

**RESEARCH
REPORT****Measuring the Banking System's Resilience**

A report prepared for The Clearing House Association

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Abstract

Central to post-crisis financial regulatory reform is the concept of banking system resilience. This report includes a review of the relevant literature and provides a definition of banking system resilience and how it can be measured. Key to the discussion is the need to define resilience as a combination of two objectives, i.e., stability and banks' contributions to economic growth and productivity. We propose two types of resilience metrics: descriptive and model-based. Our report provides a framework for assessing the cumulative progress made toward implementation of the various new regulatory requirements and industry-initiated efforts stemming from the recent financial crisis. This report can also help readers better understand the costs and benefits of a specific reform agenda; in particular, the ability of regulations to address the tradeoffs between the objectives of stability and banks' contributions to economic growth and productivity. This report builds a definitional and methodological foundation for the empirical work on banking system resilience and its impact on the overall financial system and the real economy. We believe significantly more work, especially empirical work, must be done in order to improve our understanding of the consequences recent regulation has on the banking system.

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1. Introduction

Banks¹ are a critical part of the financial system and play a vital role in the overall economy. At the same time, however, banking systems are also exposed to risks and shocks. As a result, banks must work to manage risks, such as credit and liquidity risk. An individual bank may experience problems when its risk management efforts fail. Moreover, as evidenced by prior banking crises, problems that emerge at one bank may spread to other banks and eventually jeopardize the stability of the entire banking system. Public authorities must balance the primary objectives of banking regulation, i.e., maintaining the microprudential safety and soundness of individual banking institutions as well as the macroprudential goal of enhancing banking system's stability, against the unintended consequences of regulation, such as adverse impacts on economic growth. This report provides context for studying the tradeoffs of banking system regulation by analyzing different metrics and models used to (1) measure banks' ability to withstand shocks and (2) quantify the attributes of the banking system that contribute to sustainable economic growth.

Banks make many critical, core economic contributions, including credit extension, maturity and liquidity transformation, risk management services, payment and transaction services, and money creation. Disruption of these services can have significant adverse effects on the overall financial system and the real economy, as witnessed during the global financial crisis of 2007–2008 (the “Financial Crisis”). In response, public authorities have strengthened their macroprudential regulation of banks in an effort to prevent systemic disruptions that may otherwise require extraordinary government support. This macroprudential regulation attempts to strengthen the banking system's ability to withstand stronger common shocks and to limit the knock-on effects of shocks that may destabilize the entire financial system and, consequently, the entire economy.

New regulations, complemented by actions taken by financial institutions since the most recent crisis have improved the financial system's safety and soundness. However, these same regulations can also have unintended economic costs. An optimal set of regulations maximizes sustainable economic growth and social welfare by promoting a stable financial system, while simultaneously avoiding excessive limitations on banks' abilities to perform functions critical for economic growth.² While policymakers should seek to optimize this “tradeoff” in their regulation of banks and other financial institutions, they have not conducted any comprehensive analyses that consider the costs and benefits of the totality of the regulations that have been implemented or will be in the near-term, which highlights the need for a suitable empirical framework for quantifying the tradeoffs inherent in this kind of regulation.³

Central to these post-crisis regulatory efforts is the emergence of banking system resilience — the notion that banks must be able to survive and to continue functioning during crises — as a primary goal of regulation. For the purposes of analyzing the tradeoff discussed above, we are putting forward a new definition of banking system resilience, one that addresses **both the banking system's ability to absorb shocks without relying on government support, as well as the ability to perform its core economic functions, therefore promoting sustainable economic growth**. Our definition seeks to capture the tradeoffs between the benefits of regulations, which decrease the probability of systemic crises, versus the costs of these regulations in terms of decreased economic growth.

While there is no single, observable measure to evaluate resilience, this report reviews the existing literature and models that describe the two core components of financial resilience: stability and contribution to economic growth. We propose utilizing a collection of attributes and metrics, both descriptive and model-based, to develop a framework for evaluating the resilience of the banking system as a whole. The framework provides context for examining the regulatory tradeoff we describe above and for assessing the cumulative progress stemming from the new regulatory requirements and industry-initiated efforts implemented since the recent financial crisis. The framework also enables us to identify metrics that, if developed, would improve our ability to measure banking system resiliency and the relative effectiveness of macroprudential regulatory approaches.

To approach the issue, we first review banks' economic functions and the relationship between how a financial system functions and the economy's productivity and growth. We discuss existing definitions of financial stability and resilience and present our definition of resilience. We then describe the two sets of resilience attributes, one addressing financial stability and the other addressing banks' contributions to productivity and economic growth, as well as models for measuring these attributes. We

¹ In this report, the term “bank” refers to all entities within the financial system that accept deposits and use the collected funds for lending, including both commercial and investment banks.

² Kroszner and Strahan (2011) describe these tradeoffs as well as other important regulatory challenges. Kroszner (2012) emphasizes sustainable economic growth in the context of stability and regulatory reform.

³ Post-crisis regulation changes and evolves regularly. While some analyses looked at this tradeoff in the past (BCBS, 2010), an analysis reviewing the tradeoff given the totality of current regulations, including the most recent, remains pending.

propose utilizing a collection of attributes and metrics, both descriptive and model-based, to provide a framework to evaluate the resilience of the financial system as a whole. Such a framework is achievable and provides context for examining the regulatory tradeoff and for assessing the cumulative progress made with regard to the various new regulatory requirements and industry-initiated efforts. Within the context of banking system resilience, we finish with a discussion on the tradeoff between financial stability and economic growth. We then conclude with summary remarks and a brief look at some other related issues, such as market resilience and the shadow banking system.⁴ The Appendices provide a review of related literature as well as insights from other disciplines.

2. Financial Systems, Banks, and Resilience within the Context of the General Economy

To define and measure banking system resilience, we must first understand the purpose of a banking system. In other words, we need to understand the services that banks provide and their potential positive and negative impacts on the general economy. It is well-documented that banks are central to a well-functioning financial system that contributes to economic development and social welfare by providing vital services to the rest of the economy. Without banks, our current financial system and economic engines would not function. Baily and Elliott (2013) provide a succinct and relevant summary. Allen and Carletti (2008) discuss the critical roles that banks play within a financial system. Beck (2011) provides a comprehensive survey of the role of finance in economic development, covering benefits, risks, and politics.

Borrowing from the existing literature, we first describe bank services and highlight their roles within the financial system and general economy. We then look at the impact properly functioning banks and financial systems have on economic growth and set the broader context for introducing the concept of resilience. Next, we define resilience. Our definition incorporates the system's ability to withstand shocks while continuing to provide economic services. This allows us to examine the concept and the interplay of its attributes within the context of a financial system that helps increase productivity, promote economic growth, and enhance social welfare. This view provides a framework for analyzing the effects of regulatory changes and the tradeoff between addressing the banking system's vulnerability to shocks and its contributions to the economy.

2.1 Economic Functions of Banks within the Financial System

The fundamental function of a financial system is financial intermediation; that is, a well-functioning financial system connects those with funds to those who need them. Figure 1 provides a basic illustration of financial intermediation. The process can be conducted in two ways. The first is through financial markets, such as money markets, bond markets, and equity markets. The second is through banks and other financial intermediaries such as money market funds, mutual funds, pension funds, and insurance companies.

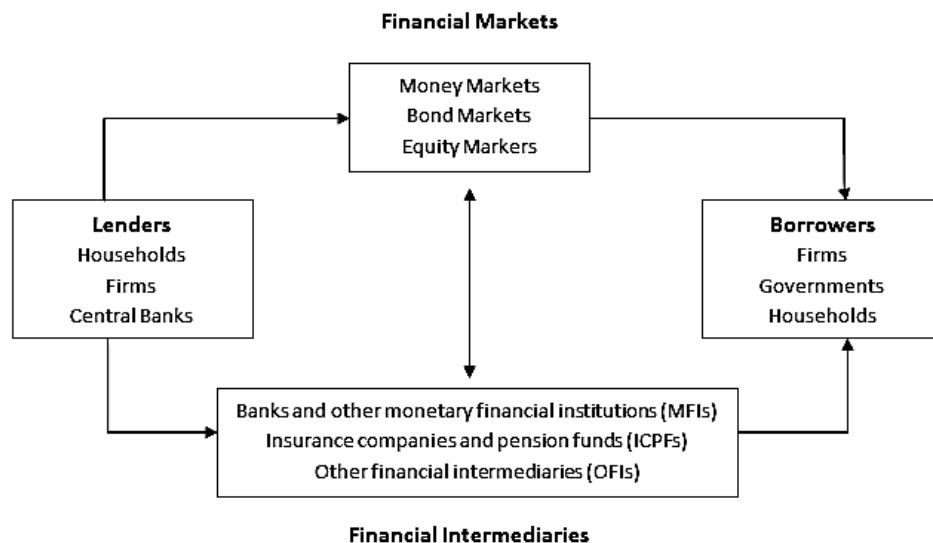
Banks play several critical roles in the intermediation process, acting as direct intermediaries or as important participants in the financial markets. Banks also provide many essential economic functions and services to the entire financial system and the overall economy. These services include extension of credit, maturity and liquidity transformation, risk management services, payment and transaction services, and money creation. We next discuss each service in more detail.

