Merton Model as a Tool to Detect Default Risk via Visualized Banking Network: Vietnamese Evidence

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Abstract. The paper investigates banking networks in Vietnam with a focus on default probability. Distance-to-Default (DD) and Conditional Probability of Default (PD) based on Merton model are used to create visualized banking networks. Some specific circumstances of Vietnamese bank network are used to test the proposed model. The results seem to be consistent with the expectations and support the model's effectiveness. The model helps to recognize the most important banks of the banking network and to warn the problematic banks, the implications of which may be useful to policy makers. Some other testing contexts are the "Before Covid 19 context" and "the fourth wave of Covid19 context", Vietnam's most severe wave. Both contexts show the two distinct clusters of the banking network, may also refer to some policy implications.

Keyword: Banking networks, Distance-to-Default, Probability of Default

1. Introduction

The banking system plays important role in the economy, especially in Vietnam. Commercial banks in Vietnam have been dominant in providing loans to firms, there- fore, risk exposure of banking system may largely influence to the economy. Re- searchers are concerned about the banking network's contagion effects, which occur when one bank's problem spreads to other banks. It may become more serious if the domino effect occurs, leading to the collapse of the entire banking system. As a re- sult, recognizing and measuring default risk and contagion effects within the banking network is critical for Vietnam. Grossman (2003), Hasan & Dwyer (1994), and Schoenmaker (1996) used autocorrelation in bank failures in relation to some macro- economic factor to recognize the contagion effects among banks. In all three studies, the authors used US data in the late nineteenth and early twentieth centuries, and while some evidence of contagion effects among banks was discovered, it is still limited by some omitted macro variables and the availability of macroeconomic data frequency.

De Bandt and Harthmann (2001) used event study to examine the reaction of banking stock prices to critical news. Literature suggests that stock price reactions to the news might vary proportionally to the degree of the news' extent of affecting the bank. The results are then more consistent with "information-based" contagion than "pure" con- tagion. However, the approach appears to fail to distinguish between macro shocks that affect all banks at the same time and "proper" contagion as defined above. Fur- thermore, Gropp et al. (2003) argued that measuring cumulative abnormal stock mar- ket returns may not be appropriate for measuring certain types of shocks, such as increases in earnings volatility or leverage.

A more comprehensive approach to measuring contagion risk is proposed, which focuses on extreme co-movements rather than statistical interdependence for the en- tire distribution (Gropp and Moerman, 2003). Longin and Solnik (2001) and Bae et

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al. (2003) demonstrated that observed co-exceedances (the presence of two or more banks in the tail of the distribution at the same time) are consistent with a different simulated distribution. It could point to a reliable method of measuring contagion risk. The co-exceedances mentioned in the paper are calculated using Distance to Default (DD), which was demonstrated by Gropp et al. (2003) to be a particularly suitable way to measure bank risk. Other risk measurements favor the DD ap- proach because it avoids issues such as subordinated debt spreads. The DD ap- proach calculates the number of standard deviations away from the default point by combining information on stock price returns, asset volatility, and leverage. The de- fault point is defined as the point at which the bank's liabilities equal the bank's total assets.

In the footsteps of Bae et al. (2003), Lau, Mitra, and Ong (2007) conducted a study to assess the risk of bank contagion across countries. The framework of extreme value theory (EVT) is still used in the paper. They used a binomial LOGIT model to predict whether a large shock to one major bank will cause stress to another major counter- part. In contrast to Gropp et al. (2003), who focus on contagion between countries and religions, Lau, Mitra, and Ong (2007) focused more on individual bank conta- gion. The benefit of this method is that it can assess the risk of individual banks. However, in developing markets, the binary regression model requires data on macro variables F (sensitivity of bank I to real and financial developments in its own coun- try and in the global market) and variables C (sensitivity of bank I to extreme shocks experienced by the rest of the banks in the sample during the previous period), which are difficult to define.

