Effect of Capital Level Requirements on Effectiveness of Banking Contagion Containment

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Abstract:

In the world’s increasingly complex and interconnected financial systems, policy makers question the ways default contagions spread or are contained, and the effectiveness of tools used to control such behavior. One such tool is the capital level requirements, a capital buffer requirement set by governments upon banks to limit individual and thus systemic risk in short term crisis situations. This papers experiments with the effects of this policy tool upon contagion spread using an extension of a model by Blake LeBaron, which was based upon Gai and Kapadia’s work with banking networks. The results of this experiment were that there exists a significant negative linear relationship between capital level requirements and welfare defaulted due to contagion spread, and a significant positive nonlinear relationship between the size of the initial shock to the system and welfare defaulted due to contagion spread.

Introduction and Literature Review:

In modern financial systems, financial institutions increasingly form a complex web of interdependencies, of asset claims and obligations. In their paper on Contagions in financial networks—which motivated this paper, Prasanna Gai and Sujit Kapeda wrote, “these interdependencies have created an environment for feedback elements to generate amplified responses to shocks to the financial system.”[1] In essence, in becoming more interconnected, banking networks present a number of conundrums in the face of policy makers seeking to prevent disaster; risk may be decreased on some level, but “...the effects can be extremely widespread when problems occur:” a frightening concern.[2] Indeed, as said by a study commissioned by the FCIC, “An important lesson to draw from the recent financial crisis is that a key criterion for judging the effectiveness of the reforms is how they deal with the interconnectedness of financial institutions and markets within and across national borders.”[3] Gai and Kapadia’s work complexly models this interconnectedness and the behavior of contagion as reflected by dynamically defaulting claims and obligations in the system. They conclude that “seemingly indistinguishable shocks can have very different consequences for the financial system depending on whether or not the shock hits at a particular pressure point in the network structure” and more importantly that “...a high number of financial linkages also increases the potential for contagion to spread more widely.” Therefore, growing interconnectedness in banking networks is dangerous and an important consideration for policy makers because not only is past robustness not a valid indicator of future robustness—making

[1] 3 Gai, Prasanna, and Sujit Kapadia. "Contagion in Financial Networks."
[2] 4 Ibid.
[3] 17 Kroszner, R. (2010). Interconnectedness, Fragility and the Financial Crisis.

crises unpredictable, but that even in decreasing risk of contagion at any point, high connectivity dramatically worsens contagions when they *do* manage to spread.

Now that financial network interconnectivity has been modelled and shown to be a dangerous and unpredictable extrapolator of contagion risk, the issue then arises about *how to best prevent widespread contagion*. Raising capital level requirement is a common answer, alongside other capital surcharge-inducing measures, such as the liquidity coverage ratio.

The effects of changing capital requirements is contested. In a paper on bank sizes and systemic risk, it is argued that "Requiring large banks to hold more capital is a powerful tool to reduce systemic risk. Higher capital reduces the likelihood of bank failure and the impact of the bank's failure on the rest of the financial system and the broader economy."[4] However, meanwhile, it is argued by Randall Kroszner in the aforementioned FCIC study, that directly attacking larger institutions "Would likely result in greater fragmentation of the financial system, with the likely consequence of increasing rather than decreasing interconnectedness of banking institutions funding sources to other financial institutions and markets. Pushing risk-taking activities just outside of the commercial banking system could have the unintended consequence of making the entire system more, rather than less, fragile."[5] Further, he follows this with a critique of the effectiveness of high capital requirements in general, stating: "High capital requirements on banks or other classes of financial institutions... can lead to strong incentives for getting around them… After all, regulatory burden and high capital requirements are part of the reasons that finance moved to the long and increasingly complex intermediation chains."[6] Capital level

[4] 20 Laeven, Luc et al. (2014). Bank Size and Systemic Risk.
[5] 16 Kroszner, R. (2010). Interconnectedness, Fragility and the Financial Crisis.
[6] 16 Ibid.

requirements are generally advocated, according to Laeven et al, by "policymakers and academics alike," but Kroszner seems unsure.

