pioneer theoretical study in this field. BHATTAHCHARYA and GALE examine how the interbank market can effectively manage liquidity among banks in time of crisis. They analyze a market in which individual banks face a liquidity shock due to massive withdrawals. Since shocks are imperfectly correlated between different banks, they provide each other through an interbank market. They suggest that even in the absence of liquidity shocks, banks must invest in long-term assets and under-invest in liquid assets mainly because of the poor performance of these assets. They stipulate that the Central Bank can mitigate this problem by ensuring proper choice of assets by banks.

Recent literature interests on the efficient functioning of the interbank market during financial crises. In his article, FLANNERY[9] modeled the failure of the interbank market. He presents the crisis as a loss of confidence's phase of banks on the interbank market, which refuse to lend to other banks when

[8] BHATTACHARYA S. and GALE D., « Preference Shocks, Liquidity, and Central Bank Policy », Caress Working , Mai 1985, n°86-01

[9] FLANNERY M.J., « Financial crises, payment system problems and discount window lending », Journal Of Money, Credit And Banking, November 1996 ,Vol. 28 No. 4, pp. 804-824

they can no longer identify insolvent banks from illiquid ones. FREIXAS and JORGE[10] analyzed the effects of market imperfections interbank on monetary transmission. Indeed, companies resort to bank credit for financing, resulting an increase of credit's demand and a liquidity shock for banks. These banks borrow from the interbank market. Under asymmetric information, the interbank market is unable to efficiently channel liquidity to solvent and illiquid banks. Thus, the liquidity reserves of banks must regulate bank loans. ACHARYA, GROMB and YORULMAZER[11] presented interbank markets as markets characterized by asymmetric information and monopoly in times of crisis. Thus, banks having an excess of liquidity have a bargaining power than banks having lack of liquidity. Banks in excess of liquidity offer insufficient loans to encourage banks in need to sell their assets. The role of the Central Bank is to propose a better option for banks in lack of liquidity.

In 2004, EIFELDT[12] developed a model for understanding the characteristics of liquidity in asset markets. The author notes that a greater economic productivity increases liquidity. FREIXAS and HOLTHAUSEN[13] focused on the possible cross-border integration of interbank markets in the presence of asymmetric information on the solvency of banks. They model a banking sector where banks face individual shocks. The difference of liquidity shocks between banks justifies the existence of an interbank market where banks can insure against these shocks. ALLEN, CARLETTI and GALE[14] show that the lack of opportunities to cover liquidity shocks by banks makes prices excessively volatile. They analyze how the Central Bank should intervene to restore efficiency. The Central Bank can act by fixing the short-term interest rates to avoid price volatility. HEIDER, HOEROVA and HOLTHAUSEN[15] analyzed the functioning of interbank markets. They show the role of the interbank market in the exchange of liquidity among banks in excess of liquidity and banks in lack of liquidity. BRUNNERMEIR and PEDERSEN[16] made a distinction between market liquidity and funding liquidity. The define market liquidity as the difference between the transaction price and the fundamental value and funding liquidity as a speculator's scarcity of capital. They show how the predatory behavior of some banks forces the inefficient liquidation of other banks assets, which may jeopardize the efficient distribution of liquidity in the interbank market. They also show that under certain conditions, margins are destabilizing and market liquidity and funding liquidity are mutually reinforcing, leading to liquidity spirals.

The model:

In what follows, we present a model that made a significant contribution to the analysis of liquidity risk in the interbank market and the explanation of contagion within the banking system of a country and / or international level[17]. ALLEN and GALE model is a generalized and developed representation of Diamond and Dybvig model. This model is mainly based on the assumptions made by Diamond and Dybvid (1983). Indeed, the model has as a hypothesis the existence of two periods - 3 dates -

[10] FREIXAS X. and JORGE J., (2007), « The role of interbank markets in monetary policy: a model with rationing », Economics Working Paper, Universitat Pompeu Fabra, no 1027.
[11] ACHARYA V.V., GROMB D. and YORULMAZER T., «Imperfect Competition in the Interbank Market for Liquidity as a rationale for Central Banking», NYU Working Paper, October 2009,
[12] EISFELDT A.L., « Endogenous Liquidity in Asset Markets», The Journal of Finance, February 2004, Volume 59, Issue 1, pp. 1–30,
[13] FREIXAS X. and HOLTHAUSEN C., « Interbank market integration under asymmetric information», Economics Working Papers , 2001, Universitat POMPEU FABRA
[14] ALLEN F., CARLETTI E. and GALE D., Interbank Market Liquidity and Central Bank Intervention
[15] HEIDER F., HOEROVA, M. and HOLTHAUSEN, C., « Liquidity Hoarding and Interbank Market Spreads: The Role of Counterparty Risk», Discussion Paper, 2009-40 S, Tilburg University, Center for Economic Research
[16] BRUNNERMEIER M.K. and PEDERSEN L.H, « Market Liquidity and Funding Liquidity», June 2007
[17] COSTISOR M., op.cit. page 22

