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The Impact of COVID-19 on Banking System Critical Transitions

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Abstract: **This paper examines the short-term impact of the coronavirus (COVID-19) outbreak on the banking system's critical transitions (bifurcation points) in all affected countries across the globe. The consequences of infectious disease are considerable and have been directly affecting the banking system across the world. Using the Lotka-Volterra complex system theory approach, this study develops the complex dynamical model for investigating the role of the pandemic outbreak towards the banking system's critical transitions. Our results confirm that the banking system in major affected economic zones fell quickly during the critical virus outbreak. The Eurozone experienced more negative financial disruptions during the crisis than other economic zones. Further results confirmed that the promotion of the banking system z-score fosters the critical transitions to large values and thus, promotes an exponential growth of the banking system. Moreover, the study of banking systems can be applied as a risk mitigation approach to reduce economic shocks, increase banking sector resilience, and avoid financial collapse.**

Keywords: **critical transitions; banking system resilience; inflation; Lotka-Volterra theory; economic zone; system bifurcation.**

1. INTRODUCTION

Many complex banking systems networks within the phase periods are often at risk of an unexpected collapse or critical transitions to alternative states. Risk and unpredictable, chaotic behaviors are inevitable facts of life for ecological and financial systems [1-4]. These disruptive economic disruptions demand that the ecosystem resist or adapt for survival [5]. Subsequently, the concept of improving banking system resilience has emerged as a potential alternative to conventional risk management strategies as applied in other industrial ecosystems [6-9]. A vital component of any resilient banking system is the improvement of adaptive capabilities that allow the system to withstand economic disruptions caused by inflation [10] structurally. Although conventional risk management strategies play significant role in reducing the impacts of specific sources of risks [11, 12], they cannot comprehensively cope with banking system dynamics and uncertainty. This study examines the short-term role impact of the COVID-19 outbreak on the banking system. The study is achieved by using the three-phase period data sourced from the global economy database. The rationale behind using such data is to investigate how the financial perturbation affected the critical transitions (tipping points) by shifting their locations towards undesirable states. Moreover, the results of this study will suggest the desired risk mitigation strategy as an adaptive capability [13-15].

Banking system resilience is broadly defined as the capability of a system to absorb financial cascading failures and reorganize while changing to retain the same function, architecture, identity and feedback [16-18]. The concept of banking system resilience embraces the fact that every productive system will always be subject to unprecedented economic disruptions. From the perspective of the banking system, many studies defined banking system resilience as an ecosystem that has developed adaptive capabilities after having experienced unexpected economic disruptions [17]. System resilience, a theory originating from socio-ecological studies investigated by Huang, Shi [19], is the ability of a system to withstand any economic shocks topologically, predicted, or unpredicted. From this perspective, banking sectors have already implemented banking resilience strategies into their risk management mitigations for many years. Yet, in terms of reasonable risk management techniques like the suggested optimal strategy, applications of system resilience in the banking sector are still evolving [20, 21]. Survival in the crisis of the COVID-19 outbreak, banking sectors need to improve their processes, system architecture, and technologies to be dynamic and flexible and meet the ongoing changes in the global market [22]. Nowadays, the economic risks lead to a high banking system threat of uncertainty. If these financial risks become real, they can negatively impact the banking system resulting in deformed. Many studies have shown that modern banking systems are at greater risk than their regulators recognize [23, 24],

The COVID-19 and Banking Critical Transitions

Examining and analyzing the role of the COVID-19 pandemic on the critical transition locations of the banking system is essential in strategically locating critical facilities as network operations strategies [4, 25-28]. In support of this, we introduce and develop the adopted Lotka-Volterra complex system approach [29-31] to analytically examine the underlying the varying inflation critical transition locations that unveil the degree of the banking system resilience during the COVID-19 pandemic. The approach investigates the variation in the inflation tipping point locations for different economic zones. The critical transition variation identifies the zone banking system's robustness against initial loss and the rapidity of the recovery process. In this study, we discuss the background of the COVID-19 pandemic outbreak and the critical transition [26, 27, 32-34]. We then define the notion of predicted banking system's behavior as an analytic measure and provide a simple strategic approach to improve the banking sector resilience. The resilience value depends on the behavioral patterns of the banking-z-score and the level of inflation during the crisis.

