Modeling and Analysis of Contagion Dynamics and Bank Risk Management using System Dynamics

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Abstract - Over the last nine years or so, different parts of the world have suffered from a host of seemingly unending financial and economic trials and tribulations, and political upheaval, the after-effects of the global financial crisis (the “Long” or “Great Recession”) that officially started in September 2008 and lasted less than a couple of years. Using system dynamics and discrete event simulation approaches, we seek to model and analyze how the interconnectedness (on the assets and liabilities sides of their balance sheets) between banks in a financial network, and between financial networks in turn, can result in a failure of a single bank triggering other defaults and spreading as a contagion through the global financial networks, generating cascades of defaults.

Keywords - bank risk, financial contagion, default cascades, housing, interest rates, rating agencies

1. INTRODUCTION

Warning about “…‘tipping points’, ‘thresholds and breakpoints’, ‘regime shifts’…all…terms that describe the flip of a complex dynamical system from one state to another” (e.g., the Wall Street Crash of 1929 and the Great Depression), and which make “…increasingly complicated and globally interlinked financial markets …no less immune to…system-wide (systemic) threats,” three biologists, May, Levin and Sugihara (May, et al., 2008), had asked very presciently, “Who knows, for instance, how the present concern over sub-prime loans will pan out?” in early 2008. Nearly nine years and a whole host of seemingly unending financial and economic trials and tribulations later, all we can truly say in response is that while the global markets have supposedly recovered from the recession, we still do not know for sure how long the after-effects of the global financial crisis (the “Long” or “Great Recession,” henceforth, the LoGR) will really last.

Most analysts see the LoGR as having had its genesis in:

- the massive global credit expansion that has taken place over the last three decades or so, and especially after 2001 when Alan Greenspan, the chairman of the board of governors of the US Federal Reserve, launched a low interest rate regime during George W. Bush’s first term as the President of the US, in order to re-inflate the economy that had been sent into a tailspin by the dot.com crash;
- the role of securitization which enabled banks to move illiquid assets, or groups of illiquid assets, off their balance sheets by transforming and combining them into securities through financial engineering, e.g., a mortgage-backed security (MBS), a type of asset-backed security secured by a collection of mortgage;
- the “liar’s loans,” or “no-docs” loans, that were written by mortgage firms to meet the demand for them by individuals and institutions whose only purpose was to securitize and sell
- subprime mortgage products based on these questionable loans, designed to fail (and yet provided attractive enough ratings by the three ratings agencies, namely, Fitch, Standard and Poor’s and Moody’s, so as to find buyers somewhere, somehow -- this is why some analysts would like to hold the ratings agencies as chiefly responsible for precipitating the crisis), and then make a fortune betting against them;
- the very significant increase in leverage or the amount of debt taken on by the banks and financial institutions relative to their equity or “capital” stocks;
- the moral hazard and potentially disastrous consequences associated with the manner in which banks, and especially the larger, more global players – secure in the tacit understanding that they would be bailed out by the taxpayers if they “blew” themselves up and hence more inclined to take on far more risks than they could have been expected to bear – managed to parlay the gains in leverage, that was mentioned above, into continued growth beyond sustainable limits, till they became “too big to fail” or TBTF. In hindsight, it is now obvious that as these massively overleveraged financial institutions had, over the last three decades or more and especially over the first seven years of this century, become increasingly reckless, rather than merely less-than-prudent, in their drive to become big enough to be deemed TBTF, they not only threatened their own continued existence but also ensured that their self-destruction would ruin not only their own balance sheets but also those of the countries that had “backstopped” them by guaranteeing their sovereign debts.

Figure 1 below depicts how a combination of causes came together in a super-additive way to unleash a “perfect” financial storm, an “ice-age”-type freezing of global trade and financial flows, and in turn a recession that all but threatened to become a full-blown depression. Some of these had their roots in the poorly governed financial sector, others with roots in the cyclical residential and commercial real estate sector, yet others that were related to the inability of a significant number of manufacturers and service providers in the US and Europe to
withstand the winds of globalization that were blowing in from Asia, for instance, and lastly, a few that stemmed from the simmering discontent that was brewing for a while in the Middle East and North Africa on the one hand, as well as in the “periphery” rather than the “core” of the European Union, on the other hand.