Extension of Credit

Credit cards, small business loans, home mortgages, and government bonds are examples of credit. Although banks do many things, their principal role is credit intermediation. Banks take in deposits or borrow from the capital markets and then lend these funds to businesses, other financial institutions, individuals, and governments. Commercial and investment banks provide most of the credit within a financial system. Banks specialize in assessing the creditworthiness of borrowers and provide an ongoing monitoring function to ensure borrowers meet their obligations. Banks can retain the credit risk or pass it on to investors via loan participations, securitizations, derivatives, or other means. In addition to directly extending credit, banks also provide other services that are critical to credit provision. They are the dominant securities dealers, as well as substantial holders of securities in their roles as investors. Without banks, the financial markets would operate much less efficiently. Other examples of banks extending credit include providing funding to alternative credit providers such as hedge funds. Collectively, these activities help facilitate the smooth and efficient flow of credit to the economy.

⁴ While most of this paper focuses on the banking system's resilience, we acknowledge the importance of the environment banks function in and their connections with the non-banking sectors of the financial system and financial markets. The analysis of banking system resilience is incomplete without providing, at least, a concise discussion of the broader context, such as market resilience and the shadow banking system. We offer a discussion at the end of the report, noting that these areas merit further acknowledgment and future research.

Figure 1 Financial Intermediation



Source: Allen, Chui, and Maddaloni (2004) p. 491

Maturity and Liquidity Transformation

The process of extending credit typically involves maturity transformation, i.e., converting short-term liabilities such as demand deposits into long-term assets such as loans, or borrowing short and lending long. Additionally, businesses and households must prepare for the contingency of unexpected cash needs, i.e., the need for liquidity. Banks can help transform illiquid assets (for example, long-term capital investments in illiquid production processes) into liquid liabilities (financial instruments). With liquid financial markets, savers can hold assets, such as equity or bonds, that can be quickly and easily converted into cash, if they need to access their savings. Banks are the main providers of liquidity, both by offering demand deposits that can be withdrawn at any time and by offering lines of credit. Furthermore, banks and their affiliates are at the core of the financial markets, buying and selling securities and related products at need, in large volumes, with relatively modest transaction costs. Specifically, securities dealers increase the liquidity of many securities by holding those instruments in inventory for sale for interested investors, or by being willing to temporarily take substantial long or short positions in order to accommodate the buying or selling demand of investors.

Risk Management Services

Finance enables businesses and households to manage their risk from exposures to financial market and commodity price changes. Banks provide much of this protection via derivatives transactions. For example, a farmer can hedge the price fluctuation risk of corn by buying a futures contract that allows selling corn at a fixed price at some future point. Other examples include derivative contracts that help institutions manage credit risk, interest rate risk, foreign currency risk, and commodity price risk. Some derivatives, generally the most standardized and liquid futures and options, are traded on exchanges. However, many derivatives are negotiated on a bilateral basis, where at least one side of the transaction is a derivatives dealer. Banks are important participants in the exchange-traded derivatives markets. Another way that banks help manage risk is by helping investors pool risk and diversify their investments, which reduces risk-bearing via the combination of less-than-perfectly correlated risks. An example of diversification is buying an Exchange Traded Fund ("ETF") of a broad representation of stocks instead of owning single stocks of a few. Another example is a syndicated loan, provided by a group of lenders, which is structured, arranged, and administered by one or several banks.

Payment and Transaction Services

Financial systems also provide payment and transaction services to customers; for example, the storage and withdrawal of funds, funds transfers, the clearing and settlement of financial transactions, automatic teller machines, and credit cards. Banks play a primary role in payment and transaction services by acting as both collection and paying agents for their clients, as well as by providing them with access to the broader financial markets and with clearing and settlement systems.

Money Creation

Banks play a central role in the creation of money in the economy and the transmission of monetary policy. Banks do not simply facilitate the flow of money throughout the economy; they also create money via lending. The process whereby banks make loans equal to the amount of their excess reserves and create new checkbook money is known as multiple deposit creation. Put another way, this multiplier effect occurs when money lent by banks finds its way back into the banking system and is then loaned out again.

These services do not necessarily need to be provided solely by banks. Market funds, mutual funds, and hedge funds can all extend loans. However, banks play a central role in the financial system, either through their direct roles in carrying out financial intermediations or by assisting other institutions and markets in the intermediation process. Using market-based intermediation as an example, large banks are the dominant securities dealers, as well as substantial holders of securities in their roles as investors. Without these banks, financial markets would operate much less efficiently, and would not be as effective in providing credit. Banks arrange the financing for major categories of investors that operate with financial leverage, including hedge funds. These investors rely on the ability to borrow against securities in order to obtain funding at a relatively low cost to support their investments. Without such funding, these investors would cut back substantially on their credit provision. Furthermore, some banks provide key elements of infrastructure for the credit and risk management markets, allowing these markets to operate efficiently through the provision of clearing services, securities lending, and other activities that enable smooth intermediation.

Next, we look at the potential impacts, both positive and negative, that banks have on economic growth and social welfare. As a result of the direct, vital services banks provide and their critical involvement within the financial system, banks may have both positive and negative effects on economic growth and social welfare, which we discuss in detail in the following section.

2.2 Impact of Banks on Economic Growth

Banks, as part of a well-functioning financial system, promote economic growth and enhance social welfare. As discussed, these contributions are achieved through the vital services banks provide. By extending credit, banks channel savings into the resources needed for investment and consumption, the primary engines for economic growth. Credit fuels economic activity by allowing businesses to invest beyond their existing cash, households to make large purchases such as cars and homes without having to save the entire cost, and governments to invest in large-scale infrastructure projects that further spur economic activities and benefit citizens.

By pooling savings from individual savers and through maturity transformation, banks facilitate long-term investment and, ultimately, economic growth. In the process of extending credit and maturity transformation, banks and financial systems at-large have a positive impact on investment and resource allocation by decreasing screening and monitoring costs and reducing information asymmetry and agency problems. By helping to increase market efficiency and reduce costs, more investment projects can be financed with greater probability of success.

Through liquidity transformation, banks help reduce liquidity risk, and thus, enable long-term investment (Diamond and Dybvig, 1983). By pooling savings of economic agents, financial institutions can transform illiquid, short-term assets into liquid, long-term liabilities, enabling long-term investment and, ultimately, more economic growth. Similarly, liquid markets enable investment in long-term investment projects while simultaneously allowing investors to access savings at short notice. Furthermore, banks can ease firms' liquidity needs by providing liquidity facilities such as credit lines, enabling long-term investment and R&D activities.

The risk management services that banks provide are also vital to productivity, economic growth, and innovation. Through derivative transactions, banks help firms manage unwanted risk and focus on their core competences, promoting specialization and enhancing productivity. For example, oil and gas exploration firms use futures contracts to protect against oil and gas price swings, allowing them to focus on what they know best — locating and drilling. Similarly, companies use foreign exchange futures to manage their currency risk when exporting their products and services abroad. Additionally, financial institutions such as banks and markets enable cross-sectional diversification across projects, allowing risky, innovative activity while delivering stable returns to savers (King and Levine, 1993).

Banks' payment and transaction services enable the efficient exchange of goods and services. These services foster specialization by providing more efficient transactions, which lead to economic growth. As part of the money creation process, banks also facilitate the flow of money throughout the financial system and economy. In addition to the direct contributions banks make to the general economy via the services they provide, there are other ways in which banks have positive impacts on economic growth. Banks facilitate financial innovation, which improves growth through better and more specialized investing and monitoring. For example, consider the introduction and development of railways in the U.S. When the need arrived, specialized financiers and investment banks emerged to mobilize capital, screen and invest in railroads, and monitor the use of such

investments (Carosso, 1970). Banks also contribute to economic growth by supporting the functioning of financial markets. For instance, larger and more liquid securities markets can improve corporate governance through better monitoring (Holmstrom and Tirole, 1993).

In addition to the economic benefits listed above, empirical research over the last two decades overwhelmingly supports a positive relationship between financial development and economic growth. As documented by Levine (2011), the services provided by the financial system exert a first-order impact on both the rate of long-run economic growth and the distribution of income, primarily by affecting the earnings of lower income individuals. Improvements in the functioning of the financial system are associated with disproportionately large increases in the incomes of those at the lower end of the income distribution, accelerations in total factor productivity growth, and sustained improvements in income per capita. Empirical research has also highlighted the channels through which financial development fosters economic growth. The impact on economic growth is primarily fostered through improved resource allocation, accumulation of knowledge, and productivity growth, rather than through quantity of capital accumulation.

The opposite of the positive link between financial system and economic growth can also be true. That is, the disruption of financial intermediation provided by financial institutions such as banks (or by markets) can have significantly adverse effects on the real economy, as the world painfully witnessed during the most recent recession. More evidence can be found in Barth, Caprio, and Levine (2001), who argue that disruption can undo economic progress, and in Reinhart and Rogoff (2010), who document that recoveries from crises in which financial intermediation has been badly disrupted can take much longer and be more uneven than recoveries from crises in which intermediation has not been impacted. Kroszner, et al., (2007) look at cross-country evidence on crises and banking development. They find that sectors of the economy that heavily utilize external financing sources are the ones hit the hardest by financial crises in the countries with well-developed financial systems.