The COVID-19 outbreak caused the most dramatic economic and financial crashes in history. The crash triggered by the virus that originated in Wuhan, China. Initially, it was not believed that this virus could be a great threat and could propagate to every part of the world. The novel COVID-19 pandemic crisis has shaped an extraordinary situation for our generation, with many economic regions being on lockdown. With this, new situation comes with many psychological encounters not only for health care workers and people suffering from COVID-19 pandemic outbreak but also for the banking system dynamics [35, 36]. Adapting to the new situation as suggested by Ashraf [13], Ma [15] can be demanding to avoid the global economic disruptions and the corresponding collapses. Recent researchers have portrayed that emotions during this situation are very similar to grief [37]. Banking customers experience financial decline on the normal banking services lives in the banking system, which can even jeopardize the exponential growth of the other sectors like fishing industry [2].

There is growing concern over tipping points arising in banking systems because of financial shocks. Specifically, a tiny disturbance in an input condition resulting in huge, sudden, and often irreversible changes in the regime of a networked dynamical system is known as "tipping" or "critical transition" [32, 38, 39]. Tipping points lead to abrupt and possibly irreversible shifts between alternative banking system regimes, potentially incurring high inflation rate. The banking system z-score is central to the banking price feedbacks that regulate the inflation rate spikes, as they govern the responses of price volatility to banking system resilience that could withstand the financial shocks. However, we know little about how the COVID-19 crisis affects the occurrence of tipping points and even less about how big-scale banking system resilience shifts reciprocally relate with system dynamics. We argue that connection between the banking system z-score and inflation should be taken into account to understand the balance of feedback governing tipping points in banking systems. Moreover, the banking system is governed by the developed model that encompasses the banking sector's mutualistic interaction. The banking sectors interaction which is governed by the coefficient of interaction strength β_i plays a vital role on enhancing the banking system resilience by improving the critical transitions to high values and promoting the exponential growth of the banking sectors.

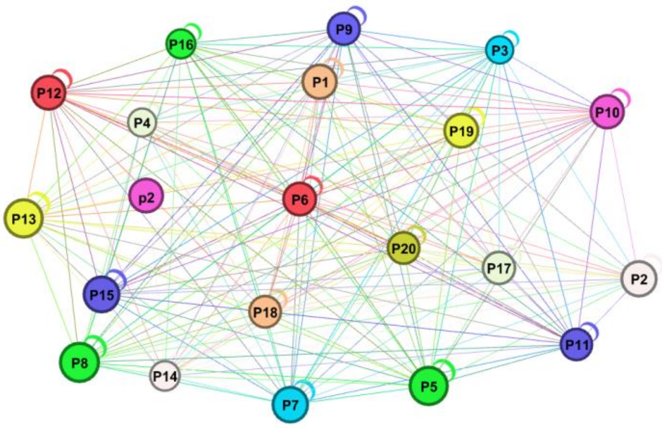


Figure 1: Graphical representation of the banking network

Key: P1-P20 is the 20 banks

Source: *Author concept visualization plot*

Simulation tool: *GEPHI*

Figure 1: Graphical representation of the seller-buyer bipartite stock market network

This study contributes to the literature in determining whether the COVID-19 pandemic crisis influences the decline in banking tipping point locations. The contribution is explored twofold. First, applying the adopted and developed Lotka-Volterra system model of the banking system dynamics context introduces the banking system resilience perspective to current risk management literature in this field. Second, the empirical outcomes provide valuable insights on risk mitigation strategies in the face of increasing the inflation value and critical transition drop caused by the COVID-19 pandemic.

The remainder of this paper is arranged as follows. The following parts unveil the related literature review and knowledge gaps. Section three develops the banking system model using the adopted Lotka-Volterra model system theory. This section also explains the data and the four economic regions (zones) under study. Section four presents and discusses the simulation results. Final section concludes the study and suggests future recommendations in banking and other economic sectors.