Many like the writer Nessim Taleb see rare “black swan” events (with fat tailed probability distributions) as the causes of bank failures. We, on the other hand, see a system that is finely tuned and usually in balance but not robust or resilient enough to absorb the shocks from one or more minor events that can then propagate throughout the system, and hence prone to being subject to upheavals and boom-bust cyclicality as a result. In what follows, we will try to make the case that the interaction between households, the private sector comprising of financial and nonfinancial players and the government and other public sector entities, in general, leads to macro-economic growth spurts and slowdowns. More specifically, we focus on the role of the various players in the construction industry or the housing sector in triggering off the boom-bust cyclicality over time.

2. DEMOGRAPHICS, DEBT, DEFICITS & FINANCIAL DISASTERS
To provide deeper insights into the impact of the cyclical ups and downs, i.e., the boom and bust cycles, of the real estate sector on the macro-economy, consider the following extension of the analysis of demographic factors offered by Kini and Melnikov (2016), comprising of various players in the macro-economy (primarily, the household sector, the private sector and the government, including public sector entities), in which they play a number of different roles, with a number of macroeconomic linkages between them, as depicted in Figure 2 below.

2A: The Household Sector: The ordinary men and women (and their dependents, viz., their young children and retired parents, etc.) in the household sector play a number of roles simultaneously, as:

- parents of families or procreators (mothers and fathers) and as heads of households who earn either by working as employees in the private or public sector or as landlords or members of the producer class, and thus look after the procreated (their children) as well as other dependents (e.g., their own parents); here the two halves (male and female) of the nation’s population pyramid depicted in Figure 3, the age-groups or cohorts, and the segments who are either of working age or too young -- or too old -- and hence dependent on their parents or children, change dynamically over time, through aging itself, the net accretion process (the net effect of the birth and death rates, as well as the net effect of the immigration and emigration processes);
- participants in the labor force who are of working age:
  - (i) who provide their labor inputs to: the private sector producers; the capitalists; the financial institutions; the government and public sector employers; as well as landlords;
  - (ii) who, in return, get paid wages and salaries;
  - (iii) who spend part of what they earn on goods and services provided by the other macroeconomic players;
  - (iv) who pay direct and/or indirect taxes to, or are provided subsidies by, the government;
  - (v) who save the remainder of their wages and salaries, which they could:
    - deposit in their accounts with one or more of those financial institutions and get paid interest in return,
    - invest in real estate (this could entail occupying a home they partly or wholly own, in which case they would save on the rent that they would otherwise have to pay to some landlord, or buying additional properties, which could elevate them to the rent-seeking landlord class),
    - or invest in the stocks, shares and bonds issued by the private sector producers, the capitalists, the financial institutions and the partially privatized public sector

Figure 1: The Origins of the Financial/Economic Crisis and its After-effects (Adapted from HBS source http://siteresources.worldbank.org/EXTPREMNET/Resources/489960-1338997241035/Growth_Commission_Workshops_Financial_Crisis_Impact_Frankel_Presentation.pdf)
entities, some or all of who pay dividends to their shareholders and interest to their bondholders; and
(vi) who may borrow money over the short-, medium- and long-term from banks and other financial institutions to cover their credit card payments, their university tuition fees, their mortgage payments, and so on, and who would very likely pay the principal back and the interest due to their creditors over time;

- consumers of the various goods and services provided by the other players in the macroeconomy;
- tax-paying, voting citizens, members of various "publics" and as stakeholders as far as the government and the other players are concerned;
- rent-payers, savers, investors and borrowers as mentioned above; and
- perhaps, as members of the producer- or capitalist- class (if they launch and grow their own companies), or as rent-seeking landlords, if they have invested in real estate, or as elected or un-elected members of the legislative/parliamentary bodies, government ministries and agencies, and so on.