The same mechanisms that underpin the positive role of banks in the general economy are also the origins of risk and fragility. Banks' vulnerabilities arise primarily from a high proportion of short-term funding, a low ratio of cash to assets, and a low ratio of capital to assets. The main risks faced by banks are credit risk and liquidity risk. In essence, both risks originate from banks' economic mandate of credit and liquidity provision, which are the drivers of banks' profitability and their contributions to economic growth. Credit risk arises if customers and counterparties cannot meet their contractual obligations. Liquidity risk stems from the lack of adequate liquid assets necessary to cover banks' obligations due to maturity mismatch between assets and liabilities. When some borrowers or counterparties default, banks may realize large losses, which can threaten their solvency and further reduce their fund-raising capabilities. With a severe liquidity problem, an immediate failure may occur.

While any specific bank failure is a natural occurrence of a competitive market economy and part of the market self-correction process, the increasing global interconnectedness of the financial system heightens the possibility of contagion. The failure of one or several banks can trigger other institutions' failures and, consequently, lead to turmoil throughout the entire banking system. Direct contagion effects take place primarily due to contractual links and counterparty exposures. Indirect contagion can take place due to common exposures to similar risk or the mark-to-market effect, such as an asset fire-sale or propagation of mistrust, resulting in widespread bank runs and a loss of confidence in the entire system. These amplification mechanisms can result in financial crises, which can be very costly to the general economy. For example, Laeven and Valencia (2012) estimate that for advanced economies, the median cumulative loss of national income relative to trend from bank crises over the period 1970–2011 was nearly 33 percent, taking into account both larger and smaller crises. In assessing the consequences of the 2007–2008 financial crisis, Luttrell, Atkinson, and Rosenblum (2013) estimate output declined between \$6 trillion and \$14 trillion, or 40–90 percent of one year's economic output. This amounts to \$50,000–\$120,000 for every U.S. household.

As an important part of the post-crisis reform agenda, regulators have imposed enhanced micro and macroprudential regulations.⁵ To satisfy these requirements, and heightened capital and liquidity requirements in particular, banks must deleverage their balance sheets and hold more liquid assets. Deleveraging reduces the total shock amplification on banks' **balance sheets and makes them stronger by giving them a higher degree of solvency when faced with adverse, stressed scenarios. However, to achieve this deleveraging, banks may need to shed assets and cut lending, which can result in a reduction in credit and tighter borrowing constraints for businesses, especially small- to medium-sized enterprises. This relative reduction in credit availability can, in turn, slow economic growth. At the same time, holding more capital and liquid assets reduces banks' profitability over the long-run. Therefore, there is a potential tradeoff between regulatory requirements and economic growth. The size of this tradeoff needs to be studied carefully.**

⁵ Strahan and Kroszner (2014) look at evidence on the link between economic growth and different regulatory regimes in the banking industry. The paper summarizes evolution of the banking regulations and their effects from the 1930s to the present.

In this context, regulation balances potential gains from economic growth and improves social welfare during good times, with the lower risk of heavy losses from a crisis. Therefore, if the goal is to ensure that banks support and contribute to economic growth and social welfare, there is a level of regulation beyond which the benefit of risk reduction may be outweighed by the reduction in long-run economic growth.

2.3 Defining Resilience

We define the resilience of a banking system as a combination of both (i) its ability to absorb shocks without relying on extraordinary government support and (ii) its ability to perform its essential economic functions and thereby contribute to the broader economy's productivity and growth. As stated before, economic functions include the extension of credit, maturity and liquidity transformation, risk management services, payment and transaction services, and money creation.

To fully understand this definition of resilience, it is useful to first discuss a closely related but distinct concept: financial stability. We observe primarily two types of definitions of financial stability in the literature. The first, "narrow" definition simply states that a financial system can be characterized as stable in the absence of excessive volatility, stress, or crisis. This definition is narrow in the sense that it does not take into account the larger role the financial system plays within the entire economy. By contrast, a second, "broad" definition of financial stability can be described as "... a condition in which the financial system — comprising financial intermediaries, markets, and market infrastructure — is capable of withstanding shocks and the unravelling of financial imbalances, thereby mitigating the likelihood of disruptions in the financial intermediation process severe enough to significantly impair the allocation of savings to profitable investment opportunities" (ECB, 2010). Similarly, Schinasi (2004) defines financial stability as a situation when a financial system is "... capable of facilitating the performance of the economy, and of dissipating the financial imbalances that arise endogenously or as a result of significant adverse or unanticipated events."

Rosengren (2011) provides another prominent definition of financial stability, closely aligned to the broad definition: "Financial stability reflects the ability of the financial system to consistently supply the credit intermediation and payment services that are needed in the real economy if it is to continue on its growth path. Financial instability occurs when problems (or concerns about potential problems) within institutions, markets, payments systems, or the financial system in general significantly impair the supply of credit intermediation services — so as to substantially impact the expected path of real economic activity." Rosengren proceeds to state that his "... definition of financial instability has three key elements: problems in the financial system, impairment of intermediation (or the supply of it), and a substantial impact on the real economy." Thus, this meaning of financial stability places a financial system's economic contribution at its foundation.

Similarly, the Office of Financial Research Annual Report (2012) gives the following, broad definition of financial stability: "'Financial stability' means that the financial system is operating sufficiently to provide its basic functions for the economy even under stress. Our framework includes an analysis of the six basic functions of the financial system — credit allocation and leverage, maturity transformation, risk transfer, price discovery, liquidity provision, and facilitation of payments — and an assessment of how threats may disrupt their functioning." This definition focuses on the provision of economic functions to the economy and specifies the functions more explicitly. The resilience of a financial system, although not directly defined, is viewed as equivalent to financial stability: "'Financial stability' simply means that ... in short, the system is resilient to the inevitable shocks and breakdowns in market confidence."

The broad definition of financial stability bears a close resemblance to our own proposed definition of banking system resilience. Similarly, Giese, Nelson, Tanaka, and Tarashev (2013) define a financial system's resilience to be its ability to withstand shocks and to continue providing essential financial services without resorting to taxpayer support. These services include efficiently allocating credit, providing payment services, and offering insurance.

Two clear common themes appear in these definitions of financial stability and resilience. One is the ability to absorb shocks, which we refer to as "financial stability" for ease of clarity and convenience throughout this document. The other is a certain level of provision of economic functions by the banking system, which, as we have explained, relates directly to economic productivity and, ultimately, economic growth. While the definition by Giese, et al., (2013) is essentially the same as ours, we make explicit the link between the economic functions by the banking system with economic growth and productivity. Furthermore, we clarify what counts as government support and what does not.

Our definition refers to the ability to survive shocks in the absence of extraordinary government support, because we focus on the system's ability to survive and perform on its own. Similar points of bank failure without extraordinary government support have been raised by other studies. For example, Moody's Analytics' definition of bank failure includes cases where banks would have failed in the absence of government bailout or support (Dwyer, et al., 2013). Fitch (2013) discusses the differences between bank default and bank failure. The report defines bank failure as a bank defaulting or having defaulted without extraordinary support. Their estimates, for the period 1990–2012, indicate that the failure rate is six times higher than the default rate. The point of

defining resilience so as to preclude extraordinary government support has practical implications for measuring resilience. For example, the level of capital and liquidity required for a stable banking system would be materially different with or without extraordinary government support. Accordingly, approaching our definition in this way creates a framework for us to appropriately analyze the regulatory tradeoff between financial stability and economic growth in a world in which extraordinary government support is not necessary.

In our definition, extraordinary government support refers to bailout or near-bailout government actions, such as the Troubled Asset Relief Program of 2008 (TARP). Ordinary, day-to-day regulatory measures such as changes to a discount window policy, the federal funds rate, and the like do not belong to the type of extraordinary government support referred to in our definition. Likewise, extraordinary government support, as described in our definition of resiliency, does not include preemptive government policies aimed at regulating the industry in the absence of a shock.⁶

In summary, our definition of resilience incorporates both the banking system's ability to absorb shocks on its own (i.e., without extraordinary government support) and the overall level of contributions and services to the financial system and the economy as a whole. Accordingly, our definition captures the tradeoff that may be present between these two ultimate goals. In this way, our definition goes beyond the banking system's mere ability to withstand shocks or to survive some bank failures without a collapse to also account for and reflect banks' contributions to the economy's performance and growth during periods in which banks are under stress, as well as during normal periods when banks conduct business as usual. The inclusive nature of this definition is useful when describing the multi-dimensional attributes of a resilient banking system and their measurement, discussed in the next two sections. Such a definition is also important for policy analysis, as it allows us to naturally frame a discussion regarding the tradeoff between the effects of banking regulation on the system's financial stability, i.e., the system's vulnerability or ability to withstand shocks, and the system's ability to perform economic functions, i.e., the system's contribution to the economy's productivity and growth.

3. Measuring and Modeling Resilience

This section presents several approaches for measuring and modeling resilience. These approaches reflect the dual nature of resilience and are organized around its two aspects: financial stability (i.e., the system's ability to withstand shocks) and the economic functions provided by banks and their contributions to the economy's productivity and growth.

A system's resilience is an abstract concept with a multifaceted nature. There is no single measurable object that we can tie the resilience to, which poses unique challenges for measuring resilience. As a result, the only way to directly describe resilience is through a collection of measurable characteristics, each of which tells us something about a certain aspect of resilience. We refer to these characteristics as "resilience attributes." We first classify and discuss resilience attributes or, in other words, the descriptive measures of resilience. Each measure describes only a certain feature of a banking system's resilience, and one must work with a collection of these measures to assess the resilience of the entire system or any of its two aspects. However, it is often difficult to provide a meaningful economic interpretation of the changes in the resilience or its two aspects using just the descriptive measures.