t=(0,1,2), a single consumption good which serves as the numeraire, a continuum of ex ante identical agents and an investment technology. There are two types of agents: patients and impatients. The preferences of the individual consumer are given by:

$$U(c_1, c_2) = \begin{cases} u(c_1) \text{ with probability } \omega \\ u(c_2) \text{ with probability } 1 - \omega \end{cases}$$

with ω public information

First, all agents have the same chance of being impatient. At t = 1, each agent learns his true private type. ω can be either a high value ω_H, ω_L is a low value with $0 < \omega_L < \omega_H < 1$. S_1 and S_2 are two states of nature whose realization depends on the realization of the type of agent ω.

The bank collects funds used to finance non-risky assets in the short term and long term and offer deposit contracts c_1 for the first period and c_2 for the second period. The short-term assets (L) are represented by the storage technology that produces 1 at t=1, and the long-term assets (1-L), partially illiquid and represented by the production technology. This investment is done at t = 0 and produces at t = 1 $0 < r < 1$ and at t = 2 $R > 1$.

ALLEN and GALE model is characterized by the existence of 4 identical banks (or four regions) in the interbank market, A, B, C and D where each bank undergoes random shocks and massive withdrawals of liquidity while the demand for liquidity of the entire system as well as the overall demand for liquidity for each region are constant. The assumption of the constancy of the overall demand for liquidity, despite the random distribution of consumers, allows to consider a mechanism for interregional liquidity insurance, where banks provide excess liquidity to banks in need of liquidity.

The repartition of liquidity shocks at t = 0 is shown in the following table:

	A	B	C	D
S_1	ω_H	ω_L	ω_H	ω_L
S_2	ω_L	ω_H	ω_L	ω_H

Table 2 : Regional liquidity shocks[18]

Each bank knows its different states of nature and the correlation between these. At t = 1, depositors know if they must consume immediately or not and the banks become aware of the state of nature where they are actually, S_1 or S_2. Each region has the same probability of being faced to a high demand for liquidity. This insurance scheme is a reassuring element for both banks and depositors.

But how the mechanism of interbank deposits works? To analyze this behavior, we analyze the balance sheets of the four banks (A, B, C, D). If at t = 1, the number of impatient agents is high for banks A and C and low for B and D, it will be low for A and C and B and D at t = 2. The authors analyze the complete and incomplete interbank (Figure 1).

In the case of complete interbank market, the balance sheet of the four banks is presented as follows:

[18] ALLEN F et GALE D., op.cit. page 8

	Banks with high demand for liquidity at t=1		Banks with low demand for liquidity at t=1	
	Assets	**Liabilities**	**Assets**	**Liabilities**
t=1	• Short term assets • Deposits on the other banks	• Withdrawals of impatients agents • Withdrawals of banks with high demand of liquidity at t=1	• Short term assets	• Withdrawals of impatients agents • Withdrawals of banks with high demand of liquidity at t=1
t=2	• Long term assets	• Withdrawals of patients agents • Withdrawals of banks with high demand of liquidity at t=2	• Long term assets • Deposits on the other banks	• Withdrawals of patients agents • Withdrawals of banks with high demand of liquidity at t=2

Tableau 3 : Structure du bilan dans le cas du marché interbancaire complet

How banks manage liquidity shocks at t = 1 and t = 2?

At t = 1 (Table 3), the liabilities of the bank (banks A and C) with high demand of liquidity, are withdrawals of impatient agents and withdrawals of banks with high demand of liquidity at t=1. Short term assets and deposits on the other banks can satisfy all these withdrawals. The liabilities of the bank (bank B and D) with low demand of liquidity, includes withdrawals of impatient agents and withdrawals of banks with high demand of liquidity at t=1. The assets of these banks are composed only of short-term assets.

At t = 2, the liabilities of the bank with low demand of liquidity (banks A and C) contain withdrawals of patients agents, withdrawals of banks with high demand of liquidity at t=2 while the assets include sales of long term assets. For the bank that faces a high demand of liquidity (bank B and D), liabilities includes withdrawals of patient agents and withdrawals of banks with high demand of liquidity at t=2 while assets includes deposits on the other banks and sales of long term assets.