We should note that demographic effects are primary economic growth and development drivers in a number of different ways:

(i) marriage rates (new family “starts” in turn drive housing “starts” over time, if not immediately), birth and death rates and aging population dynamics (through a combination of the birth and death processes and immigration and emigration processes, some countries grow and are relatively young in terms of the average age of their populations, e.g., India and Iran, while others shrink and age rapidly, e.g., Japan and Germany);

(ii) workforce participation rates (i.e., the fractions of the males and females in the population who are of working age, say in the 15 to 65 age group, and that are actually gainfully employed in productive activities);

(iii) the family-related workforce dropout and reentry rates (these are much less critical for males than for females, who in the child bearing age group may drop out of the workforce to bear and raise children – this could be temporary, if the mothers return to the workforce when their children have reached an age where they can be looked after by child care providers, or be admitted to nursery and then primary school – or permanent, as in the case of Japan, where mothers seldom return to the workforce even after their children go to school, attributable perhaps to the some-what patriarchal and chauvinistic attitudes adopted by their male colleagues and by employers in general);

(iv) the unemployment-related workforce dropout and reentry rates (given that male workforce participation rates fell during the LoGR, and did not recover long after, unlike in the case of the rates for females, especially where young males were disproportionately employed in sectors hardest hit by the recession, e.g., construction, mining, etc., the effect of unemployment has to be taken into account since discretionary and non discretionary expenditures by the household sector and investments of savings in bank deposits, stock and commodity markets, or in real estate, education, and so on, which are vital drivers of growth in the macro economy, would be either severely curtailed or even missing pieces of the puzzle in the case of unemployment);

(v) aging and retirement (since retirees are generally no longer in the workforce and draw down, rather than build up, their savings to cover their living and medical costs, its is vital that safety nets, Social Security and other pension schemes remain viable for the foreseeable future – these could be traditional PAYG, or Pay As You Go, defined benefits-type or the defined contribution-type schemes that are being increasingly used more recently, especially during the transition from the former to the latter); for instance.

2B: The Financial and Non-Financial Sectors:

While the non-financial sector serves to mostly employ the people in the household sector and to produce the goods and services which individual consumers and other private and public sector customers consume in general, the construction industry has a central role to play in making the global financial system more vulnerable, as we argue below. While the financial sector comprises of the banks, pension funds, VCs, etc., act as financial intermediaries who channel funds from savers to borrowers, our analysis is specifically centered around the financial sector’s exposure to both commercial and residential real estate markets, which are affected by different business drivers, and this also affects the risks associated with those

Figure 2: The Role of Ordinary Male and Female Citizens and their Dependents in the Macro-Economy. (Adapted from the figure provided in Wikipedia, the free encyclopedia: https://en.wikipedia.org/wiki/Macroeconomic_model)
loans. People in the household sector who are gainfully employed by private or public sector firms earn, bear the usual household expenditures (rent, food and sustenance, travel, interest on automobile and personal loans, etc.), save what is left after spending, and invest these savings in bank deposits, equity markets, i.e., shares of companies through IPOs, FPOs, and secondary markets, and also in bond and commodity markets. While they also borrow to cover personal debt and for credit card payments, education loans, and so on, we focus only on the impact of real estate mortgages on the financial system.

We note that there is a built-in asymmetry vis-à-vis real estate boom-bust cycles, in that the appreciation in value during the boom portion of the cycle accrues to the borrower as a capital gain (while the bank's valuation is capped off at the level of the loan principal plus unpaid interest if any), but the drop in value during the bust portion of the cycle, which should normally have been absorbed by the borrower as a capital loss, may have to be borne by the banks in case the borrower were to choose to abandon the underwater mortgage1 (leaving the bank to absorb the difference between the yet to be paid portion of the loan principal plus unpaid interest if any, and the value of the asset on its books, as "marked to market," as a capital loss and this could escalate as more underwater mortgages get surrendered). This serves to attenuate or limit the banks' share of the real estate valuation gains during the boom period and amplify the losses that accrue to the banks during the downturns in the real estate markets.

Changes in the residential real estate stock and the related loan portfolio would depend on: (i) the # of new housing starts, and so on, which would depend on the population, its growth rate (net effects of birth and death, immigration and emigration), and its distribution; (ii) sales of older units on the secondary market (this in turn would depend on sales by the owners or the banks in case of repossessed dwelling units); (iii) the fraction of the units at the rental versus ownership ends of the spectrum and the fraction of loans by borrowers who borrow to buy, own and occupy and those who borrow to buy, own and rent out to others; and (iv) the interaction between these market segments (for instance, if more people rent, then the demand for housing units on an ownership basis would be lower, and vice versa).