2. LITERATURE REVIEW

Recently, the impacts of the COVID-19 pandemic crisis on the banking system have been broadly studied by the recent scholars [35, 36, 40, 41]. The studies associated, in fact, how banking systems affected by the pandemic outbreak challenges as the ability of the latter networks not to return to a regime of equilibrium after a temporary disruption [4, 23]. In the education perspective, scholars in recent studies have argued that the COVID-19 pandemic is a huge challenge to education systems [42]. To curb the challenge, the scholars further suggested asynchronous learning as an adaptive capability risk mitigation tool. The rapid spread of COVID-19 across the created subsequent fear and finally triggered to the halt of various economic and banking activities [36]. The banking network responses to the pandemic crisis have differed markedly depending on the nation culture [13]. Using Ordinary Least Square (OLS) regression approach, Herwany, et al. [43] aimed to confirm if the COVID-19 pandemic has had a significant effect on existing banking sectors, and how that shakes the stock systems. Judging from the aggregate value of abnormal returns, the results showed that, banking systems on were affected by the COVID-19 pandemic. By investigating the effect of the rapid spread of COVID-19 on financial systems, Zhang, et al. [33] used the quantitative easing (QE) approach to argue that, the pandemic has created an unprecedented level of risk, causing stock investors to suffer significant financial losses in a very short period. Ashraf [13] examined the stock markets' response to the COVID-19 pandemic. In the analysis, the researchers found that, the negative market reaction was strong during early days of confirmed cases and then between 40 and 60 days after the initial confirmed cases. Overall, their results suggested that banking systems quickly responded to the COVID-19 pandemic and this response varies over time depending on the degree of the outbreak [36, 40]. In the perspective of the US and Canada, the recent studies confirmed that, the COVID-19 pandemic crisis has dragged down the economy at both global and country-specific levels since the beginning of 2019 to 2021. Using a structural VAR model, which is adopted to accommodate GARCH-in-mean errors, the researchers further revealed an unexpected increase in the COVID-19 cases to hurt the stock return with persistence in Canada [44].

Our study proposes the concept of tipping points on banking systems. This is a state shift where turning back the direction of change will not immediately restore the level of banking system services. In recent studies, the scholars have been carrying out the analysis of critical transitions of diversified ecosystems to mitigate the corresponding risks. Farazmand [14] examined the capability of linear delay feedback control to control these tipping points, ensuring that the systems stay near a desirable state. Thresholds exist in ecological, social, and environmental systems and those systems are increasingly causally intertwined in the anthropocene [38]. The study of Tàbara, et al. [39] introduced the notion of positive tipping points as emergent properties of systems which would allow the fast deployment of evolutionary-like transformative solutions to successfully solve the present financial ecosystem challenges. Their research revealed how to identify the required capacities, conditions and potential policy interventions which could eventually lead to the promotion of positive tipping points in various social–ecological ecosystems. The study of threshold values (tipping points) has been broadly examined in diversified disciplines. In social perspective, Bentley, et al. [37] investigated the Social dynamics system behavior and confirmed that, social tipping points are particularly difficult to predict. Critical transitions in complex ecosystems are structural transitions from one regime to another. In banking systems these critical points are connected to systemic disruptions, which have steered to financial crisis in the past [4]. Gualdi, et al. [45] examined the possible types of phenomena that simple macroeconomic Agent-Based models (ABMs) can reproduce. By proposing a methodology inspired by statistical physics, that characterizes a system model through its phase diagram in the space of parameter values, they found that, there is a generic existence of tipping points (critical transition) between optimal economic strength where unemployment is low and bad economy where unemployment is high.

This paper is the first to investigate how the COVID-19 pandemic crisis can influence the banking system configurations towards the low state shifts using the Lotka-Volterra complex theory approach. First, our adopted Lotka-Volterra model system includes the banking system z-score, which dampens the inflation rate towards the critical transition. Second, it empirically reveals the equilibrium points (points to which the banking system bifurcates) from desirable regime to undesirable regime and from which managers, scientists and regulators can strategically optimize the banking systems to resilient and stable regime. Third, we introduce the coefficient of banking mutualistic interaction strength parameter. This makes the study robust and innovative in a sense that, all the banking sectors in the system are getting connected mutualistically. Finally, we reduce the adopted and developed the banking multi-dimensional complex model to get one-dimensional which is feasible system for an effective simulation. The combination of all these steps makes the study new and innovative.

3. ECONOMETRIC METHODOLOGY AND DATA

This study adopts the model theory of the Lotka-Volterra complex systems approach [46]. This method highlights systems' nonlinear, networked, adaptive, and emergent behavior [47]. Therefore, we developed a new banking system model based on the Lotka-Volterra complex system approach and reduced it from multiple dimensions to one dimension. The rationale behind system model reduction is to promote the efficiency and reliability of empirical outcomes [48, 49]. The stepwise derivation of the banking complex model from formulation to analysis is provided in Appendix B.