This paper seeks to expand upon this debate by examining the effects of varying capital level requirements on the welfare loss induced by varying sizes of shocks to the network model.

Model Description:

Purpose:

The purpose of our extended model is to add to the original contagion model's capacity to simulate bank contagion in the real world through the expansion of the buffer capital concept. Although the initial model designed by Blake LeBaron, based upon Gai and Kapadia's work, provides a strong foundation for bank contagion analysis, it falls short in this area. The capital buffer, in Gai and Kapadia's model, is "a random variable… between the book value of [a bank's] assets and liabilities," which does not reflect the actuality of buffer capital.[7] Furthermore, LeBaron's implementation hardcoded this buffer simply as a 40% without justification.[8] These buffers' real life equivalents are government mandated values, not random variables calculated partially by the "difference between assets and liabilities," but rather measured separately as liquidity coverage ratios and capital requirements, affecting risk in different ways depending on bank size, claims, and obligations.[9] Distinguishing and parameterizing these elements is crucial to understanding and distinguishing the effects of capital buffers on the intensity of network contagions.

Entities and State Variables:

[7] 12 Gai, Prasanna, and Sujit Kapadia. "Contagion in Financial Networks."
[8] LeBaron, Blake. "Gai and Kapadia (2010)."
[9] 9 Erol, S., & Ordonez, G. (2017). Network Reactions to Banking Regulations.
28 Laeven, Luc et al. (2014). Bank Size and Systemic Risk.

What kinds of entities are in the model?