Schott (2012) recently created an entirely new method for measuring contagion risk based on asset and liability interconnectedness. The approach calculates bank inter- connectedness using Basel III regulation, which seems comprehensive. However, data on bank interconnectedness is typically difficult to obtain and untrustworthy. Basel III has also not yet been implemented in Vietnam as this method appears to be inapplicable to a specific situation such as Vietnam. Even though the literature on contagion effects has evolved in a variety of ways, the findings are limited in terms of defining and measuring contagion risks and default risk. Few studies have focused on estimating or warning of collapses or bankruptcies if the risks occur.

Many approaches to default risk research exist, but the goal is the same: to measure and warn about the possibility of a firm or bank defaulting. The Merton model is used to calculate default probability and conditional default probability based on financial data and historical data of listed stock prices of listed companies (1974). The PD measurement approach, on the other hand, only studies the company when it operates independently, without considering the spillover effects from other companies in the larger context. The conditional PD approach considers the influence of other firms, calculating the PD of one company when another company defaults, which is also a condition when calculating the PD. Using stock price history rather than the firm's book value aids in the resolution of accounting period gaps as well as the problem of inter-firm interactions. Interactions between firms include both direct interactions, which are represented by the values of financial statement items, and indirect interac-

tions, which are not recorded by accounting numbers. The use of stock price movements and inter-company interaction studies based on stock market movements will show that closely related companies respond in the same way to market movements. Firms will be linked by identifying the conditional PD of companies in the general volatile economic conditions (Hisakado & Kaneko, 2016).

Following the methodology proposal of capturing visualized firm networks on credit risk (Kaneko & Hasakado, 2019) and the outcome of application on banking networks of developed countries (Hisakado & Kaneko, 2020), this research is applied to the banking network of Vietnam, a developing market with a limited number of banks. The findings of the study aim to put Hasakado and Kaneko's proposed model for developing countries where the banking system still plays an important role in the economy to the test. Furthermore, the research findings can be used to identify interactions between banks in the network, which can indicate potential propagation risks in the network, as well as identify network hubs and important banks.

2. Model Explanation

The banking network was created based on the calculation of Single Probability of Default (PD) and Conditional PD of the banks. The single PD of each bank was measured based on the Merton model (1974). There is a probability triple (Ω, $\mathcal{F}$, P) and a filtration $\{\mathcal{F}_t\}_{t\geq 0}$. Firstly, we suppose that we can check a market value of bank's total asset amount A_t at any moment: t. This indicates that A_t is $\mathcal{F}_t$ adopted ($A_t \in \mathcal{F}_t$). We write the dynamics of bank's total asset amount at time t as:

$$dA_t = A_t\mu dt + A_t\sigma dW_t \quad (1)$$

where μ is a drift which is the instantaneous expected rate of return per unit time. σ is volatility which is the instantaneous variance of the return per unit time. dW_t is a standard Gaussian process.

We recognize bank's default only at fixed horizon time T like European type derivatives and define the default as the status of its total asset amount being smaller than its debt amount. Namely, we calculate PD of a bank based on Merton model at the time T as

$$(A_t < D) = P\left(A_0 exp\left[\left(\mu - \frac{1}{2}^2\right)T + \sigma W\right\}_T < D\right)$$

$$= N\frac{ln\left(\frac{}{A_0}\right) - \left(\mu - \frac{1}{2}^2\right)T}{\sigma\sqrt{T}} \quad (2)$$

Where D is total debt amount of a bank and is supposed to be fixed by the time T. N (·) is a cumulative density function[1]. We denote PD of bank i as p_i and use , D_t^i, μ_i, σ_i, and W_t^i as parameters for bank i's asset dynamics.

**Conditional PD*

We define the default impact received by another bank based on Merton model. We call this probability as the conditional PD. This measure as default probability on the