2C: Government and the Public Sector: The government earns revenues (through the taxes it collects, including indirect taxes such as sales taxes, VAT, excise and duties, and direct taxes such as individual and corporate income taxes, wealth taxes and estate duties, etc.), spends, borrows (through treasury bills and "munis"), invests, and so on, just like any other player in the financial system. More importantly, it has a critical regulatory oversight role and it controls the macro-economic framework through its fiscal and monetary policies (e.g., setting tax rates and controlling money supply which in turn affects inflation, setting of interest rates which affects the ability of households and corporations to borrow money and service existing debt, etc.) and its budgetary exercises (since most governments rarely enjoy surpluses, government deficits have to be financed and these attempts by the government to borrow in the markets tends to crowd out private sector borrowers). Governments, along with the public sector entities, are also employers who provide salaries and wages to a significant fraction of the workforce (who spend, borrow and repay, save and invest, etc., just like private sector employees) and also consumers and customers for goods and services offered by other public sector enterprises and private sector corporations. For traditional defined benefits-type pension schemes, governments also honor an intergenerational compact, by financing the pensions and Social Security payouts to retirees as well as their medical expenses through taxes levied on current working group adults (as mentioned earlier, aging populations which are also shrinking like Japan's lead to much higher dependency ratios and excessive government debt levels).

Additionally, since exports and imports determine the current account balance and in turn the foreign exchange conversion rates between any country's currency and internationally traded currencies such as the USD, the Euro, the British pound, the Japanese yen, and increasingly the Chinese yuan, governments and central banks pay substantial attention to exchange rates and act decisively to prevent steep declines (which may make exports more competitive but also end up impoverishing their citizens) or steep gains (which can make exports less competitive and domestic producers incapable of fighting off cheaper imports) in their respective currencies.

These are vital monitoring and control measures as far as the economy is concerned. Take interest rates, for example: when the economy is struggling to overcome factors that tend to depress the economy, low interest rates can be used (as Alan Greenspan did in the wake of the dot.com bust) to jump start the recovery or "unleash" the animal spirits, and when real estate prices have reached unaffordable levels and asset bubbles seem to be forming, then high interest rates can be used to keep "irrational exuberance" in check (Alan Greenspan was also held responsible for the housing asset bubble that led to the LoGR because he did not act soon enough to raise interest rates and deflate the asset bubbles that were forming before they reached dangerous proportions).

Governments also enter into treaties that bind successive governments to act in certain ways that citizens may or may not find conducive to their welfare. If, for instance, several sovereign countries in a region wish to form a union, they have different routes to one: (i) a political union, which would entail complete loss of sovereignty for the members (a worthy goal but not one that can be achieved easily except through a long drawn out process of mutual adjustments and compromises made by equal partners); and watered down versions such as: (ii) a banking union (where the banks are subject to the same set of rules and oversight by a common regulator – perhaps, with the benefit of hindsight, Europe should have started with this as first step); (iii) a fiscal union and monetary (in which an elected

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1 In some countries, laws relating to full recourse prevent borrowers from walking away from real estate deals that are currently under water and leaving the lenders to absorb any capital losses -- they can proceed against borrowers and guarantors to recover any difference between the loan amount on the books (principal plus unpaid interest) and the current valuation of the asset as marked to its market price.
parliament and other bureaucratic entities, such as a central bank for instance, would control most of the decisions that would have otherwise been made by sovereign countries, including money supply and interest rates, taxation and outlays and all the other aspects of the budgetary calculus that parties, aiming to form sovereign governments at the member rather than at the unified level, take into account when making promises to voters, e.g., public sector jobs that are more like sinecures offered to supporters, generous pension levels, early retirement ages, and so on.

Single currency unions like the Euro region with otherwise sovereign members having no control over foreign exchange rates, money supply, and interest rates (and in turn the degree to which some of them can compete on their own with the others within the union and other countries outside the union) and only partial control over taxes, fiscal expenditures and deficits budgetary revenues and outlays or expenditures, etc., can be difficult to hold together if economic growth is somewhat two paced (a faster growing North versus a slower growing or even stagnant South, hamstrung by having a currency out of its control, as it struggled to recover from the recession). Furthermore, if the richer members (who had benefited disproportionately from the currency union in the first place, e.g., Germany) mistakenly mandate austerity and internal adjustments for the weaker members of the union, rather than the Keynesian approach to preventing sovereign defaults as countries, this will cause further contractions, much higher unemployment levels (and especially for the youth, fresh out of schools and universities, who need the early on-the-job training, exposure and experience in order to succeed over the rest of their careers), and in turn even more political upheaval and instability in Greece, Portugal and Spain, for instance. If the "have-nots" in the EU’s periphery, or the PIIGS, see their duly elected governments perforce having to tighten their belts and recant on the promises made earlier in the with respect to public sector jobs and pensions, etc., in accordance with the dictates of the "haves" in the core of the EU, this can lead to wide-spread street protests and the instability of elected governments.