Banks

Interbank-assets : Float

illiquid-assets : Float

interbank-liabilities : Float

deposits : Float

bank-size : Int

default-closeness : Float

calculated-required-capital : Float

calculated-required-liquidityCoverage : Float

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V

Links

Weight : Float

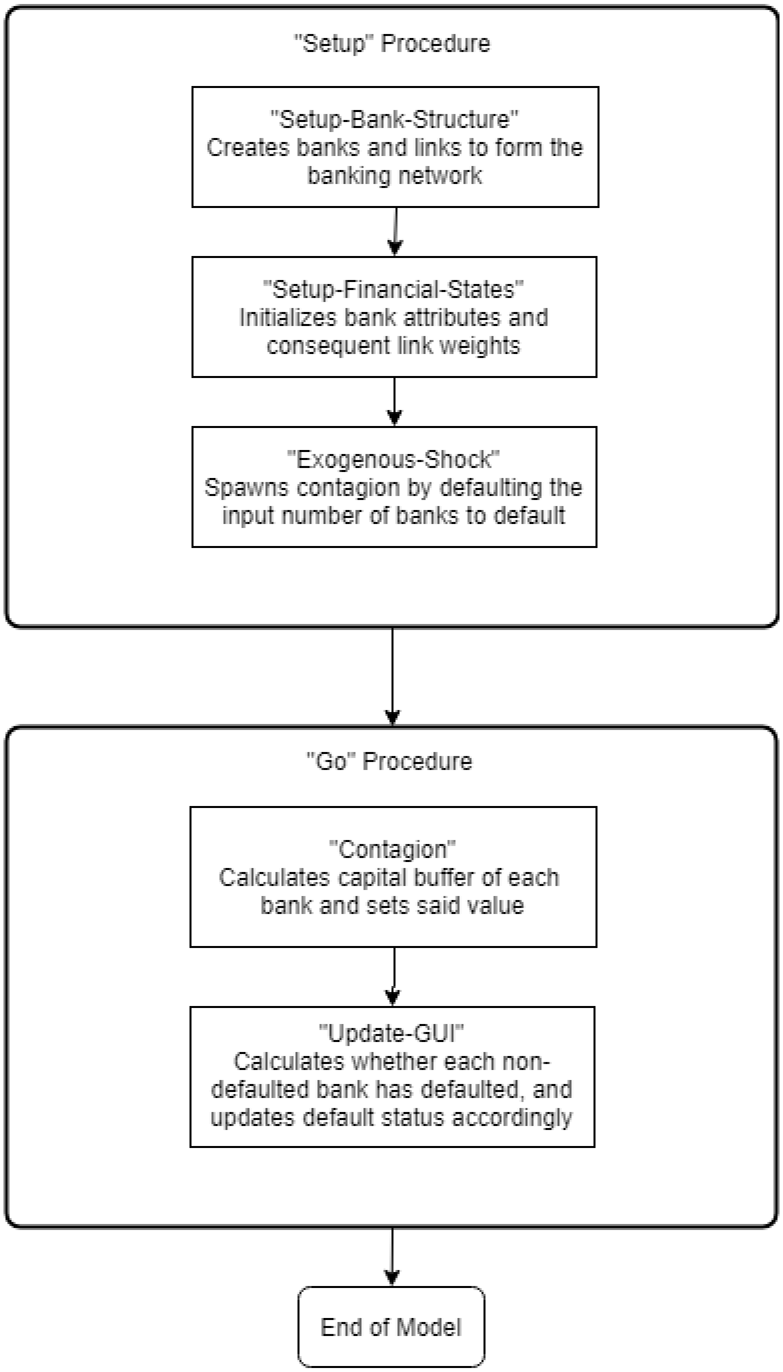
The original model as well as our own consists of agents, links between those agents, and the global environment. The agents, delineated as "banks" in our model, are the most complex entities within the model. Their attributes are described in our model as follows: interbank-assets are the amount of assets each bank holds in different banks; illiquid-assets are the amount of non-short term assets each bank holds from different banks; deposits are the amount of consumer claims that banks hold; bank-size is a normally distributed value for each bank that determines the amount of assets the bank has total between all its links; default-closeness pertains to the visualization of the banks; calculated-required-capital is the amount of capital a bank must have accessible as determined by the capital level requirements; and the calculated-required-liquidityCoverage is the amount of liquid assets a bank must have accessible as determined by the liquidity coverage ratio. Deposits and liabilities increase the likelihood of default, while total assets and calculated capital buffers decreases the likelihood of default.

The second entity type, links, are the manifestations of asset claims and liabilities between banks, existing only in connection between two banks; they have only one attribute, weight, which pertains to the amount of assets flowing through said connection. Specifically, weight consists of the the percentage of assets that is connected from one bank to another in one direction, hence the arrow visualization of this connection in the diagram above. Links are crucial for the spreading of bank defaults and are the main force behind whether banks actually default or not, as a defaulting bank defaults the links representing its obligations. These entities remain unchanged from the original model.

Finally, the global environment is composed of numerous reporters of information about the model pre and post-contagion, as well as the variables that initiate the agent attributes, such as the capital level requirements, liquidity coverage ratio, number of banks in the network, initial level of connectivity, and number of banks defaulted in the initial shock.

Process Overview and Scheduling:

Who does what, and in what order?



The setup procedure creates and then initializes the agents, links, and relevant globals at the start of the program, followed by an initialization of the contagion. The latter of these is a function named "exogenous-shock" that sets a number of random banks and their connections red, signifying default.

Within the subsequent “go” procedure, the capital buffers are calculated for each bank in another procedure called “contagion.” Once every bank’s capital buffer is calculated, the “go” procedure calls an “update-gui” procedure that asynchronously updates all of the agents’ and their links’ default status as defaulted or not, signified by the color red, as opposed to the starting blue. It is a simple two period model, and the model thusly ends here, with the “go” procedure updating post-contagion reporters (those that are represented as global variables) for analysis.

How is time modeled, as discrete steps or as a continuum over which both continuous processes and discrete events can occur?