3.1 Model Formulation

Let $p_i \in \mathbb{R}$ be the growth rate of the banking network at node i with time t, assuming that one banking sector has transactions with the other banking sectors. The bank sectors are the nodes in the networked system, and banking transaction connections correspond to edges, as shown in Figure 1. The highest possible banking sector growth rate $K_i(K_i > 0)$ with an intrinsic revenue growth rate constant $\alpha_i(\alpha_i > 0)$, as per the logistic model system for this sector, is as follows:

$$\frac{dp_i}{dt} = \alpha_i p_i \left(1 - \frac{p_i}{K_i}\right) \qquad (1)$$

The revenue growth rate p_i of bank sector i can also be affected by the inflation I_i. Here, we apply population dynamics and organizational ecology concepts to adopt and examine dynamic systems and system resilience variation. This computation can be achieved by adopting the inflation as a harvesting effort parameter and introducing it into Equation (1) to obtain the harvesting effort model [50]. The equation becomes:

$$dp_i/dt = \alpha_i p_i \left(1 - p_i/K_i\right) - I_i p_i \qquad (2)$$

The functioning of the entire banking sector is determined by the system configuration (topology structure) in which the banking sectors are linked. The banking topology architecture of the system is weighted using the connectivity matrix that captures mutualistic interactions between nodes (banking sectors) [51, 52]. A concept in Figure 1, exhibits how banking sectors (nodes) are connected to form a system structure matrix $A_{ij} > 0$ of the sector transactions. Thus, Equation (2) can be further developed by incorporating the mutualistic interaction term to obtain:

$$dp_i/dt = \alpha_i p_i \left(1 - p_i/K_i\right) - I_i p_i + \sum_{j=1}^{N} A_{ij} G(p_i p_j) \quad (3)$$

For simplicity, the sector topology can be expanded by introducing the interaction strength parameter together with applying the Holling type II functional response as suggested by [53] to obtain

$$dp_i/dt = \alpha_i p_i \left(1 - p_i/K_i\right) - I_i p_i + \sum_{j=1}^{N} \left(\beta_{ij} p_i p_j / D_i + E_i p_i + H_j p_j\right) \quad (4)$$

where D_i, E_i and H_j are parameters that characterize the saturation rate of the response function

$$g(p_i) = \beta_{ij} p_i / D_i + E_i p_i + H_j p_j \qquad (5)$$

The improving of the banking system z-score can also enhance the exponential growth p_i [54]. We adopted the model system by adding the banking system z-score parameter to the banking system resilience function $f(I_i, p_i)$. This can be achieved by adding the term σ_i into the governing parameter coefficient of the banking system z-score. Thus, the developed banking model becomes:

$$dp_i/dt = \sigma_i p_i + \alpha_i p_i \left(1 - p_i/K_i\right) - I_i p_i + \sum_{j=1}^{N} \left(\beta_{ij} p_i p_j / D_i + E_i p_i + H_j p_j\right) \quad (6)$$

In Appendix B, we detail the steps of our dimension-reduction procedure, which leads to the banking reduced model.

$$dp_{eff}/dt = \sigma_{eff} p_{eff} + \alpha_{eff} p_{eff} \left(1 - p_{eff}/K_{eff}\right) - I_{eff} p_{eff} + \beta_{eff} p_{eff}^2 / \left(D_{eff} + h_{eff} p_{eff}\right) \quad (7)$$

The first term of the right hand side of the Equation (7) describes for the resilience of the banking network at a rate $\sigma_{eff} p_{eff}$. The second term accounts for the effective logistic growth of the banking system with an effective maximum potential capacity K_{eff} and the effective banking resilience, according to which for weak resilience ($p_{eff} < 0$) the banking system features negative growth. The third term portrays the banking system collapse at a rate $I_{eff} p_{eff}$ and fourth term reveals banking sectors' mutualistic interaction, captured by a response function that saturates for large p_i and p_j, indicating that j's positive contribution to p_i is bounded. To portray the estimated β_{eff} which is an effective interaction coefficient, we used the adopted symbiotic interaction relationship [3], collected for financial returns of all banking sectors, accounting for networks ranging from $N = n_1$ to $N = n_2$ nodes where $n_1 < n_2$ and $\{n_1, n_2\} \in$ □ .

3.2 Numerical Simulation

We numerically solved Equation (7), and tested its resilience under realistic inflation spikes perturbation caused by the COVID-19 crisis (Figure 2a and 2b): first, we took the curated data outcomes of the three phase-periods (2018-2019, 2019-2020 and 2019-2021. The rationale behind choosing the range of time is to obtain the three distinct periods (before, during the crisis, recovery) of the banking system dynamic equilibrium when the system was perturbed to collapse. Finally, using

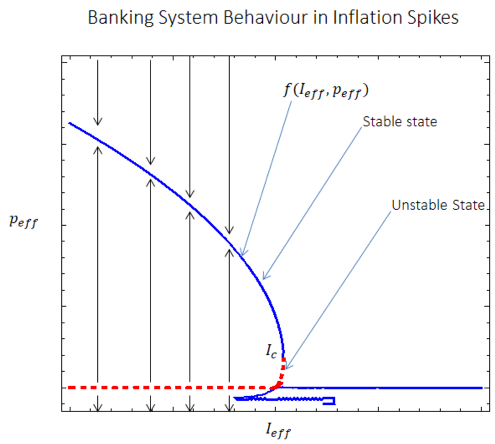
MATHEMATICA and MATLAB mathematical tools, we set α_{eff}, K_{eff}, $\langle\gamma\rangle$, D_{eff} and h_{eff} to examine the impact of inflation rate degree triggered by the COVID-19 outbreak towards banking system resilience in the three phase-period.