This misplaced emphasis in Europe on austerity, has left a vast majority of the citizens, and especially the younger generation of employment seekers who found their degrees were worthless in the job market, feeling increasingly disenchanted in the wake of the financial turmoil in the West, and susceptible to what was on offer from a host of hitherto-marginal or even fringe political parties and movements. These erstwhile fringe parties and movements, with a litany of ultra-right-wing and ultra-left-wing causes to espouse, have become increasingly strident and on the ascendant since the onset of the LoGR and who are displacing the more moderate centrist groups. Analysts have started to equate the political upheaval as we recently witnessed with the Brexit referendum in the UK and the elections in the US as a backlash against globalization and expect a raft of protectionist measures to be adopted by governments in the future.

3. Modeling Financial Contagion Between Banks

Bank balance sheet problems resulting in bank defaults are contagious. If banks in a financial network, and those financial networks in turn, are more closely interlinked with each other on the assets and liabilities sides of their balance sheets, the failure of a single bank (say Lehman Brothers at the start of the crisis on Sept 11, 2008) can trigger other defaults and spread through the global financial networks, generating cascades of defaults. A number of analysts and authors hail from various fields, e.g., natural and social sciences, have sought to analyze the causes of financial contagion and the efficacy of measures to prevent the spread of contagion effects and cascading defaults.

To more fully comprehend the genesis and after-effects of the LoGR, we will seek to bring in the role of boom-bust type cyclical in, and multi-year lagged effects of, the residential and commercial real estate sectors, as well as the functions of the central banks in inflating and deflating the economy, along with the government departments such as treasury, and so on.

As depicted in Figure 2, we extend the basic model of interconnected banks to interconnected financial networks, where the interconnectedness between banks in a region, country and across continents (in the latter case, foreign exchange fluctuations can amplify or attenuate the shocks transmitted from one bank to another across national boundaries) can lead to the contagion spreading locally/nationally/globally as it did in the days following Lehman’s bankruptcy. The trigger event could be the boom-bust cyclicity in the housing sector, as shown, or the

![Figure 2: Interconnectedness between Banks and Financial Networks and linkages to the Real Estate Boom-Bust Cycles](http://www.economist.com/node/21553459)
possibility of one or more banks in a region being defrauded either by an internal or external actor.

Noted analysts, e.g., Pozsar, et. al (2013) blame shadow banking for the recurring financial sector problems and define shadow banks as “financial intermediaries that conduct maturity, credit, and liquidity transformation without explicit access to central bank liquidity or public sector credit guarantees.” While we agree that the nature of financial intermediation has changed substantially since the mid-1980s with the advent of market-based financial system, and that shadow banks which have played a key role in the market-based financial system, particularly in the run-up to the financial crisis, can be expected to be an important part of the financial system for the foreseeable future, we feel that our model cannot be easily extended to incorporate the “plumbing” of the shadow banking system – we will present a simpler analysis of financial system interlinkages. Future extensions may help point towards reform efforts that seek to remediate credit bubble excesses and to change capital and liquidity standards for the sector as a whole.

4. DISCUSSION: THE AFTERMATH OF LOGR

We now focus on the after effects, and especially those that become manifest over the medium to long term basis, of a severe downturn triggered off by a contagious string of bank failures such as the one we witnessed in 2008-2009.

Consider what happens when the loss of employment opportunities in the short run persists over the longer haul for a number of different reasons. As a result of longer term and hence skill-atrophying levels of unemployment especially for young fresh male^2 graduates, they could become increasingly addicted to the Internet and games. This has a sort of “double whammy” effect in that because they fail to acquire the skills valued in the employed and employable in the first place, they are severely at a disadvantage relative to the employed males, Notice that as males drop out of the workforce (either because or because they were too), vis-à-vis their ability to perform some or all of the functions and roles earlier in Section 2).