Time in this two-period model is modelled as a 30-day period, as that is the time the federal reserve defines as the stress period that defines liquidity. Specifically, the federal reserve states that the “Assumed stress horizon over which outflows occur [is] a 30-day window and is intended to capture risks on both the asset and liability sides of a bank’s balance sheet.[10] For this reason, we defined the model as a two-period model intending to represent one 30-day stress period in post of an exogenous shock, to measure the capital buffers as they are defined by the federal reserve, who sets those values in the United States.

Design Concepts

The basic principle addressed by this model is the way a contagious symptom in a network makes its way around that network. In addition, this model simulates different ways agents in networks can better protect themselves against the spread of the contagion. This is modeled by the spread of default from bank to bank travelling through channels of connections: links. Bank

[10] 7 Macchiavelli, M., & Pettit, L. (2018). Liquidity Regulation and Financial Intermediaries.

attributes and interbank connections dictate the strength of each bank's financial status and therefore its likelihood of default.

Experimental Design:

Research Question:

What is the effect of varying the capital level requirements of banks within a network on the effectiveness of that network in containing contagions? How does varying the initial size of the contagion map to this effect? My hypothesis is that there is a *negative quadratic* relationship between the capital reserve requirement and the percent welfare defaulted due to the contagion, while there is a *positive linear* relationship between the number of banks defaulted in the shock and the percent welfare defaulted due to the contagion. My logic is that the effect of raising capital level requirements will quickly reach a stable high percentage chance of contagion containment, gradually flattening out the curve, while the effect of adding initially defaulted banks will have a linear relationship with welfare defaulted, because each additionally bank initially defaulted, on average, defaults the same additional percentage of welfare, hence an additive effect on contagion spread.

Model Name and Attribution:

This model was made by Alex Mead, Brendan Sakosits, and Elissa Cohen. The name of our model is **banking01**, and is largely based upon the model **NetworksV1.2** by Axel Szmulewiez, Blake LeBaron,[11] which itself is based upon a paper by Gai and Kapadia.[12] All code that is and is not ours is commented appropriately within the model.

Baseline Scenario:

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[11] LeBaron, Blake. "Gai and Kapadia (2010)."
[12] Gai, Prasanna, and Sujit Kapadia. "Contagion in Financial Networks."

Parameter	Type	Baseline Value
Number of Banks	Integer	100
Number of Banks Defaulting from Exogenous Shock	Integer	1
Liquidity Coverage Ratio	Float	0
Capital Level Requirements	Float	0
Percentage of Banks Linked	Float	30
Percent of Assets Illiquid	Float	80
Mu	Float	1
Sigma	Float	$\frac{1}{2}$

[13]

There are no unlisted exogenous constants.

<u>Treatment Table:</u>

The value ranges for the parameters varied by the experiment are below, with the first, last, and step values formatted in accordance with the syntax of the "range()" python function, for ease.

Parameters Varied	First Value	Last Value	Step Value
Number of Banks Defaulting from Exogenous Shock	*1*	*20*	*1*
Capital Level Requirements	*0.00*	*0.10*	*0.01*

My justification for measuring 1-20 initial defaults stems from centering the number about the rough location of the baseline for the model this model is based upon, which was 1/12th of total banks. Due to the 100 bank baseline, I took the liberty of rounding this to 1/10th for simplicity. My justification for going to 10% capital level requirement is the current US Federal Reserve's reserve requirements for American banks, which ranges from 0% to 10%.[14]

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[13] Diagram of Baseline Parameterization by Elissa Cohen.
[14] "Policy Tools: Reserve Requirements." Board of Governors of the Federal Reserve System.

<u>Number of Replicates:</u>

Seeing as there will be plenty of variability arising from the compounding of the two variables, there being 20 different outcomes per reserve requirement level (totalling 220 scenarios), the number of replicates need not be very large. Because it is a non-intensive two-period model, number of replicates also need not be small. I settled on 20 replicates—leading to 4400 points of data—as sufficient for in-depth analysis while still keeping the runtime of the experiment low.