3.3 Data Structure

The data structure investigates the impact of the COVID-19 pandemic outbreak on the resilience of banking sector systems. To calibrate the developed banking model, we took the information of banking sectors of all countries across the globe and relied on transaction connection data sources. In this study, we obtained the banking system z-score and inflation data from 2018 to 2021 from a secondary source (https://theglobaleconomy.com/). The selected data involve the 2019-2020 COVID-19 outbreak crises, making the study relevant. Moreover, all selected member economic regions collectively comprised more than the threshold sample size

4. SIMULATION RESULTS

Using the mathematical software tools we simulate the banking resilience function (Equation (7)) on the increasing inflation degree in three consecutive years (2018-2019, 2019-2020 and 2020-2021) to investigate the impact of COVID-19 on the banking system resilience (banking sector growth). Results reveal the influence of banking z-score on the banking system growth. At $p_{eff} > 0$, the system collapses when the inflation rises. On the other hand, the banking system loses stability to the point of no return I_c as shown in Figure 2a. This dynamic equilibrium in which the banking system bifurcates (deviates) from stable state (thick blue line) to unstable state (red line) is called tipping point Q_c (Figure 2a, 2b) [32]. This is the point beyond which, the system experiences irreversible states (the banking system collapses completely).



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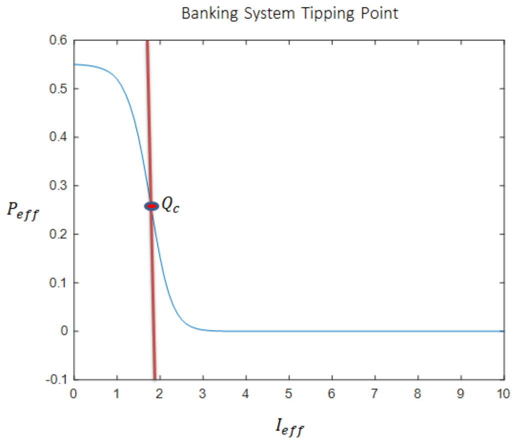


(b)

Figure 2: (a) The banking model function that shows the critical transitions of the banking system (b) The tipping point location of the banking system

The results in Figure 3a and 3b unveil the dynamic system behavior based on the empirical results. In all the banking systems, the results reveal that, first, when $p_{eff} > 0$, the banking system experiences two states (stable p_h at $\frac{\partial f}{\partial p_{eff}} < 0$ and unstable M at $\frac{\partial f}{\partial p_{eff}} > 0$).

Furthermore, the results reveal that, in all systems, the inflation upsurge enhances the collapse towards the critical transition. The tipping point location (Figure 3b) (at the intersection between the shaded area and the blue line) was varying with the period and banking system of different values of banking z-scores. This indicates that each banking system with different value of banking system z-score experiences different location in critical transitions. Second, when $p_{eff} = 0$, all banking systems were at zero stable and unstable state where the system is neither growing nor collapsing. Despite experiencing the stable state, the banking system was less resilient because of the lowest degree of the system growth rate (i.e. $p_{eff} = 0$). Finally, when $p_{eff} < 0$, the tested simulating results are unrealistic and thus, no conclusion drawn. Moreover, the results of the banking system are discussed in a three-phase period (before, during the crisis and recovery).

4.1 Before the COVID-19 pandemic (2018-2019) crisis

This was the period in which no one could predict the economic disruptions. In this period, the banking system was much more robust with high values of banking z-score. On the other hand, the inflation was not at an extreme value and thus, the critical transitions were located at high thresholds. The banking z-score much influenced this bifurcation point (critical transitions) locations. The empirical results further reveal that during this period, the global economic zone experienced the highest critical transition location of inflation with $I_c = 4.80$ followed by the China zone with $I_c = 3.22$. The Eurozone was the economic region with the smallest value of threshold location with $I_c = 0.80$.