[1] $(a) = \int_{-\infty}^{a} \frac{1}{\sqrt{2\pi}} exp\{-\frac{1}{2}x_2\}dx$

condition of another bank' default. When we calculate bank i's default probability on the condition of bank j's default, we write this as . When cp_{ij} is greater than cp_{i2}, bank i will receive more serve default impact from bank 1 than bank 2. When cp_{ij} is the highest conditional PD among $\{cp_{i1}, cp_{i2}, \cdots, cp_{in}\}$, bank j is the most influential bank for bank i in term of default infection. That is why we think it natural to suppose that bank j's default will be easily propagated toward bank i. Based on this idea, we define the connected banks. In the numerical experiments, we calculate this conditional PD by $n \times (n-1)$ times, because cp_{ij} is not same as . The number times of calculation will be the critical issue if we have to treat a large number of banks, so choosing Vietnam's banking system with limited number of banks is reasonable. We calculate PD of bank i on the condition of bank j defaults as follows:

$$P\left(A_T^i < D^i \middle| A_T^j < D^j\right) = \frac{P\left(A_T^i < D^i, A_T^j < D^j\right)}{\left(A_T^j < D^j\right)} = \frac{\int_{-\infty}^{d_i}\int_{-\infty}^{d_j} \phi(\xi_i, \xi_j, \rho_{ij})\, d\xi_i\, d\xi_j}{p_j} := cp_{ij} \quad (3)$$

Where ρ_{ij} is a correlation between bank i and j. $(\cdot,\cdot,\cdot)$ is a density function of two-dimensional standard normal distribution [2]. ξ_i and ξ_j are correlated random variables following standard normal distribution. d_i and d_j are default thresholds for ξ_i and ξ_j as follow:

$$d_i = \frac{\ln\left(\frac{D^i}{A_0^i}\right) - \left(\mu_i - \frac{1}{2}\sigma_i^2\right) T}{\sigma_i\sqrt{T}}, d_j = \frac{\ln\left(\frac{D^j}{A_0^j}\right) - \left(\mu_j - \frac{1}{2}\right) T}{\sigma_j\sqrt{T}} \quad (4)$$

$N^{-1}(1-(d_i))$ is called as default distance: DD in credit risk management.

** Connecting banks to form the visualized network*

We connected banks based on the size of conditional PD to create banks' network. We use directed graph (arc) to express direction of easiness of default propagation. We express default risk flow from bank i toward bank j as $i \longrightarrow j$ in the networks and the set of banks which propagate default toward bank i as $\{banki\}$. Namely, bank i has inflow arcs from banks in $\{banki\}$. If we draw a network connecting banks by limiting top 3 largest impacts, $\{\text{bank}i\}_{i\in\{1,\cdots,n\}}$ is created based on the following algorithm

For i is 1 to n
$\{banki\} = \emptyset, n_i := 1, \cdots, n/\{i\}$
For k is 1 to 3
$\{banki\} = \{banki\} \cup arg_{j\in n_i} max\ \text{cp}_{ij}, n_i = n_i \setminus \{banki\}$ (5)
Next k
Next i

Where i and k are counters for loops, "$\setminus$" is subtracting of set operation. There are three elements in each $\{banki\}$. We connect banks in $\{banki\}$ with bank i by using

[2] $\phi(\xi_i, \xi_j, \rho_{ij}) = \frac{1}{2\pi\sqrt{1-\rho_{ij}^2}} exp\left[-\frac{1}{2(1-\rho_{ij}^2)}\left(\xi_i^2 - 2\rho_{ij}\xi_i\xi_j + \xi_j^2\right)\right]$

arrows directing toward bank i. For top k network, we repeat the step of adding bank step in the algorithm (Equation (5)) k times.

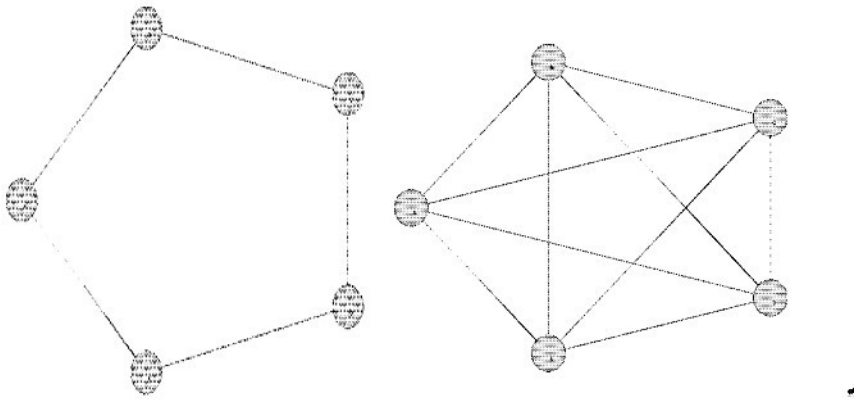


Figure 1: Examples of banking network images

In Figure 1, circles represent banks, and arrows represent commercial connections between banks. The size of the circles represents the banks' default probabilities. While one image shows a bank network that is only connected to the most powerful firms, the other one shows a bank network linked to first and second influential firms.