<u>Replicability:</u>

Each run will have a seed connected to the BehaviorSpace run number to ensure replicability. Each run stops automatically after one iteration; the model is a two-period model.

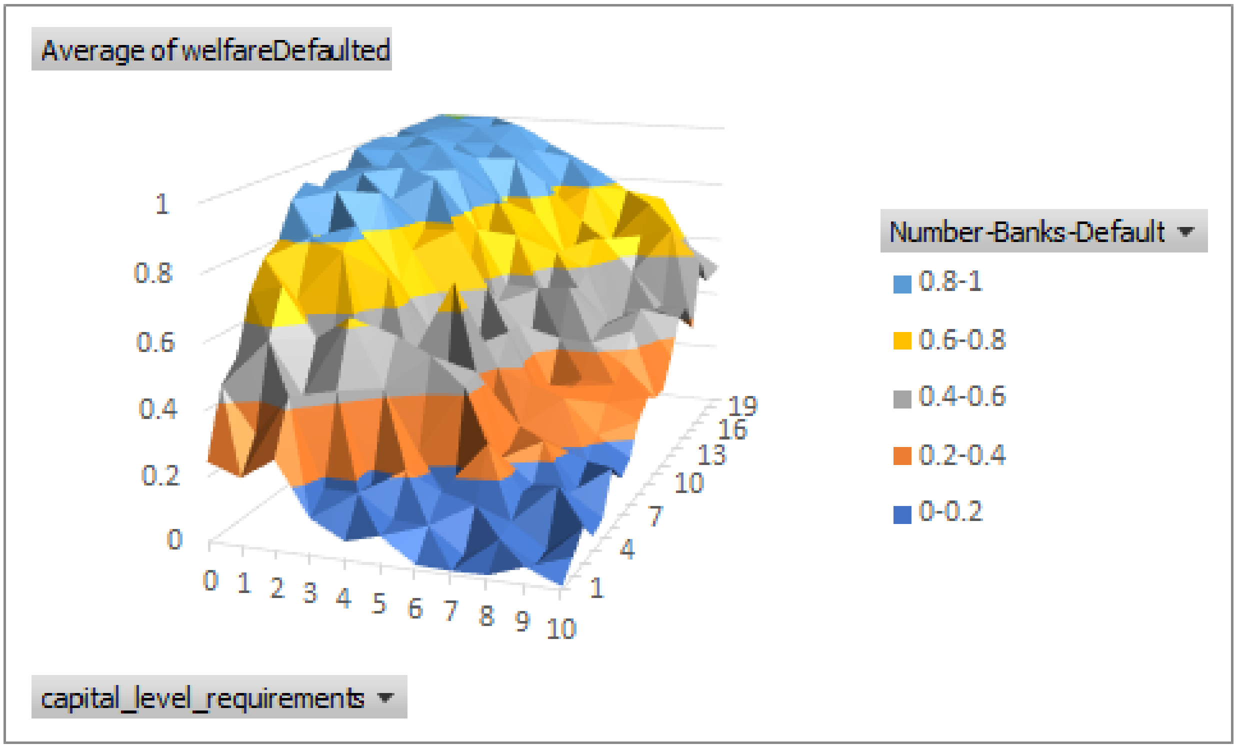
<u>Outcome Measures:</u>

To measure the "effectiveness of the network in containing contagions," the BehaviorSpace experiment will export the "Percent Welfare Defaulted" at the end of the exogenous shock and just before the stopping condition of each scenario. This reporter essentially measures the change in defaulted assets from the beginning of the contagion to the end of the run. Specifically, the "Percent Welfare Defaulted" output is computed by measuring the total network assets defaulted upon divided by the total initial network assets. Seeing as this is directly impacted by defaulting banks and systemic failure resulting from contagion, all hypotheses can be measured with this single output.