A remedy for the multiplicity of measures is to use composite indexes that aggregate each collection of descriptive measures into a single metric. We discuss this approach to measuring resilience after classifying and describing the sets of resilience attributes. A composite index ties together many resilience attributes, but does so somewhat mechanically. Consequently, economic interpretation of a composite index remains limited at this time.

Finally, we provide a discussion of models that facilitate measuring banking system resilience and its two aspects: financial stability and provision of economic functions. Model-based measures are much harder to construct. They rely on economic theory and require making simplifications and assumptions. Like indexes, the model-based measures can unify different resilience attributes and, thus, measure the overall level of resilience and its two aspects. Unlike indexes, these measures have much more intuitive economic interpretations.

⁶ It is difficult to provide a precise and explicit definition of extraordinary government support. Here, we provide a spirit of the notion. Resilience is a systemic concept, and extraordinary government support refers to system-wide actions, but not actions that target a specific institution. Much of the government involvement in the financial system's operations has routine character and, correspondingly, would not qualify as the extraordinary support.

3.1 Classifying Resilience Attributes

We describe a number of descriptive measures (resilience attributes) for each of the two aspects of resilience: financial stability and provision of economic functions to the greater economy. These measures have the advantage of being directly or almost directly observable. They typically do not require advanced statistical or econometric tools for computation. These measures can be aggregated into composite indexes as described later. They serve as both the data for the construction of and inputs to the models employed to measure resilience. Using these measures, we can obtain a rough sense of the current level of resilience, its two sides, and how they change over time. Consequently, one might be able to develop preliminary insight into the complex effects of regulation by examining resilience attributes.

Table 1 lists and classifies the resilience attributes. We discuss each of the attributes in more detail below.

i. The Financial Stability Aspect of Banking System Resilience

A system is regarded as more stable and, all else equal, more resilient whenever it is better equipped to withstand shocks. The financial stability aspect of resilience focuses on the ability of the banking system to survive shocks. Like the broader notion of resilience, stability is not associated with a single observable characteristic, but rather can be monitored through a collection of many descriptive attributes. There are two groups of such variables. The first group includes buffer metrics, i.e., the amount of capital and liquid assets that can be drawn on if some bank is in distress. The banking system becomes more capable of absorbing shocks if the capital and liquid assets held by the banks increase. The second group characterizes the interconnectedness of the banking institutions, i.e., the prevalence of mutual interactions between banks and other financial institutions that give rise to the propensity of banks to experience the stress simultaneously and to transmit the stress from one individual bank to other banks. Whenever banks become more connected and more exposed to the same risks, there is an increased likelihood of a major distress that affects not just a single bank but the entire system.

Buffer Metrics

We use standard definitions of buffer metrics from the regulatory literature. We provide only a brief summary of the definitions in this report and refer the reader to the documents from regulatory bodies such as the Federal Reserve System and the Basel Committee on Banking Supervision (BCBS) for details.

We propose using the following direct measures of capital: total capital ratio, Tier 1 leverage ratio/supplementary leverage ratio, and Common Equity Tier 1 ratio.^{7, 8}

The capital ratio is commonly defined as the ratio of qualifying capital to the risk-weighted assets (RWA). Qualifying capital consists of two components: Tier 1 and Tier 2 capital. Tier 1 capital represents a bank's ability to absorb losses in the short-term. Tier 1 capital includes common stockholders' equity, non-cumulative perpetual preferred stock, qualifying Tier 1 minority interest, and restricted core capital elements subject to limits. Tier 2 capital includes allowance for loan and lease losses, perpetual preferred stock and related surplus, hybrid capital instruments, perpetual debt, mandatory convertible debt securities, term subordinated debt, and intermediate-term preferred stock, including related surplus and unrealized holding gains on equity securities. Computation of RWA splits bank assets into several categories. RWA is the sum of assets weighted by the risk weights assigned to the asset category.

⁷ These capital ratios were introduced at different times, as the understanding of what capital banks use to cover losses gradually shifted. Total capital ratio is the oldest measure, while the rest are more recent. Utilizing some older measures, even as they phase out of regulatory focus, eases the task of collecting data that cover significant time period.

⁸ It may be worth considering augmenting the capital ratios with the assessment of the share of Level 3 assets. There is empirical evidence that Level 3 assets may have explanatory power for predicting bank failure, after controlling for the regulatory capital ratio (also see Glaser, et al., 2014).

Table 1 CLASSIFICATION OF RESILIENCE ATTRIBUTES

Financial Stability Attributes	Attributes for Economic Functions' Aspect of Resilience
<ul style="list-style-type: none"> • Buffer Metrics (Capital): <ul style="list-style-type: none"> ○ Total capital ratio ○ Tier 1 leverage ratio / supplementary leverage ratio ○ Common Equity Tier 1 ratio • Buffer Metrics (Liquidity): <ul style="list-style-type: none"> ○ Liquidity coverage ratio ○ Net stable funding ratio ○ Maturity mismatch ratio • Interconnectedness Metrics (simple): <ul style="list-style-type: none"> ○ Banks exposures to other banks ○ Banks exposures to similar industries (concentration risk) ○ Share of a few largest exposures in total exposures ○ Share of derivatives cleared through the clearing house • Interconnectedness Metrics (Return Co-movement): <ul style="list-style-type: none"> ○ Share of return volatility attributed to the largest principal component ○ Degree of Granger causality ○ Numbers of "in" and "out" connections ○ Closeness ○ Eigenvector centrality • Interconnectedness Metrics (Interbank Exposures): <ul style="list-style-type: none"> ○ Default impact ○ Contagion index 	<ul style="list-style-type: none"> • Credit Availability Metrics: <ul style="list-style-type: none"> ○ Total credit and bank credit to the non-financial private sector ○ Mortgage Credit Availability Index ○ Net percentage of domestic banks that indicate tightening in lending standards ○ Outstanding loans to individuals ○ Share of bank debt as a percentage of total corporate debt • Costs of Credit Metrics: <ul style="list-style-type: none"> ○ Credit spreads ○ Costs of Funds Index • Bond Liquidity Metrics: <ul style="list-style-type: none"> ○ Quoted bid-ask spread ○ Effective bid-ask spread ○ Realized bid-ask spread ○ Trading volume ○ Number of days with recorded trades ○ Yield spread between RefCorp and U.S. Treasury bonds • Derivatives Trading <ul style="list-style-type: none"> ○ Volume of trading associated with banks ○ Overall volume of derivatives trading ○ Amount of required collateral • Economy's productivity and growth metrics <ul style="list-style-type: none"> ○ Nominal and real Gross Domestic Product ○ Nominal and real GDP per capita ○ Unemployment rate

The second capital measure is the Tier 1 leverage ratio/supplementary leverage ratio. The Tier 1 leverage ratio is defined as the ratio of Tier 1 capital over the total consolidated on-balance sheet assets. It is straightforward to compute on the base of the previously described capital components and total consolidated assets. Currently, the Tier 1 leverage ratio is being replaced with its modification, the supplementary leverage ratio, which is the ratio of Tier 1 capital over the denominator, which includes all on-balance sheet and many off-balance sheet items such as derivatives, repo-style transactions, and other off-balance sheet exposures. As these ratios do not involve the calculation of risk-weighted assets, they are considered by some as less subjective and more robust compared to the capital ratio measure.

The most recent regulation splits Tier 1 capital into Common Equity Tier 1 (CET1) capital and Additional Tier 1 capital and emphasizes a new capital measure, the Common Equity Tier 1 ratio, which is CET1 capital divided by RWA. CET1 capital includes common stock and retained earnings, accumulated other comprehensive income, and qualifying CET1 minority interest, subject to regulatory deductions and adjustments.

We suggest collecting bank-level data sets for the above capital ratios. This permits construction and the examination of both individual bank-level and system-wide ratios as well as the distribution of individual ratios. For the system-wide ratio, we propose treating the entire banking system as a single institution while constructing the system's measures for resilience attributes. For instance, the Tier 1 leverage ratio for the banking system would be the ratio of the sum of Tier 1 capital across all banks in the entire system over the sum of total consolidated assets across all banks. In such a way, we can obtain a system counterpart for each of the buffer metrics for both capital and liquidity listed here. While the system's capital measures are useful in describing

system-wide capital, they conceal the information on the distribution of capital across different banks in the system. Such information is important for assessing financial stability. The granular data allows us to construct both the capital measures for each individual bank and the capital measures for the banking system as a whole.

Besides capital, banks maintain liquidity buffers to absorb shocks. We propose three ratios to measure liquidity: liquidity coverage ratio, net stable funding ratio, and maturity mismatch ratio.

The liquidity coverage ratio is constructed as high quality liquid assets divided by the total net liquidity outflows over a 30-day time period. High quality liquid assets consist of cash, central bank reserves, and marketable securities, where marketable securities must be claims on or claims guaranteed by sovereigns, central banks, public sector entities, the Bank for International Settlements, the International Monetary Fund, the European Commission, or multilateral development banks.⁹ High quality liquid assets also include securities issued and guaranteed by government sponsored enterprises and corporate debt and equity securities, with these categories subject to progressive haircuts. Total net liquidity outflows is the difference between liquidity outflow and liquidity inflow over a 30-day time period.

The net stable funding ratio is the ratio of the available amount of stable funding and the required amount of stable funding over a one-year period. The ratio is used to assess the sustainability of a bank's funding structure and its ability to withstand disruptions to regular funding sources.