3. Methodology

The authors estimate dynamic bank networks in this paper using historical stock prices and financial data (i.e. total assets and total liabilities) extracted from the bank's financial reports, using the Merton model approach to creating banking networks. Based on the visualized image of the bank network, clusters of tightly connected banks are expected. The most powerful (or important) bank will be located in the center of each cluster and designated as a "Hub-bank." Because it can identify both positive and negative impacts of relevant events, the visualized network would be useful for investment and risk management (Kaneko and Hisakado, 2019).

The paper focuses on three specific cases. In 2012, the first case was dubbed the "Habubank case." On August 8th, 2012, the Hanoi Stock Exchange (HNX) issued an official announcement regarding the cancellation of the listing of Hanoi Housing Commercial Joint Stock Bank (Habubank - abbreviated as HBB). As a result, on August 17, 2012, 405 million shares of HBB were delisted, and HBB was merged into Saigon - Hanoi Commercial Joint Stock Bank (coding as SHB). HBB last traded on the Hanoi Stock Exchange on August 16, 2012. The second case is the "Before Covid 19 case," which examined the 2018 banking network for Hubs or important banks. The network of 13 listed banks in 2018 reveals a significant cluster of banks,

which may aid in identifying the influenced banks. In the third case, data from the third quarter of 2021 with 20 banks is used to detect any hubs during the fourth wave of Covid 19, Vietnam's most severe Covid period.

In terms of data collection, the data used in this paper came from Fiingroup (previously known as Stoxplus), a well-known provider of Vietnamese financial data. The information includes stock codes, stock prices, total assets and total liabilities of banks listed on Vietnam stock exchanges. The data for the Habubank case is gathered from the first quarter of 2011 to the first quarter of 2012. The banks involved in the "Habubank case," "Before Covid 19 case," and "fourth wave of Covid 19 case" will be listed in Appendix. Some banks have been excluded from the study due to their small size and short-listing time.

4. Finding and Discussions

The Habubank case

The first case is the 2012 delisting of 405 million Habubank shares from the Hanoi Stock Exchange (HNX). At the time, the Vietnamese Exchange listed nine banks. The Habubank case was first studied to establish the banking network at various points in time between 2011 and 2012. Figures 2 and 3 show statistics about stock prices and debt/total asset ratios among banks in the Habubank case. The bank stock prices were represented by dividing the daily stock prices by the base date, the first day of the investigated period. As a result, on the first day of the investigated period, the stock price equaled 1. Then, for the next five quarters (2011-2012), the stock prices of banks are reflected with the movement compared to 1. In comparison to others, the stock prices of Habubank appear to be declining. At the same time, the Habubank's debt/total asset ratio is expected to fall sharply. A bank's decreased debt/total asset ratio indicates a bad financial situation when the liabilities of the bank, including deposits and borrowing, deteriorate. The two statistical ratios provided a consistent signal about Habubank's situation during its difficult period.

Table 1: List of banks related to Habubank case

No	Stock Exchange	Bank name	Stock code	Total assets in billion VND	Total liabilities in billion VND	Number of branches
1	HOSE	Vietnam Joint Stock Commercial Bank for Industry and Trade	CTG	406,852	376,632	
2		Vietnam Commercial Joint Stock Export Import Bank	EIB	170,934	155,662	
3		Military Commercial Joint Stock Bank	MBB	144,629	130,865	
4		Sai Gon Thuong Tin Commercial Joint Stock Bank	STB	140,850	125,561	

5		Bank for Foreign Trade of Vietnam	VCB	358,908	317,117	
6	HNX	Asia Commercial Bank	ACB	265,556	252,865	
7		National Citizen Commercial Joint Stock Bank	NVB	23,849	20,530	
8		Saigon Hanoi Commercial Joint Stock Bank	SHB	74,369	68,246	
9		Habubank	HBB	34,649	30,181	

Source: Fiin Group at Quarter 1, 2012

Table 1 shows total assets, total liabilities of listed banks in Vietnam at Quarter 1, 2012. CTG and VCB took the first and second places while NVB and HBB had the lowest total assets and liabilities.