In the absence of policy initiatives by governments, unemployed youth, more susceptible to getting addicted to Internet gaming, for instance will grow in size over time, as addicts in each cohort grow older and “infect” their peers in the same cohort, as well as their juniors (above, as younger addicts grow older, they could become more addicted, more socially isolated, less employable (since they may lack skills that their non-addicted cohort mates had picked up in schools & universities, while they were getting their online “fixes”) and hence, or otherwise, less attractive to potential mates. If the younger unemployed and unemployable males (being jobless and addicted) cannot find spouses because they cannot support families in the first place, new household formation levels as well as new housing starts will be depressed -- one of the main drivers and leading indicators for GDP and GDP growth.

Figure 3: Interaction between Youth Unemployment and Gaming Addiction over Time (adapted from Kini and Melnikov, 2016)

We can think of this as having a “multiple whammy” negative economic impact over time (as depicted in Figure 5 below):

- incomes, otherwise earned by younger unemployed and unemployable men, will be missing as far in the GDP and GDP growth rate calculus;
- the multiplier effects of the money they would have otherwise spent (if they had stable incomes), would be missing and this would depress most if not all of the goods and services markets over time;
- the inability to start and form stable households would translate either into a drop in birth rates over time (and this would have ripple effects over time, when the missing contribution of the unborn next generation to the GDP and GDP growth rates, two decades or more later, is taken into account), or worse; and
- the local, state and federal governments would have to ramp up their law and order and criminal system related expenditures heavily over time to tackle the concomitant social problems, crime rates, and so on (as the old saying goes, “an idle mind is the devil’s workshop”).

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^2 We have more or less resorted to stereotyping unemployed and increasingly unemployable youth, most vulnerable to becoming gaming addicts, as males. Research indicates that addicts can be of any race or gender, generally falling between 18 and 55, with an average of 15 years of education. We however, believe that younger males are more at risk in the current environment, and will continue our analysis based on this assumption.
This can have significantly adverse socioeconomic implications for society and the nation as well, in the “here and now” sense, and it could get worse over time. Why? As shown in Figure 4, the population of unemployed youth, who could potentially get addicted, can be expected to grow over time, in the absence of any policy initiatives by the government, since addicts in each cohort, as they grow older, will most likely “infect” more of their peers in the same cohort, as well as their juniors (and perhaps seniors, too), in the same unemployment “boat”.

As the population of unemployed youth, who are susceptible to becoming gaming addicts for instance grows over time, the macroeconomy gets adversely impacted in a two-way feedback cycle. In a direct sense, as explained above, the economy will suffer adverse consequences in three or four different ways as the population of unemployed potential addicts grows over time. Indirectly, there could be just as many and just as deleterious side-effects, namely:

- the balance of trade or the current account deficit (imports minus exports) will become increasingly adverse to the nation facing a serious and growing youth unemployment problem, because imports will increase and at the same time exports could decrease because of a growing shortage of skilled and committed human resources over time;
- the capital account deficit (capital outflows minus inflows) could also become increasingly adverse, with FDI and FII (foreign direct and indirect investment, respectively) flows finding their way to other nations that can have adequate resources, including human resources, and which are therefore more growth oriented;
- lower GDP growth rates, in turn, translate over time into lower investments in accumulated tangible and intangible capital stocks, or conversely increases in the tangible and intangible liabilities, for the future (this includes human capital, social capital, financial capital, manufactured capital, and even natural capital), and this could trigger off a vicious, rather than virtuous, cycle, with even more serious negative externality effects.

5. CONCLUSIONS

We have to recognize that there are a number of functions and roles that we all play for most of our lives, if the economy is to grow sustainably and equitably, and if we are to attain what we all aspire for, i.e., a better life for ourselves and for our children, and so on. Our home ownership-related roles, along with several financial and nonfinancial factors with lagged or leading effects, do end up driving boom-bust cycles in the housing sector, which in turn adversely affect the financial sector.

Using system dynamics and discrete event simulation approaches, we model and analyze the impact of inter-connectedness (on the assets and liabilities sides of their balance sheets) between banks in a financial network, and between financial networks in turn, on the financial sector, and show how a failure of a single bank can trigger other defaults – this could spread as a contagion through the global financial networks, generating cascades of defaults.

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