In this period, the results confirm that, the US economic region was the most resilient zone followed by the China banking system and the Eurozone was the least resilient banking system in a sense that, for the US zone to collapse completely, needs to reach the high inflation while the Eurozone collapses completely (tipping point) at low inflation rate. Additionally, all economic regions including the global zone experience the moderate values of banking system z-score as summarized in Table A1 (Appendix A) and data based inflation which were not exceeding the thresholds, indicating the optimal banking system performance.

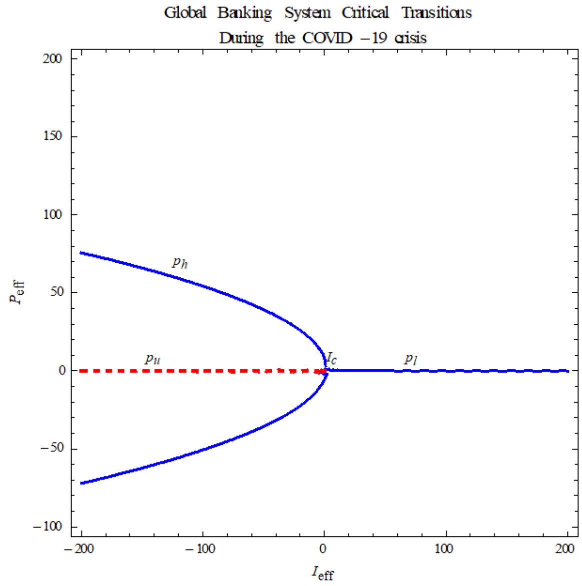
4.2 During the COVID-19 pandemic crisis (2019-2020)

This was a time-phase in which the pandemic started to prevail. The results confirm that during the COVID-19 crisis in the period of 2019-2020, the global banking system experienced the rise of inflation critical transition locations for all economic zones (summarize in Appendix Table A2). This indicates that the banking systems were improving despite the COVID-19 challenges. The results further unveil the US to continue experiencing the enormous value of threshold inflation of $I_c = 4.83$ during the crisis. This implies that, the US was the zone that continued to experience the most resilient economic region followed by China zone with $I_c = 3.49$.

4.3 Critical COVID-19 outbreak crisis (2020-2021)

This was the period where vaccination and other shock mitigations measures were carried out to curb the COVID-19 crisis. In this phase there all the economic zones went into critical shocks. The results show that, there was a decline of inflation thresholds for in a sense that, all economic zones dropped in critical transition locations. Here we see that, global zone showed the largest critical transition drop from $I_c = 2.162$ (2019-2020) to $I_c = 1.43$ (2020-2021) equivalent to 33.36% drop, followed by the Eurozone with a decline from $I_c = 2.05$ (2019-2020) to $I_c = 1.38$ (2020-2021) which was equivalent to 32.68%

The smallest banking system collapse occurred to China which experienced the drop of only 0.05% ($I_c = 3.49$ to $I_c = 3.30$). On the other hand, the system was collapsing during the critical global crisis in a view that, all the economic zones were still experiencing the rise in inflation I_{eff} .



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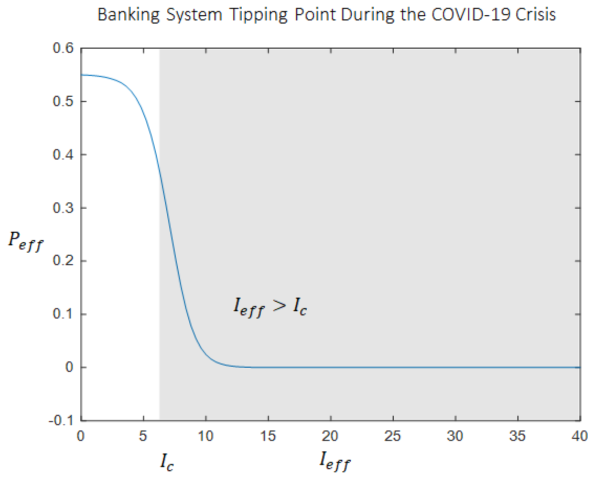
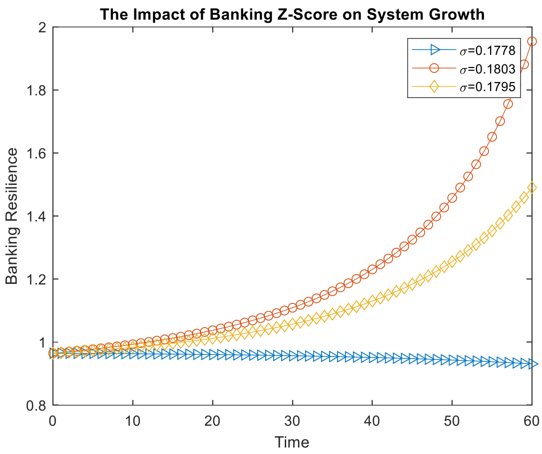


(b)

Figure 3: (a) The critical transitions of the banking system based on the data outcomes. (b) The tipping point locations of the banking system based on the data outcomes.