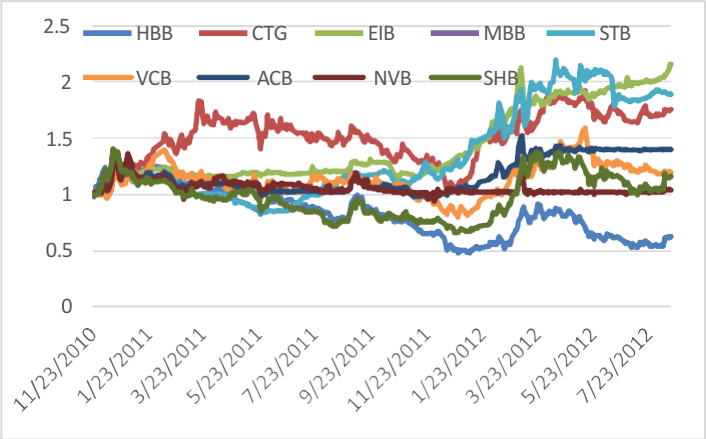


Figure 2: Stock Price Performance of the Banks in 2011-2012
Source: Author's results

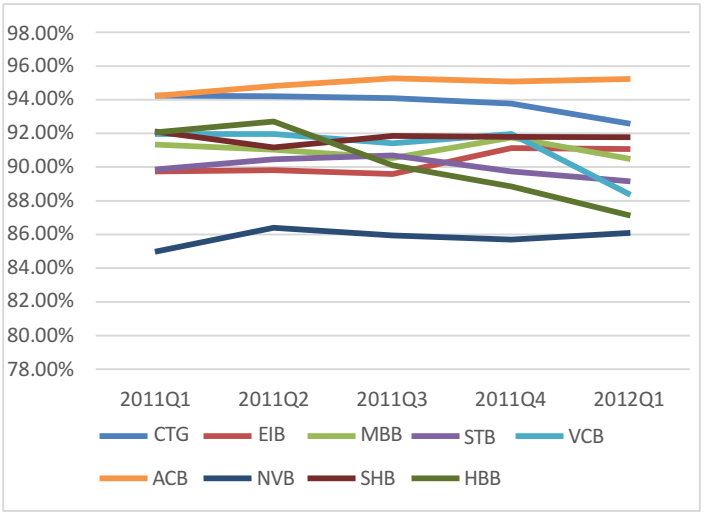


Figure 3: Debt/Total assets ratios of the banks in 2011-2012
Source: Author's results

The results of banking networks are visualized based on discussed methodology above. Some banks are excluded from the network due to their small size and short-listing time such as NVB (listing from September 13, 2010) , SHB (listing from June 25, 2009…The bank hubs are the banks having the largest connection with other banks. The data is set to the quarterly financial statements of the banks, so the banking networks are exposed to change through the quarters. The banks considered as the hubs are also changed, (i.e. STB, ACB, VCB in the Figure 4). It may be reasonable when the banks may swap their roles in the network through different quarters of the year. The hub banks also raise the implication about the contagion effects. That are the banks spread the most severe contagion to the banking system. Following the positions of the Habubank in the network through the 5 quarters, they are highlighted in the red circles. The Habubank was always exposed into the position far away the center of the network. The outliner bank is the bank having the least connection to others and situates far from the center of the network. Continuously, five quarters before the Habubank's problem, the model has shown that the Habubank seems to be the outliner every quarters. This may consider as the warning signals to the bank as well as to the system. The model results are consistent as expected hypothesis. The backtest process on the Habubank case is the first step of confirming the effectiveness of the model. It may be useful to test the banking network for the other two cases.