	A (High demand of liquidity)		B (Low demand of liquidity)	
	Assets	**Liabilities**	**Actifs**	**Liabilities**
t=1	L $3\left(\frac{\omega_H - \gamma}{2}\right) c_1$	$\omega_H c_1$ $\left(\frac{\omega_H - \gamma}{2}\right) c_1$	L	$\omega_L c_1$ $\left(\frac{\omega_H - \gamma}{2}\right) c_1$ $\left(\frac{\omega_H - \gamma}{2}\right) c_1$
	L + $3\left(\frac{\omega_H - \gamma}{2}\right) c_1$	$\omega_H c_1$+ $\left(\frac{\omega_H - \gamma}{2}\right) c_1$	L	$\omega_L c_1 + (\omega_H - \gamma) c_1$
	C (High demand of liquidity)		**D (Low demand of liquidity)**	
	Assets	**Liabilities**	**Actifs**	**Liabilities**
t=1	L $3\left(\frac{\omega_H - \gamma}{2}\right) c_1$	$\omega_H c_1$ $\left(\frac{\omega_H - \gamma}{2}\right) c_1$	L	$\omega_L c_1$ $\left(\frac{\omega_H - \gamma}{2}\right) c_1$ $\left(\frac{\omega_H - \gamma}{2}\right) c_1$
	L + $3\left(\frac{\omega_H - \gamma}{2}\right) c_1$	$\omega_H c_1$+ $\left(\frac{\omega_H - \gamma}{2}\right) c_1$	L	$\omega_L c_1 + (\omega_H - \gamma) c_1$

Table 4: Functioning of complete interbank market at t=1

With:

- γ : $\frac{\omega_H - \omega_L}{2}$: Average demand of banks;
- L: Short term assets;
- ω_H : Highest value of ω;
- ω_L : Lowest value of ω;
- c_1 : Deposit contract for the first period;

	A (High demand of liquidity)		B (Low demand of liquidity)	
	Actifs	**Passifs**	**Actifs**	**Passifs**
t=2	(1-L) R	$(1 - \omega_H) c_2$ $\left(\frac{\omega_H - \gamma}{2}\right) c_2$ $\left(\frac{\omega_H - \gamma}{2}\right) c_2$	(1-L) R $3\left(\frac{\omega_H - \gamma}{2}\right) c_2$	$(1 - \omega_L) c_2$ $\left(\frac{\omega_H - \gamma}{2}\right) c_2$
	(1-L) R	$(1 - \omega_H) c_2 + (\omega_H - \gamma) c_2$	(1-L) R + 3 $\left(\frac{\omega_H - \gamma}{2}\right) c_2$	$(1 - \omega_L) c_2 + \left(\frac{\omega_H - \gamma}{2}\right) c_2$
	C (High demand of liquidity)		**D (Low demand of liquidity)**	
	Actifs	**Passifs**	**Actifs**	**Passifs**
t=2	(1-L) R	$(1 - \omega_H) c_2$ $\left(\frac{\omega_H - \gamma}{2}\right) c_2$ $\left(\frac{\omega_H - \gamma}{2}\right) c_2$	(1-L) R $3\left(\frac{\omega_H - \gamma}{2}\right) c_2$	$(1 - \omega_L) c_2$ $\left(\frac{\omega_H - \gamma}{2}\right) c_2$
	(1-L) R	$(1 - \omega_H) c_2 + (\omega_H - \gamma) c_2$	(1-L) R + 3 $\left(\frac{\omega_H - \gamma}{2}\right) c_2$	$(1 - \omega_L) c_2 + \left(\frac{\omega_H - \gamma}{2}\right) c_2$

Table 5: Functioning of complete interbank market at t = 2

With:

- (1-L): Long term assets;
- c_2 : Deposit contract for the second period;

In what follows, we will analyze the interbank market incomplete. The balance sheets of the four banks are as follows:

	Bank High demand of liquidity at t=1		**Bank Low demand of liquidity at t=1**	
	Assets	**Liabilities**	**Assets**	**Liabilities**
t=1	• Short term assets • Deposits on the neighboring bank	• Withdrawals of impatients agents	• Short term assets	• Withdrawals of impatients agents • Withdrawals of neighboring bank with high demand of liquidity at t=1
t=2	• Long term assets	• Withdrawals of patients agents • Withdrawals of neighboring bank with high demand of liquidity at t=2	• Long term assets • Deposits on the neighboring bank	• Withdrawals of patients agents

Table 6: Structure of the balance sheet in the case of incomplete interbank market

At t = 1, the assets of the bank which faces a high demand for liquidity (banks A and C) are composed of short term assets and deposits on the neighboring bank that hedge the impatient depositor withdrawals. At t = 2, this bank faces a low demand of liquidity. Its assets contains long term assets while its liabilities are withdrawals of patients agents and withdrawals of banks with high demand of liquidity at t=2.