The results (Figure 4a-4g) show that the banking system z-score enhances the banking sector performance by lowering the inflation and improving the exponential growth of the function of the banking system. This implies that, the banking system becomes more resilient at lower inflation than at higher inflation. The simulation results further confirm that, all economic zones including the global economy were experiencing more optimal banking system performance when the inflation index was small. In all three periods of COVID-19 existence, the empirical outcomes revealed that the banking system z-score values were affected much by the COVID-19 pandemic outbreak. The results confirmed this by revealing the drop of z-scores during the critical COVID-19 crisis. The decline occurred for all economic zones as exhibited in Figure 4(a-d).

Furthermore, Global economic zone showed a tremendous rise in z-score in the period 2019-2020 that promoting the growth of banking system resilience (Figure 4a). Figure 4b reveals that Eurozone experienced chaotic behavior in two phases of the pandemic (2019-2020 and 2020-2021) and gives an early warning for the risk mitigation measures to be taken immediately before the total banking system collapse occurs. Figures 4c and 4d portray the banking system resilience of China and the US, respectively. The results confirm that despite the disruptions triggered by the COVID-19 outbreak, China and the US were resilient enough to withstand the financial perturbations in all three periods.



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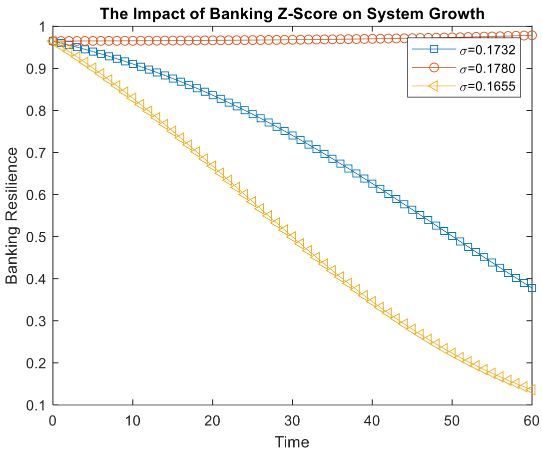

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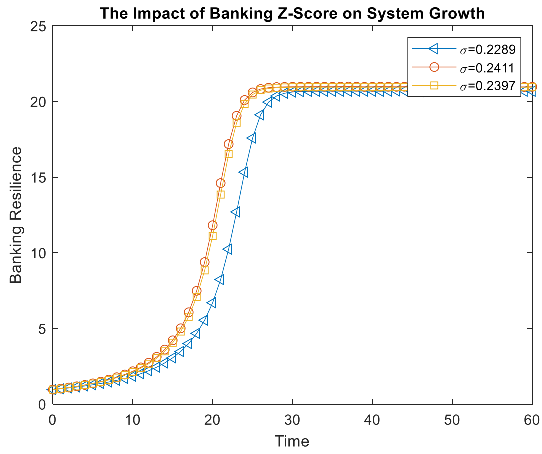

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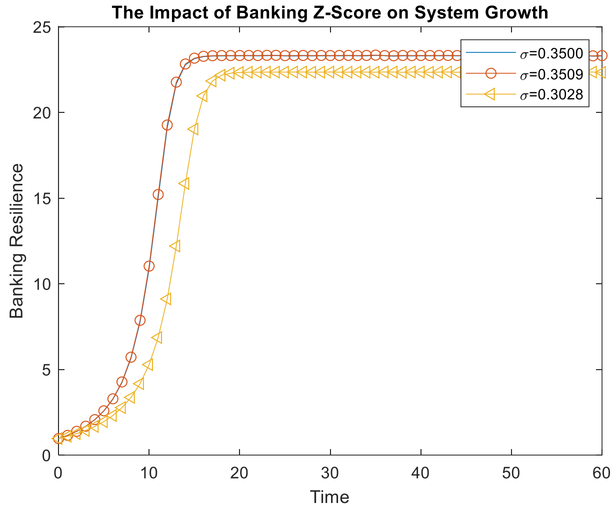

(d)

Figure 4 (a-d): The effect of banking z score on the banking system resilience in the three phase-periods (2018-2019, 2019-2020 and 2020-2021) for four economic Zone.