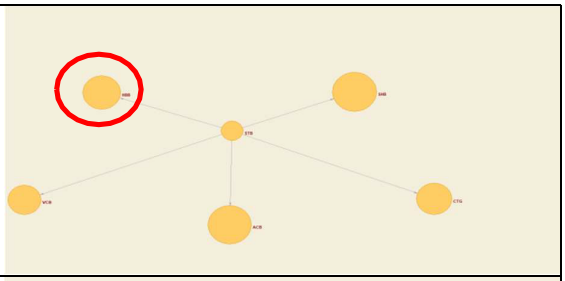
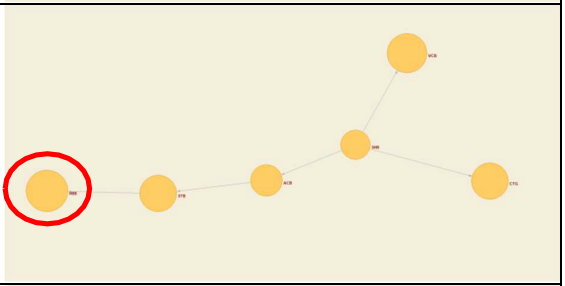
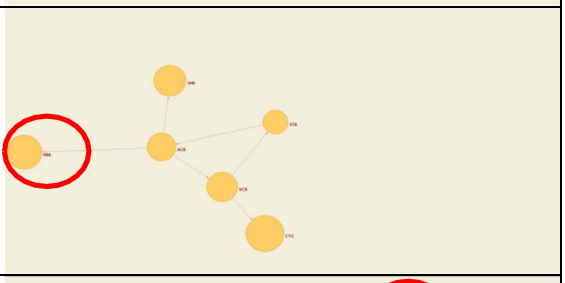
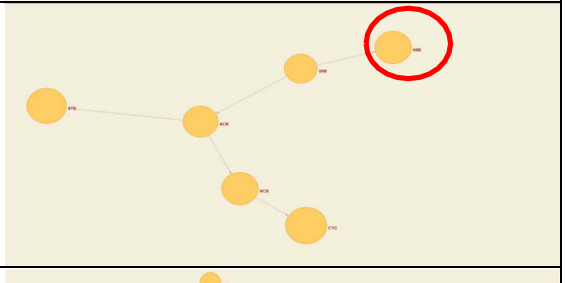
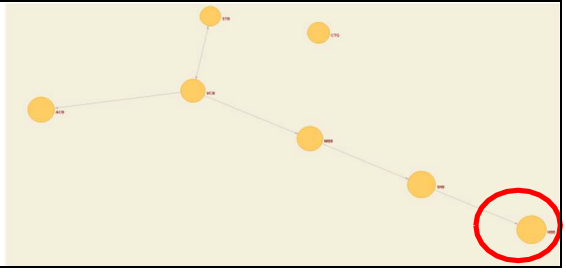
Vietnamese banking network Quarter 1, 2011	
Vietnamese banking network Quarter 2, 2011	
Vietnamese banking network Quarter 3, 2011	
Vietnamese banking network Quarter 4, 2011	
Vietnamese banking network Quarter 1, 2012	

Figure 4: Banking Network through 5 quarters of 2011-2012
Source: Author's results

Figure 4 shows the use of the methodology proposal of capturing visualized firm networks on credit risk (Kaneko&Hasakado, 2019) showing the case where Habubank was gradually pushed out as the outlier of the system, signaling a problem bank before Habubank is actually declared to be delisted. This is a testament to the predictability of the model and methodology.

The "Before-Covid 19" context
The second case is the "Before Covid 19 case," which includes 13 banks and collects data quarterly from 2014 to 2018. The visualized network is shown in Figure 5 below.