Finally, we construct the maturity mismatch ratio by dividing the difference between short-term debt and cash by total liabilities. The ratio indicates how vulnerable the banks and the system are to shocks to short-term funding and interest rate risk.

As for capital ratios, we suggest collecting bank-level data sets for the above liquidity ratios. This method permits the construction and the examination of both individual-level and aggregate-level ratios, as well as the distribution of individual ratios. As discussed above, we suggest constructing the aggregate measures for the system by treating it as an individual bank and summing up the ratios' components across all banks in the system.

Interconnectedness Metrics

Interconnectedness lies at the core of financial stability and, by extension, the resiliency of the banking system. Banks form a complex web of mutual exposures to each other, share exposures to the same asset classes and other financial institutions, and are subject to common risks. Through these connections, trouble in one bank can spill over and put other banks under stress. Interconnectedness effectively makes a collection of banks a system. Without interconnectedness, banks would not strongly influence one another, and the failure of a single bank would represent little threat to the entire system. A high degree of interconnectedness helps transform the distress of an individual institution to an eventual system-wide, extreme distress and threatens the stability of the banking system.

The transmission of shocks (contagion) can occur through different channels. The most direct one is counterparty exposure, such as contractual links, over-the-counter derivatives positions, etc. Indirect linkages may arise from mark-to-market risk and information contagion. Mark-to-market risk comes primarily from the potential fire-sale of assets: a drop in the "fair" market price of some asset can force banks to sell more of the asset in order to manage risk or to achieve the required capital target due to mark-to-market accounting, which may further reduce the price and trigger more sales, potentially affecting the entire financial system and greater economy. The main idea behind information contagion is that many banks are influenced by the same systematic factors. The failure of one bank can reflect adverse information about the systematic factors and, thus, increase the cost of borrowing for the surviving banks (Acharya and Yorulmazer, 2008). Decreased financing capabilities can potentially force more banks to default.

Compared to capital and liquidity buffers, interconnectedness is much more difficult to measure in a purely descriptive way using only directly observable variables. Of course, some sense of the degree of financial institutions' interconnectedness can be obtained from such characteristics as banks' exposures to other banks, as well as their exposures to similar industries (concentration risk), the percentage of the first few largest exposures to total exposures, and the share of derivatives cleared through the central clearing house. However, there are better, albeit more complicated, measures of interconnectedness which, although still remaining rather descriptive in nature, involve some econometrics/statistics for their construction.

⁹ Public sector entities include states, local authorities, or other governmental subdivisions below the level of a sovereign.

Many such methods have been proposed to assess the interconnectedness of the financial system. One approach focuses on examining the co-movement in, i.e., correlation of, asset or equity returns. The advantage of co-movement measures is that they are easy to construct with publicly available data. Their disadvantage is their silence regarding the channel through which interconnections take place. Another approach uses a different source of information, the interbank exposure data, to analyze interbank networks and study how the distress in a single banking institution can generate distress in the rest of the system. We suggest using measures derived via both approaches. They may complement each other and jointly trace interconnectedness better than each group taken separately.

Billio, et al., (2012) propose a group of co-movement measures. In particular, they use Principal Components Analysis (PCA), a statistical technique, to break down the overall variation in stock returns of financial institutions into a collection of independent sources (principal components).¹⁰ Then, the interconnectedness of the system is measured as the share of return volatility attributed to the largest principal component. The reasoning is that the explanatory power of the first principal component represents the share of the most universal co-movement in the returns for different institutions.

The paper also proposes using Granger causality measures computed from equity returns for each pair of financial firms. Granger causality evaluates the predictive power of one firm's return on the future values of another firm's return. Intuitively, if the return of one institution has large predictive power for other institutions, they must be highly interconnected. The paper lists a number of statistics to access interconnectedness, such as:

- Degree of Granger causality, defined as the fraction of statistically significant Granger causality relationships in the total number of possible relationships.
- Numbers of "in" and "out" connections and their sum. For each institution, define the "in" connection to be the number of other institutions whose stock returns Granger-cause the return of the institution of interest. The number of other institutions whose returns are Granger-caused by the return of the institution of interest is called the "out" connection.
- Closeness, defined as a ratio of the sum of the shortest paths between a financial institution and all other institutions reachable from it, in the sense of Granger causality over the total number of all other institutions.
- Eigenvector centrality, which measures the relative importance of the institution in the network. This measure summarizes how connected a given institution is with the rest of the network.

There are some difficulties in interpreting Granger causality links, unless all links are considered together. It is impossible to distinguish between whether one firm Granger-causes another or if a third firm Granger-causes both. However, our use-case for these measures does not truly focus on establishing the direction of causality, but rather on constructing a proxy variable to capture the level of interconnectedness of the institutions within a system. The aggregate measures described above may accomplish this goal, even if they do not describe the directionality of the links between institutions.

As mentioned before, another approach to measure interconnectedness relies on network analysis. The starting point is the construction of a matrix of inter-institution exposures, which includes gross exposures among financial institutions. Frameworks based on interbank networks can naturally account for contagion between banks due to capital losses (through direct counterparty exposures).

Two measures described in Cont, Moussa, and Santos (2013) are the most useful: Default Impact and Contagion Index. They use individual banks' exposure data to model default contagion when the default of one bank leads to an immediate write-down in the value of its creditor's assets, possibly causing them to default as well and, thus, leading to more losses and more defaults. Their Default Impact measure equals the total loss in capital in the loss cascade triggered by the default of a particular bank. Their Contagion Index of a particular institution is defined as its expected Default Impact conditional on a macroeconomic stress scenario affecting all institutions in the network. This measure jointly accounts for contagion effects and correlation in portfolio losses through common shocks. In principle, the more connected banks are, mainly through counterparty exposures, the higher the total loss induced by the default of one bank, and, thus, the higher the index is as well.

These network measures provide a granular and dynamic description of shock propagation across the banks in the system, supplemental to what we learn from co-movement measures. They are better-suited for assessing the impact of a single bank failure on the entire system. Besides, the network measures address some of the shortcomings in the correlation measures, which essentially measure linear co-movement but miss the non-linear effects.

¹⁰ Putting it more technically, PCA decomposes the stock returns' correlation matrix into orthogonal factors.

ii. The Economic Function Aspect of Resilience and Economic Productivity/Growth

As discussed, banks mobilize and allocate savings to the best investment opportunities, which increases total productivity and growth, and they monitor the use of those funds. Banks pool and diversify risk, including liquidity risk, which makes higher-return, higher-risk projects possible. Banks ease the exchange of goods and services, which facilitates trade and specialization. These activities lead to more efficient capital allocation and raise the level of economic growth, contributing to the banking system's resilience. As is the case with the attributes of financial stability, there is no single, observable measure for the economic function aspect of resilience; it manifests itself through many different attributes.

Credit supply is the most important venue through which the banking sector delivers its services to the broader economy. The aggregate amount of provided credit is commonly used as a proxy to quantify the banking system's contribution toward the economy's productivity and growth, as well as the tradeoff between financial stability and the economy's productivity and growth (e.g., see Giese, et al., 2013). This is based on the logic that banking regulation in recent years may decrease the amount of credit (lending) provided to the economy, reducing the volume of investments and banks' contributions to efficient capital allocation across investment opportunities, ultimately affecting growth.

Following the commonly accepted approach, we concentrate on credit availability and cost of credit to measure the economic functions provided by banks, while also including the variables that measure liquidity of corporate bonds and variables that describe the contribution of banks to risk management in the economy through banks' participation in derivatives trading. We augment these financial metrics with measures of economic growth and productivity.

Credit availability refers to the level of lending to non-government borrowers by banks. Data on credit availability can be obtained from multiple sources:

- The Bank for International Settlements recently released a new data set, which includes total credit and bank credit to the non-financial private sector.
- United States Flow of Funds, collected by the Federal Reserve, provides data on total level of corporate bank loans.
- The Mortgage Bankers Association constructs the Mortgage Credit Availability Index, a barometer on the availability of mortgage credit that takes into consideration the loan purpose, amortization type, property type, loan term, loan-to-value ratio, credit score, and payment type.
- The Federal Reserve's Senior Loan Officer Opinion Survey on Bank Lending Practices reports the net percentage of domestic banks that indicate tightening in lending standards.
- The Federal Reserve's Consumer Credit report provides data on changes in the dollar amounts of outstanding loans to individuals.
- Following the intuition of Becker and Ivashina (2014), the share of bank debt as a percentage of total corporate debt financing can also serve as an indicator of available bank credit. As described in the paper, this variable can be constructed using Flow of Funds data, reported by the Federal Reserve.

To measure the cost of credit, one can use credit spreads for corporate bank loans, commercial mortgages, and consumer loans. In addition, the Federal Home Loan Bank of San Francisco constructs a Costs of Funds Index, which is a regional average of interest expenses incurred by financial institutions.

Apart from the metrics mentioned above, bond liquidity can also serve as a metric for measuring the performance of economic functions by a banking system. In normal times, banks are important market makers, providing liquidity in the secondary bond market. In times of distress or due to new regulations on the leverage ratio, banks can be less willing to hold inventory of bonds, which can decrease the liquidity of the bond market to a great extent. The drying-up of liquidity in the secondary market can quickly influence the primary markets, because it raises the cost of buying into a position for investors and lowers the benefit from selling out. This change eventually damages the financial markets' capability of meeting the financing needs of the real economy.