For the bank (B and D) with low demand for liquidity, at t = 1, the short term assets are used to cover withdrawals of impatiens agents and withdrawals of neighboring bank with high demand of liquidity at t=1. At t = 1, the bank liquidate its long term assets and deposits on the neighboring bank (facing weak demand liquidity) to cover withdrawals of patients agents.

	A (High demand of liquidity)		**B (Low demand of liquidity)**	
	Assets	**Liabilities**	**Assets**	**Liabilities**
t=1	L 3 $(\omega_H - \gamma)\, c_1$	$\omega_H\, c_1$	L	$\omega_L\, c_1$ $(\omega_H - \gamma)\, c_1$
	L + $(\omega_H - \gamma)\, c_1$	$\omega_H\, c_1$	L	$\omega_L\, c_1 + (\omega_H - \gamma)\, c_1$
	C (High demand of liquidity)		**D (Low demand of liquidity)**	
	Assets	**Liabilities**	**Assets**	**Liabilities**
t=1	L $(\omega_H - \gamma)\, c_1$	$\omega_L\, c_1$	L	$\omega_L\, c_1$ $(\omega_H - \gamma)\, c_1$
	L + $(\omega_H - \gamma)\, c_1$	$\omega_L\, c_1$	L	$\omega_L\, c_1 + (\omega_H - \gamma)\, c_1$

Table 7: Functioning of incomplete interbank market at t = 1

	A (Low demand of liquidity)		B (High demand of liquidity)	
	Assets	**Liabilities**	**Assets**	**Liabilities**
t=2	(1-L) R	$(1-\omega_H)\,c_2$ $(\omega_H-\gamma)\,c_2$	(1-L) R $(\omega_H-\gamma)\,c_2$	$(1-\omega_L)\,c_2$
	(1-L) R	$(1-\omega_H)\,c_2+(\omega_H-\gamma)\,c_2$	(1-L) R + $(\omega_H-\gamma)\,c_2$	$(1-\omega_L)\,c_2$
	C (Low demand of liquidity)		**D (High demand of liquidity)**	
	Assets	**Liabilities**	**Assets**	**Liabilities**
t= 2	(1-L) R	$(1-\omega_H)\,c_2$ $(\omega_H-\gamma)\,c_2$	(1-L) R $(\omega_H-\gamma)\,c_2$	$(1-\omega_L)\,c_2$
	(1-L) R	$(1-\omega_H)\,c_2+(\omega_H-\gamma)\,c_2$	(1-L) R + $(\omega_H-\gamma)\,c_2$	$(1-\omega_L)\,c_2$

Table 8: Functioning of incomplete interbank market at t =2

However, even if the interbank market plays the role of liquidity insurance, in some situations, it also promotes the spread of the liquidity crisis in the entire banking system. In this sense, it is important to note that if there is an excess of aggregate demand for liquidity, the interdependencies between banks can cause many bankruptcies. The question is if the way in which banks are connected (interbank market) is a key element for the spread of the liquidity crisis from one region to other regions through interbank deposits.

In the complete market, each bank is forced to pay its share as interbank connections are reciprocal. When the total demand for liquidity exceeds the supply, and the gap is not very important, each region absorbs some liquidity shocks through the liquidation of a small proportion of long-term investment. The impact of the crisis is then much more attenuated; it is possible to prevent the spread of the crisis.

Instead, in the incomplete structure, a liquidity shock in a region is strongly felt in the neighboring bank. If this shock is very strong, then there is a spread of the crisis which then transforms the illiquidity of banks into insolvency. The explanation is related to the unilateral nature of interbank connections. Banks in not affected by the liquidity crisis refuse to liquidate a portion of long-term assets until they are themselves exposed to the crisis.

Conclusions:

To conclude, we can say that there are three mechanisms that can spread the failure of one bank into other. The first one is the pure speculation which is explained by the fact that withdrawals of some depositors affect the depositor's behavior of the bank and of the others bank who withdraw their deposits. The second mechanism is the similarity of their assets which occurs when banks invest in similar assets. The third and the last mechanism is related to the interbank market structure.

In the complete market, the risk of contagion is almost absent. The impact of shocks are attenuated and absorbed by the interbank market's banks which prevent the spread of the crisis. In the opposite, the incomplete interbank market structure facilitates the spread of the crisis, and amplifies the negative effects of the interaction between liquidity and solvency. The complete interbank market is then the structure that allows the better allocation of liquidity.

The intervention of Central Bank is very important to regulate and complete the market. Central Banks should create trust between different banking institutions of the system so that relationships become reciprocal and thus complete the market. They also have to distribute efficiently liquidity among banks. The effect of liquidity risk spread will be reduced.

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