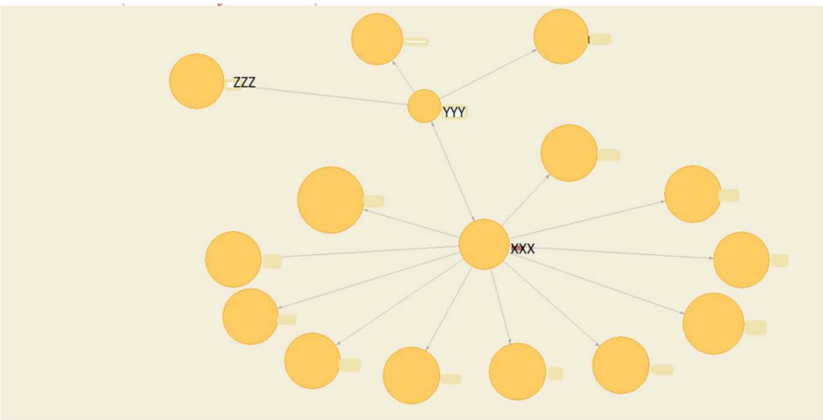


Figure 5: Banking network estimation in 2018 – the before Covid 19 case.
Source: Author's results

The bank names are coding to avoid sensitive judgments. The network's meaning is to define the hub banks, which are the influenced banks. Failures or collapses of hub banks may have serious knock-on effects on the entire system. The bank XXX is considered the hub bank in this study. It may have some implication in terms of keeping tabs on the major banks. Simultaneously, the bank ZZZ may be considered one of the problem banks at the moment. In the future, some more supervised actions may be required. However, no bank failures were reported in Vietnam between 2018 and 2021. With State Bank of Vietnam's flexible operating policies on a small bank system, SBV always solves small bank problems in a timely manner and asks large banks for assistance when situations arise. When bad things happen, the results of Vietnam's banking network remain stable

Table 2: List of banks related to Before Covid 19 case

No	Stock Exchange	Bank name	Stock code	Total assets in billion VND	Total liabilities in billion VND
1	HOSE	JSC Bank For Investment And Development Of Vietnam	BID	1,268,412	56,871
2		Vietnam Joint Stock Commercial Bank for Industry and Trade	CTG	1,172,517	1,102,602
3		Vietnam Commercial Joint Stock Export Import Bank	EIB	146,991	131,804
4		Military Commercial Joint Stock Bank	MBB	343,850	310,643
5		Sai Gon Thuong Tin Commercial Joint Stock Bank	STB	403,602	379,822
6		Bank for Foreign Trade of Vietnam	VCB	995,111	933,585
7		Vietnam Prosperity Joint Stock Commercial Bank	VPB	296,216	264,229
8	HNX	Asia Commercial Bank	ACB	312,778	293,259
9		National Citizen Commercial Joint Stock Bank	NVB	69,505	66,294
10		Saigon Hanoi Commercial Joint Stock Bank	SHB	299,698	283,644
11	UPCOM	Kien Long Commercial Bank	KLB	39,452	35,755
12		Lienviet post bank	LPB	167,328	157,260
13		Vietnam International Commercial Joint Stock Bank	VIB	132,507	122,388

Source: Fiin Group at Quarter 3, 2018

Table 2 shows total assets, total liabilities of listed banks in Vietnam at Quarter 3, 2018. BID andCTG took the first and second places while NVB and KLB had the lowest total assets and liabilities.

The "Fourth wave of Covid-19" context

The third case contained 20 banks in the third case. In the third case, data from the third quarter of 2021 with 20 banks is used to detect any hubs during Vietnam's most severe wave, Covid19. The visualized network is shown in Figure 6 below

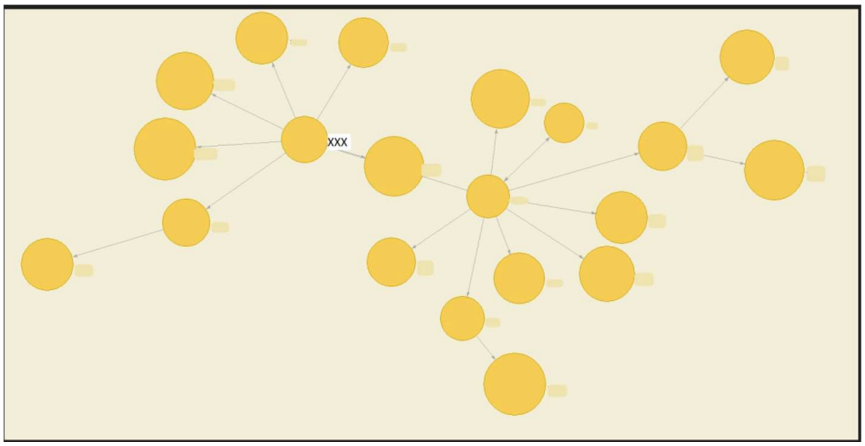


Figure 6: Banking network estimation in 2022 - the fourth wave of Covid19 case
Source: Author's results