An intuitive and widely-used measure of market illiquidity is the bid-ask spread (Vanyanos and Wang, 2012). There are three main versions: quoted spread, effective spread, and realized spread. Quoted spread is the most straightforward, defined as the difference between the quoted ask and bid price. The drawback of quoted spread is that many trades are executed inside the spread. To remedy this problem, effective spread is constructed as two times the absolute difference between the transaction price and the

mid-point of the quoted spread. The realized spread is defined as two times the difference between the price of the current transaction and the post-trade price. Huang and Stoll (1996) discuss these in more detail.¹¹

There are also some measures related to trading activity. For example, liquidity can be measured by trading volume (Bhushan, 1994). Another possibility is to use the number of days with recorded trades to measure the liquidity of bonds (Chen, Lesmond, and Wei, 2007). Trade size and trade frequency can also be used to measure liquidity.

To obtain a measure of liquidity at the aggregate level, a common approach is to average the measures presented above over individual assets. There are a few other market-wide liquidity measures, such as the yield spread between RefCorp and U.S. Treasury bonds used to measure the "flight to liquidity" premium (Longstaff, 2004).¹² Since both bonds are guaranteed by the U.S. government, the spread should reflect relative liquidity.¹³

As discussed in Section 2, banks provide risk management services to the rest of the economy, mostly through derivatives. We suggest using the derivatives' volume associated with banks to assess banks' contribution to risk management in the economy. To account for the possibility of substitution between banks and other market participants, the data on the overall volume of derivatives contracts should be collected too. It makes sense to supplement the volume data with a variable such as the amount of required collateral to describe the costs associated with the derivative transactions. This method helps provide a holistic view into the amount of risk protection banks actually deliver, as well as the costs of such protection. Unfortunately, the historical data on derivatives is less than perfect, because most of the derivatives were bilateral, over-the-counter transactions. Some data can be extracted from the surveys collected and published by the International Swaps and Derivatives Association (ISDA).¹⁴

The economic functions provided by banks matter to the degree that they influence the economy's productivity and growth. Gross Domestic Product (GDP) is a standard measure of the economy's size and growth. It assesses the value of all goods and services produced in the economy. Measurement is in money terms, and GDP should be supplemented with a price measure, called the GDP deflator, to convert the nominal GDP figures into real GDP. It makes sense to refine GDP growth from the impact of the changes in population/labor force, which requires population and labor force data to derive per capita measures of productivity, e.g., real GDP per capita. The unemployment rate is another important aspect of the economy's productivity/growth.¹⁵

Regulations typically influence both aspects of banking system resilience. Their impact is complicated and manifests itself through changes in multiple attributes of both financial stability and the economic function aspects of resilience. These effects often run in opposite directions across different attributes. For instance, the most recent changes in regulation, geared toward dealing with the system's vulnerabilities revealed by the financial crisis of 2007–2008, have likely improved shock absorption by banks but are also likely to suppress contributions to the general economy. Tracking and analyzing the consequences of such regulations is difficult if only using a collection of resilience attributes. There is a need to aggregate the multiplicity of resilience attributes into a smaller number of higher level metrics which, while being more abstract and, thus, more detached from what can be observed directly, are able to deliver more clarity to the overall picture and, therefore, simplify analysis of the regulation. We undertake this task in remainder of this section.

3.2 Construction of Composite Indexes to Represent Banking System Resilience

As discussed, both financial stability and the economic functions provided by banks and, consequently, the overall resilience of the banking system, can be tracked only through collections of observable attributes. Below, we discuss composite indexes that, if successfully constructed, could aggregate the attributes for each of the two aspects of resilience, financial stability and the

¹¹ Apart from the descriptive measures listed here, there are also empirical measures motivated by theory, such as price impact and price reversal. Price impact is defined as the regression coefficient of returns on signed volume. It is based on the idea that trades in illiquid markets should have a large price impact. Price reversal is defined as minus the autocovariance of returns (i.e., the "inverse" of the autocovariance). The idea is that the lack of liquidity in an asset gives rise to transitory deviations between price and fundamental value. Thus, the magnitude of such transitory price movements can reflect degrees of illiquidity in the market. Many papers study price reversal. Bao, Pan, and Wang (2011) is an example for corporate bonds.

¹² While the rest of the bond liquidity measures listed above can be applied to both corporate and government bonds, the yield spread between RefCorp and U.S. Treasury bonds uses two types of government obligations, each with different liquidity.

¹³ Hu, Pan, and Wang (2012) measure the illiquidity of the U.S. Treasury market by the deviations of observed Treasury yields from a fitted term structure, which reflects their fundamental values. The idea is that during normal times, abundant arbitrage capital keeps the deviations small and, during market crisis, the shortage of arbitrage capital leaves the yield to move more freely relative to the curve, resulting in more "noise" in prices. Thus, the "noise" can be informative about the broad market liquidity conditions.

¹⁴ <http://www2.isda.org/functional-areas/research/surveys/>

¹⁵ As we focus on the effects of recent regulation, the time series of resilience attributes are likely to be relatively short. However, if the analysis were to concern longer time periods, additional metrics could be introduced, such as volatility of economic growth, frequency of "material" disruptions, etc.

provision of economic functions, into a single metric. Combining each collection of resilience attributes into a single composite index would be very helpful for measuring banking system resilience and could facilitate the practical use of our definition.

While much literature focuses on composite indexes and the techniques used to construct them, creating indexes remains, to a large degree, an art. A composite indicator is similar to a model in some senses. Like an economic model, it is a simplified representation of a complex process or phenomenon that typically relies on econometric or mathematical techniques. As is the case with economic modeling, the modeler's craftsmanship contributes more to the index's success than blind adherence to some universally accepted scientific techniques. But, unlike an economic model, composite indexes are directly shaped by the information contained in the data. Without the data, we are limited to making only a few general points on the structure and construction of resilience indexes.

Index construction begins with defining the notion that the composite indicator is supposed to capture. The definitions are of critical importance, because they shape both the understanding and the content of the indexes. In our case, it makes sense to examine each resilience aspect separately; that is, construct one composite index for the financial stability aspect and another for the economic functions aspect. If such indexes are properly constructed, there may be times when we see the tradeoff in action: while the financial stability index moves up, the index summarizing the economic functions of the banks may move down. However, at other times, both indexes may move together, simultaneously increasing or decreasing.

In other words, there is a need to have two separate indexes for measuring resilience in our context. The first would aggregate the buffer and interconnectedness metrics into an index of financial stability of the banking system (i.e., system's ability to absorb shocks). The second would aggregate the metrics of economic functions provided by banks to the general economy. It is likely that the GDP and unemployment variables will need to be omitted in computing the second index because, to a large degree, banks' contributions to GDP and growth take place over the long-run, and therefore, are difficult to discern in the contemporaneous values of the economy's productivity and growth.

While constructing an index, one arrives at the important choice between aiming to capture either a forward-looking or a point-in-time behavior of the underlying economic notion. The statistical techniques differ substantially if designing a forward-looking versus a point-in-time index. We think of resilience and its aspects (i.e., financial stability and the economic functions of the banking system) as describing the current state of the banking system and incorporating the impact of both current regulation of and the ongoing processes in the banking system. Consequently, the indexes should track the point-in-time values of the two aspects.

An index is typically a combination of selected observable indicators that are weighted and aggregated into a meaningful single composite variable. The weights represent tradeoffs between observable indicators: a deficit in one dimension can be compensated by a surplus in another. There are many ways to tie multiple observable indicators together. For instance, the variance-equal method, i.e., normalizing each variable by its standard deviation and then assigning equal weights, is one of the most commonly used methods (see Hanschel and Monnin, 2005; Illing and Liu, 2003; Cardarelli, et al., 2009). Additionally, the weighted-average method, where each factor is assigned a weight representing the importance of the parameter it proxies, and common factors analysis are often used (Hakkio and Keeton, 2009; Illing and Liu, 2003). These are relatively simple techniques and may be a good starting point for constructing composite indexes capable of measuring the two aspects of banking system resilience.

Another interesting and relevant example of index construction is a "composite indicator of systemic stress" (CISS), introduced in Hollo, et al., (2012).¹⁶ CISS aims to capture the overall level of stress of the entire financial system by aggregating the sub-indexes across five key components: financial intermediaries, money markets, equity markets, bond markets, and foreign exchange markets. The advantage of this method stems from the aggregation procedure that accounts for time-varying cross-correlations between the sub-indexes. Consequently, CISS tends to place larger weight on the situations when several of the key components of the financial system are under stress. Unfortunately, this method may be of little use in our case, because estimation of time-varying cross-correlations requires higher frequency data (daily or weekly) than much of the data on resilience attributes may be.

3.3 Model-Based Metrics

Comparing the magnitudes of descriptive resilience attributes over time enables one to obtain a rough sense of the changes in the overall resilience of the banking system, as well as each of the two aspects of our definition. However, it is difficult to give this information a proper economic interpretation. For instance, suppose that the average capital ratio for banks was approximately 5% before the financial crisis of 2007–2008, and it grew to, say, 8.5% today. Assuming all other conditions are equal, the banking

¹⁶ Cabrera, et al., (2014) and Milwood (2013) are examples of the application.

system clearly possesses a better capability to absorb shocks now than it did during the pre-crisis period. But this finding tells us little about the change in the likelihood of another major financial disaster comparable to the 2007–2008 crisis. Simply put, the capital ratio improvement from 5% to 8.5% cannot be properly translated into the crisis incidence frequency. Similarly, it is difficult to construct a composite index that aggregates the descriptive measures of financial stability into the crisis incidence frequency. Model-based measures of the banking system's resilience can answer this challenge. Models can be of great value in assessing the effects of different regulatory policies such as, for example, policies that employ different combinations of higher capital ratio, higher liquid assets, and lower short-term liabilities. It is important for policymakers to be able to compare the effects on banking resilience derived from a change in any of these parameters, but such comparison is not attainable with solely descriptive measures.