5. CONCLUSION

There is a significant effect of the COVID-19 outbreak crisis on the banking system critical transitions (bifurcation points). This is to say that; COVID-19 is considered as an economic risk that jeopardizes the banking system's performance by reducing its critical transition locations and dampening the exponential growth of the resilience. This work proposes a theoretical framework for examining the role of COVID-19 towards the critical transition by revealing the three-phase variation of the location in threshold values of the inflation at which the system bifurcates. Our formulated banking complex dynamic model is based on the Lotka-Volterra system theory. This methodological approach bridges the theoretical gap by investigating the variation of the inflation parameter when the system is subjected to the COVID-19 pandemic crisis using the Lotka-Volterra complex system theory. In many recent studies, researchers discussed the Lotka-Volterra network model on the ecology of plant-pollinator and prey-predator relationships [29, 31, 55, 56]. Brodie, et al. [57] pointed out the effect of COVID-19 on complex system performance (resilience) using an approach based on a review of the service ecosystem. Still, all these studies could not appeal the using of Lotka-Volterra theory in recent banking system crises. Applying the Lotka-Volterra system model theory on the, examining of the point to which the banking system bifurcates gives the study novelty. The results revealed that the system is more likely to crash when bifurcates at low critical transition locations. Moreover, we confirm that the banking system becomes more optimal at large value of the banking z-score. Small degree of z-score exerts a tremendous negative impact on the critical transition locations by lowering its inflation threshold value, thereby triggering the banking system collapse.

Our study contributes for financial ecosystems in policymaking decisions. First, from an ex-ante perspective, policy makers, economic managers and regulators can improve the stability and resilience of the banking system by controlling the degree of the inflation rise and the critical transition locations. This improvement can be achieved by promoting the value of banking z-score as carried out by China during the COVID-19 critical crisis of 2019-2020 in which stabilized from $\sigma = 22.89\%$ to $\sigma = 24.11\%$ while all of the zones were collapsing during the critical crisis (2020-2021).

This outcome will make the banking system robust and focused on withstanding the economic collapse caused by the COVID-19 pandemic crisis. This work contributes an intuitive and straightforward way to identify the inflation degree that can push the banking system towards critical transition collapse. Thus, regulators and policymakers can recommend an appropriate risk mitigation technique as a system control method. We hope that our adopted Lotka-Volterra system model approach will influence the interest of future economic and financial researchers from diverse disciplines. The theory approach includes investigating the influence of the inflation and banking system z-score on the system performance. It thus provides chance for future scholars to have a deeper insight into financial and other global economies.

Table A1: Average banking system z-score and inflation for four Economic Zones from 2018-2021

Banking System Z-Score (σ_{eff})				
	Period	2018-2019	2019-2020	2019-2020
Economic Zone				
Global		17.78	18.03	17.95
Eurozone		17.32	17.80	16.55
China		22.89	24.11	23.97
The US		35.00	35.09	30.28
Inflation (I_{eff})				
	Period	2018-2019	2019-2020	2019-2020
Economic Zone				
Global		3.91	4.82	7.68
Eurozone		2.58	-0.23	1.43
China		1.00	2.40	2.90
The US		2.40	1.20	1.80

Source: *Author computation*

Table A2: Threshold values of inflation for four economic zones from 2018-2021

Appendix A: Threshold Values

Bank-Cost (I_c)				
	Period	2018-2019	2019-2020	2019-2020
Economic Zone				
Global		0.80	2.16	1.43
Eurozone		0.80	2.05	1.38
China		3.22	3.49	3.30
The US		4.80	4.83	3.98

Source: *MATHEMATICA Simulation*

Appendix B

- **Model Reduction**

Taking Equation (7), our derivation process is based on the assumption that the carrying capacity K_i for all seller-nodes $i = 1, 2...n$ has an identical value: $K_i \cong K_{eff}$ which is similar to, $D_i \cong D_{eff}$ and $\beta_{ij} \cong \beta_{eff}$. The basic idea of dimension reduction is to feature the banking network's architectures by determining an effective dynamical parameter [58, 59]. This calculation can be achieved by having an approximate manipulation as

$\sigma_i p_i \cong \sigma_{eff} p_{eff}$, $\alpha_i p_i \cong \alpha_{eff} p_{eff}$, $I_i s_i \cong I_{eff} s_{eff}$ and $h_i p_i \cong h_{eff} p_{eff}$ where p_{eff} is the effective growth rate of the banking sector return (bank resilience). By combining all these reduced terms, the Equation (6) becomes an effective Equation (7).

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