Compared to the case of before-Covid19, the number of banks listed on the Vietnamese stock exchange had increased significantly as of 2022. Based on the proposed method and model, the image results for Vietnam's banking network show two significant clusters of banks. Bank XXX is still the hubs bank in this result, as it was in the previous case. In addition, a cluster of banks was formed, and another influence bank was established. At this time, some banks appear to be outliners and may require additional attention from the system as well as State Bank of Vietnam.

Table 3: List of banks related to the fourth wave of Covid 19 case

No	Stock Exchange	Bank name	Stock code	Total assets in billion VND	Total liabilities in billion VND
1	HOSE	JSC Bank For Investment And Development Of Vietnam	BID	1,847,704	1,757,867
2		Vietnam Joint Stock Commercial Bank for Industry and Trade	CTG	1,663,730	1,565,434
3		Vietnam Commercial Joint Stock Export Import Bank	EIB	172,343	153,894
4		Ho Chi Minh City Development Joint Stock Commercial Bank	HBD	381,046	348,235
5		Military Commercial Joint Stock Bank	MBB	649,039	581,976
6		Vietnam Maritime Commercial Join	MSB	195,740	172,626

		Stock Bank			
7		Orient Commercial Joint Stock Bank	OCB	187,748	165,276
8		Sai Gon Thuong Tin Commercial Joint Stock Bank	STB	552,539	517,058
9		Southeast Asia Commercial Joint Stock Bank	SSB	231,222	208,631
10		Vietnam Technological and Commercial Joint Stock Bank	TCB	615,270	516,684
11		Tien Phong Commercial Joint Stock Bank	TPB	302,622	275,242
12		Bank for Foreign Trade of Vietnam	VCB	1,462,748	1,345,670
13		Vietnam Prosperity Joint Stock Commercial Bank	VPB	563,923	468,721
14	HNX	Asia Commercial Bank	ACB	528,636	480,433
15		Bac A Commercial Joint Stock Bank	BAB	117,078	107,830
16		National Citizen Commercial Joint Stock Bank	NVB	73,897	69,612
17		Saigon Hanoi Commercial Joint Stock Bank	SHB	515,553	477,734
18	UPCOM	Kien Long Commercial Bank	KLB	80,844	76,059
19		Lienviet post bank	LPB	284,918	266,695
20		Vietnam International Commercial Joint Stock Bank	VIB	333,850	307,838

Source: Fiin Group at Quarter 1, 2022

Table 3 shows total assets, total liabilities of 20 listed banks in Vietnam at Quarter 1, 2022. BID, CTG, VCB were the three biggest banks while NVB and KLB still had the lowest total assets and liabilities.

Figures 5 and 6 show the banking network in both contexts, the “before-Covid19” and the “fouth wave of Covid19”, the banking network in both is formatted into clusters, with some banks located in between the clusters, implying that banks take the important role of the network. These additional explanations have been added in the text.

5. Conclusion

Based on the research findings and the initial application of the model to a developing country such as Vietnam, the model has not proven its policy implications effectiveness. The commercial banking system of Vietnam consists of a small number of banks, and this number is slowly growing over time. The test results therefore do not hold meaningful significance. However, the model's viability was initially confirmed by tests conducted on Habubank, the sole case considered to be a problematic bank in Vietnam. The results of the remaining two context indicate that the Vietnamese banking system remains stable as there have been no instances of problem banking and that and Vietnam's banking system operates with a rather 'high cluster' nature, while a number of commercial banks (XXX bank) continue to play the 'main hub' role in the system. The policy implication from this study's findings is that Vietnam's commercial banking system, up to now, is still a stable one, but commercial banks play an important role, whereby the hub of the system are banks that need attention, to avoid bad indications for the whole system. Banking network needs to be monitored regularly to detect outlier movements of banks, especially signs of movement of bank hubs, which can have great effects on the system as a whole.

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