Below, we discuss the models that can be used to measure banking system resilience. These models help link different attributes of a banking system's resilience together, and they also facilitate economic interpretation. On this subject, we follow the advice given by Hansen (2013), which examines the current literature on systemic risk and calls for the increased use of economic models to study systemic risk, and, by extension, resilience. While no model is perfect, a carefully constructed model can greatly enhance our understanding and help quantify resilience.

i. Models that Measure Financial Stability

The banking system's financial stability, i.e., the system's ability to absorb shocks, can be summarized as the probability of a systemic event (defined as a major financial distress, such that the banking system requires government bailout), possibly paired with the expected loss (the so-called "expected shortfall") of the entire banking system, conditional on such an event. The first measure covers the likelihood of a major financial distress, and the second measure covers its severity. Such probability and expected shortfall can serve as a unified measure of financial stability, but these are not directly observable and must be derived using a model from the observable data.

Two types of models can be used to derive these two measures. The first includes models widely used by banks to manage portfolio credit risk. Such models incorporate interconnectedness of the individual banks through co-movement (correlation) of the associated assets. The second are network models that rely on interbank exposure data to take into account the interconnectedness of the individual banks in the banking system. Both model types are capable of producing a joint distribution of losses for individual banks. The ultimate choice of which model to employ depends on the available data, precise research questions, and the researcher's preferences for these models.

a. Credit Risk Type Model

The transition from a credit risk model to a model of financial stability for the entire banking system measure is, to some degree, straightforward. We utilize a credit risk type model to derive the joint distribution of losses for individual banks. We consider the banking system as a portfolio that consists of debt instruments issued by banks under consideration. Rather than the portfolio of interest being an individual institution's loan or fixed income portfolio, the idea is to take the total liabilities of banks as the portfolio. The banks are viewed as "exposures" in the portfolio, with each name's position size proportional to its total liabilities.

The idea behind this approach is similar to the models used to measure systemic risk (e.g., Adrian and Brunnermeier, 2011; Acharya, et al., 2010; Brownlees and Engle, 2012; Huang, Zhou, Zhu, 2009). It is worth pointing out that the proposed framework is very close to the Distress Insurance Premium (DIP) framework designed to measure systemic risk, developed by Huang, Zhou, Zhu (2009). Unlike their framework, which constructs a "risk-neutral" measure¹⁷ using a credit risk model, we suggest measuring financial stability using the actual, i.e., "physical" probability. A financial stability measure that relies on risk-neutral probability is difficult to interpret. In addition, the use of risk-neutral probabilities limits the choices of the exact content for a systemic event that underlies the financial stability measure and may complicate the derivation of the relationship between PDs and capital/liquidity variables discussed below.

This approach allows empirical construction of the loss distribution for such a portfolio and its components. To achieve this, we require three main building blocks. The first is the probability of default (PD) for each institution being considered. The second is a correlation model that can account for the interconnectedness among the institutions. Third, we must also specify Loss-Given-Default (LGD) parameters and possibly PD-LGD correlations. It is worth pointing out that the information collected for the attributes (descriptive measures) of financial stability (capital, liquidity, total assets, equity return correlations, etc.) can be used to

¹⁷ Unlike physical measures, risk-neutral measures mix the actual probability with risk preferences of the market participants. In other words, they blend market expectations with the market's desire to protect itself against risk.

derive the relationships/values for the building blocks needed to construct a model-based measure of financial stability. Below, we briefly discuss each building block.

For the first building block, we express the probability of default for each bank as a function of institution capital, liquidity ratio, financial network exposures, macroeconomic conditions, and so on. Building such a function from scratch is a challenging yet feasible task. However, it may be possible to simplify this task. A number of commercially-supplied PD models produce PD values for a broad universe of firms in the economy, including almost every bank.¹⁸ These models, however, supply PD values, but not necessarily the explicit relationship between PDs and the underlying capital, liquidity, exposures, macroeconomic conditions, etc., we seek to have. Although it is possible to use just the PD values that change over time to study the changes in the modeled financial stability over time, even a simple version of a relationship between PDs and banks' characteristics enables analysis of the impact and comparing different regulatory policies within the terms of our model. To model such a relationship, we require historical data on bank defaults, which may be empirically feasible yet challenging, as such a dataset can be difficult to obtain. An alternative is to construct a version of such a relationship, treating commercially-supplied PD values as data and, using empirical analysis tools, relate such data to observable characteristics of the banks such as, at the very least, capital and liquidity, and possibly additional characteristics as well. It would be desirable to incorporate the link between the individual banks' PDs and the aggregate capital and liquidity of the system into the estimated relationship.

A model of correlations between the individual banks' positions in the portfolio provides the co-movement/interconnectedness information for the banks in the banking system. It can be a very simple model, such as assuming the same pairwise correlations for any pair of financial institutions, or a fairly sophisticated model that allows for a complex co-movement of portfolio positions representing banking institutions. There is a range of choices for the content of such a model and a range of ways to construct it. For simpler models, one can look at the papers on systemic risk measurement summarized in the literature review in the Appendices. Basically, each paper in the list models correlations. Correlation models employed in Huang, Zhou, and Zhu (2009) and Brownlees and Engle (2012) may be of specific interest. Besides building a correlation model from scratch, again, multiple commercial suppliers provide correlation models.¹⁹

Correlation models are flexible enough to capture some contagion effects among different banks, despite abstracting from the granular description of the channel the contagion works through. For instance, one can imagine that the interbank exposures are such that for each larger bank there is a group of smaller banks that are highly exposed to the larger bank. Whenever the larger bank is in distress, the closely connected smaller banks are stressed as well and are more likely to default. This specific correlation structure can be described with a factor model, where the assets for each big bank are modeled as a combination of a single-common systematic factor and bank-specific systematic factor. The assets for the group of smaller dependent banks are modeled as a mix of the common systematic factor, the relevant bank-specific systematic factor, and the idiosyncratic shock, which is unique to each of the smaller banks. Such structure creates clusters of correlated behavior (defaults) among smaller banks linked to the financial health of the relevant larger bank.

Additionally, the last building block includes Loss-Given-Default values (LGD) and, possibly, PD-LGD correlations. Similar to the Correlation Model, this part can employ different levels of complexity, beginning with an extreme assumption of a constant LGD value for all banks. Besides this extreme simplification, there are many other alternatives. One can use different LGD values across banks to reflect the propensity of each banks' assets to fall in value in case of default, incorporating information on the type and risk properties of the banks' investments. The LGD behavior can be further customized with PD-LGD correlations, which lets us model sophisticated recovery processes and, in particular, enables relating the recovery value of a bank to the variables that drive its chances of default.

Relying on a standard simulation approach adopted in credit risk, one can use our three described building blocks to construct a joint distribution of correlated losses for individual banks. The total portfolio loss is a sum of losses for individual banks. This loss distribution can be supplemented with a definition of systemic event, i.e., major financial distress such that the banking system would require a government bailout, to allow financial stability quantification.

At this point, it is justifiable to deviate somewhat from the standard definitions of the risk measures adopted in corporate risk management, namely, Economic Capital (VaR), a certain quantile of loss distribution, and Expected Shortfall, an expected loss conditional on the loss being higher than a certain quantile of the distribution.

¹⁸ The probabilities of default can be purchased from Moody's Analytics, Kamakura Corporation, Standard & Poor's, etc.

¹⁹ Correlations can be sourced from Moody's Analytics, Kamakura Corporation, Algorithmics Inc., etc.

A standard derivation of Economic Capital (VaR) and Expected Shortfall relies on a pre-specified confidence level (probability). Instead, for our purpose, it makes sense to begin with the definition of a systemic event and then measure financial stability as the probability of such an event to occur. The proposed model allows for very granular definitions of a systemic event up to a specific combination of defaults of individual banks. Other possibilities are to define the event as a certain number of individual banks defaulting or total portfolio loss exceeding a certain level, which appears to be the most frequently used operational definition of systemic event in the literature. Having chosen the exact content of the systemic event, it is straightforward to compute its probability, our chosen measure of financial stability, on the basis of the loss distribution. A complementary variable is the expected shortfall of the system, conditional on the systemic event, which is an expected loss for the total portfolio (banking system), conditional on the systemic event.

The proposed model represents both individual and aggregate risk in a coherent manner that accommodates the impact of bank size and leverage. Because the framework is analogous to those used by many institutions for managing credit portfolio risk, it can be implemented, potentially, by using the current generation of tools, may require little or no additional calibration for its simplest version, and benefits from a rich body of extant empirical research that has evolved over the last decade or so for corporate credit risk management.

The approach discussed above facilitates a fairly comprehensive analysis of the impact the regulation (e.g., capital and liquidity requirements) has on the financial stability of the banking system. As mentioned previously, one can link the regulatory variables to the building blocks, such as PDs for instance. Then the change in values of regulatory variables can change PDs for each bank and, thus, change the loss distribution and the stability of the entire banking system. This allows use of the model and capital/liquidity data for individual banks to study the tradeoffs between different combinations of capital and liquidity requirements. The recent regulatory requirements differ across individual institutions. For example, Bank 1 is subject to higher capital and liquidity requirements than Bank 2, if Bank 1 is deemed to be of higher systemic significance, i.e., has a larger impact on the overall health of the banking system during times of system distress. The framework we discuss permits studying the effects of such asymmetric regulation on the system's financial stability.