<u>Data Analysis Tools and Methods:</u>

BehaviorSpace will export the data to an excel spreadsheet, where the tools of analysis will be a surface plot showing the connection between variance in "Capital level requirements" and variance in "Number of banks defaulting from exogenous shock," as well as an excel-computed regression of the variables and their squares in order to check for linear and quadratic relationships and their strengths.

Results:



The generated surface plot clearly shows a negative relationship between increases in the capital requirements and the average welfare lost due to contagion, while showing a positive relationship between increases in the number of bank initially defaulted and the average welfare lost due to contagion.

SUMMARY OUTPUT								
Regression Statistics								
Multiple R	0.672006227							
R Square	0.451592369							
Adjusted R Squ	0.451093249							
Standard Error	0.314146593							
Observations	4400							
ANOVA								
	df	*SS*	*MS*	*F*	*Significance F*			
Regression	4	357.1631901	89.29079753	904.7779182	0			
Residual	4395	433.7341211	0.098688082					
Total	4399	790.8973112						
	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0.375388776	0.019211099	19.54020359	1.32584E-81	0.337725343	0.41305221	0.337725343	0.41305221
Number-Bank:	0.068352619	0.003455832	19.77892024	1.75491E-83	0.061577448	0.075127791	0.061577448	0.075127791
capital_level_ı	-0.06680381	0.005567601	-11.9986699	1.16323E-32	-0.07771911	-0.0558885	-0.07771911	-0.0558885
sq_Number-Ba	-0.00153023	0.000159848	-9.57298034	1.681E-21	-0.00184361	-0.00121684	-0.00184361	-0.00121684
sq_capital_lev	0.000725403	0.000536239	1.352758954	0.176202236	-0.0003259	0.001776702	-0.0003259	0.001776702

The generated regression shows high significance for these positive and negative relationships, as well as a statistical significance of the square of the initial number of banks defaulted variable, indicating the presence of a quadratic relationship. The coefficients stand to indicate that a 1 unit increase in number of initially defaulted banks will lead to an average estimated 7% increase in welfare lost due to contagion and that a 1 unit increase in capital level requirements (a 1% increase) will lead to an average estimated 7% decrease in the same. The square of the capital level requirements variable had an insignificant coefficient, and so he null hypothesis that the relationship is not quadratic could not be falsified.

Conclusion:

The direction of the relationships between both the number of initially defaulted banks and the capital level requirements and the welfare lost to contagion were hypothesized correctly as positive and negative, respectively. This stands in line with the vast majority of the literature and logic on the subject, with specifically the significance of the effect of the capital level requirements on welfare loss—indicating contagion spread—adding valuably in academic support of such as a policy tool. My most poignant hypotheses, however, failed to be verified or were falsified, respectively. The capital level requirement could not be shown to have a quadratic relationship in this model, while the number of banks defaulted did in fact have a quadratic relationship with the welfare lost due to contagion spread. The root of this flip of projected shapes of the relationships of these variables is simply that I overestimated the effect of capital level requirements as likely bottoming out earlier than they did, and that the added connectivity of one more defaulted bank to the initial shock of a contagion has a more complex than just additive relationship to the decrease in likelihood of that contagion being contained.

Moving forward, it would be interesting to explore this relationship further, looking for what drives the nonlinearity of the relationships between size of initial shock to network and welfare lost due to contagion. More advanced regressions and examinations of specific banks and connectivities would be valuable here. Another extension of this model would clearly be to measure the other capital buffer: the liquidity coverage ratio. This would be a simple addition and would extend conclusions to the effects of variance in the liquidity coverage ratio on contagion spread in the 30 day stress period the model simulates. Finally, the model could be modified temporally to show contagion spread and containment past the initial liquidity crisis period, when banks and governments have time to react. While this significantly increase in complexity would constitute a lot of work, it would pay off in its ability to map the change of contagions over time given different constraints and controls—something this model does not do.

Overall, there is much more work to be done before one could ever declare capital level requirements or other capital buffers as any sort of panacea to banking contagions, and this paper, above all else, shows that they also at least cannot be discounted in such discussions.

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