Besides analyzing regulatory impacts, this approach enables stress-testing, and, therefore, allows us to examine the banking system's response to possible stress scenarios. Stress-testing can be implemented via the method discussed in Huang, Zhou, Zhu (2009) by relating PDs to macroeconomic variables. Another recent, viable alternative is Moody's Analytics' GCorr Macro extension of the correlation model (Pospisil, et al., 2013).

b. Network Models

The research on network models in systemic risk and financial stability remains very active. It includes models that, although resembling one another, can hardly be nested.²⁰ Presently, there is no generally accepted, codified network model similar to what we find in the credit risk area. This is why we present two modeling options instead of specifically discussing how to adopt a single model for the task of measuring banking system stability.

This line of research traces back to Eisenberg and Noe (2001), who lay out a conceptual framework to analyze static payment clearing in a network of financial institutions. Elsinger, Lehar, and Summer (2006) combined this network framework with a credit risk model to include uncertainty and bankruptcy costs. Their model allowed for distinguishing between the joint defaults of many banks caused by correlation in the banks' portfolio values and the joint defaults caused by insolvency spreading from one bank to another through the network of interbank exposures (contagion) in domino-like fashion when the default of one bank causes other banks to default. The paper also makes an important point that pure contagion is a rare event when compared to correlated defaults caused by external shocks, which is also echoed elsewhere in the literature.²¹ The recent models, for instance, those of Gauthier and Souissi (2012) and Anand, et al., (2013), incorporate amplification mechanisms such as fire sales, bankruptcy costs, loss of confidence in the financial system that cause mark-to-market losses in the value of bank assets, and bank runs. These amplification mechanisms focus on the interaction of financial institutions' behavior and the pricing of risk and can increase contagion effects significantly.

Gauthier and Souissi (2012) outline a framework geared toward examining banks' vulnerability to a combination of low liquid asset holdings and a high reliance on short-term funding while, at the same time, accounting for the credit risk and the spillover effects of interbank exposures. Their analysis is conducted over a one-year time horizon split into three periods. During the first half-year

²⁰ Two models are nested if one model includes all the terms and relationships of the other, and, in addition, includes some features not covered by the other model.

²¹ For another example of this conclusion, see Glasserman and Young (2013).

period, individual banks realize losses from their exposures to non-bank borrowers that default, with probability modeled conditional on a certain stress scenario. At the end of the half-year, the banks' short-term creditors observe the first-period losses, are aware of the distribution of losses that may occur by the end of the year, and decide whether to roll over their claims for the rest of the year. This decision can lead to a run on some banks and, consequently, cause the banks to either default or to experience a capital shortfall serious enough to prevent them from fulfilling their obligations in the interbank market, causing credit losses for other banks and potentially causing them to default as well. Such default cascades are modeled on a network at the end of the one-year horizon. The size of the interbank exposures, capital, and liquidity distribution across the individual banks in the system influences the likelihood of spillover effects by counterparty defaults. The model has been calibrated to reflect the realities of the Canadian banking system. This model can be applied to macroeconomic stress testing and the analysis of policy alternatives such as different combinations of capital and liquidity requirements.

Anand, et al., (2013) construct a model that examines systemic events within a financial network that includes three types of agents: domestic banks, overseas banks, and firms. Each agent is a node in the network. The network is used to mirror a specific set of relations between the agents. Each domestic bank in the network interacts with all other domestic banks and also lends to, or borrows from, a group of randomly chosen overseas banks. Each overseas bank interacts only with subsets of other overseas banks, domestic banks, and firms. The firms are assumed to not lend to one another or to own equity in one another. Therefore, each firm is linked only to a subset of banks within the network. The model captures how the shocks are propagated in the economy through the interplay of claims and obligations in the network. The macroeconomic shocks trigger corporate defaults, which lead to credit losses and losses in the value of corporate equity held by banks on their books. This situation may place some banks in default and generate a default cascade. The distressed banks respond with fire-sales of equities and cut back on credit to the corporate sector. The credit tightening for the firms increases their default probabilities, magnifying the initial shock and placing even more banks in distress. The model omits the formal optimizing behavior of the agents and relies instead on the "rules of thumb" that describe how banks curb lending and become drawn into asset fire-sales. The model was calibrated primarily using data from the U.K. However, the paper states that it does not intend to exactly quantify systemic risk in the U.K. The model serves the rather illustrative purpose of how to derive systemic risk measures and demonstrates the interplay between macroeconomic shocks and network structure in the economy.

Both these network models construct a joint-distribution of losses for the banks in the banking system and enable quantifying the banking system's financial stability as the probability of a systemic event and the resulting expected loss, conditional on such an event taking place. The method for computing these measures using the network models is identical to that offered for the credit risk type model.

Both network models focus on the asymmetric linkages between individual banks, which allows us to understand and pinpoint a system's vulnerabilities within the network context, something that is difficult to achieve using the credit risk models. Generally, network models make a step forward in providing a granular, dynamic description of systemic events as compared to the credit risk type model, which is rather static and omits many details. However, a more realistic network model remains desirable. Unlike credit risk models, where the parameters are typically estimated, the discussed network models are only roughly calibrated to real world data and involve strong assumptions regarding many aspects of economic behavior. For example, see the use of "rules of thumb" in Anand, et al., (2013) to describe the agents' behavior or the rather formal time dynamics used by Gauthier and Souissi (2012). Interestingly enough, while Anand, et al., (2013) focus mainly on fire-sales, Gauthier and Souissi (2012) examine bank runs and ignore the fire-sale mechanism. This difference in coverage of amplification mechanisms is not surprising considering the fact that network models of systemic events are in the early stage of research. Bridging the gaps between different network models and putting them into more realistic context is likely the next challenge for research in this area. Additionally, network models require interbank exposure data, which may be difficult to attain — another practical restriction of using these models.

ii. Models that Measure the Contribution of Banks' Economic Functions to Economic Growth and Productivity

On the one hand, whenever the banking system is in distress, banks may decrease the supply of credit and credit intermediation to the economy, which is likely to cause a recession. Such recessions can be deep but transitory. On the other hand, tighter financial regulation, while improving financial stability, can damage the flow of credit to the economy and cause a small but permanent reduction in banks' provision of economic functions, decreasing the economy's productivity and growth in the long-run relative to its potential.

Unlike the first effect, the long-run effect on growth is difficult to examine empirically using data for a single country. The existing literature relies on macroeconomic models to evaluate the effect. A standard approach is to convert the effect of tighter capital and liquidity requirements into the effect on the economy's output/growth using a model out of the dynamic general equilibrium family.

Dynamic Stochastic General Equilibrium (DSGE) models are the standard tools used to provide an interesting glimpse into the competing factors of micro- and macro-prudential regulations on capital and liquidity levels and optimal bank services. DSGE models have come to play a prominent role in the formulation and communication of monetary policy at many of the world's central banks. The advantage in using DSGE models is their flexibility and versatility. They aim to model the macro behavior of an economy or system by making decisions based on microeconomic principles. The "general equilibrium" of these models comes from the evaluation of a system using modeled agents (e.g., Banks, Firms, Households, Governments) that make an equilibrium decision based on a variety of factors and micro-principles. They are "dynamic," unlike other general equilibrium models, because they look beyond one period, analyzing how decisions and assumptions made today affect how the actors behave tomorrow. Finally, they are also "stochastic," meaning they introduce uncertainties into the model that take into account the fact that the economy is affected by random shocks. As a whole, DSGE models are very useful for evaluating the effect of banking regulations on long-run economic productivity and growth.

Angelini, et al., (2014) survey a cohort of macroeconomic models suitable for this exercise, most of which are DSGE models. Some of these models include credit/liquidity requirements explicitly. Others require first considering the impact of the new credit and liquidity requirements on the lending spreads. Extensive literature exists on such impact and is discussed in the next section. Then the change in the lending spreads is mapped into the change in the GDP or growth using the macroeconomic model. Only some of these models are estimated, while the rest are calibrated, therefore potentially making the quantitative results somewhat debatable.²² The common weakness of the models discussed in Angelini, et al., (2014) is that they do not model banking defaults. Therefore, these models are not suitable for measuring the banking system's financial stability.

As mentioned, modern DSGE models are useful for analyzing the effects of the recently introduced banking regulations on economic growth and social welfare. For example, Adrian and Boyarchenko (2012) study the dynamic stochastic general equilibrium of an economy with three sectors: intermediaries (banks), production (passive player), and households, and evaluate the model of the economy numerically. This paper is closely related to He and Krishnamurthy (2012) and Brunnermeier and Sannikov (2014), who introduce the financial sector into dynamic models of the macro-economy. The paper demonstrates that very loose capital constraints generate excessive risk-taking, while very tight capital constraints inhibit risk-taking and investments, therefore, affecting growth. In a follow-up paper, Adrian and Boyarchenko (2013) incorporate a liquidity requirement into this model. As the liquidity constraint is tightened, banks must take on more liquid assets in proportion to the short-term riskiness of their liabilities. Within the context of this paper, liquidity requirements are a preferential policy tool when compared to capital requirements, because liquidity tightening lowers the likelihood of systemic distress without impairing economic growth significantly.

As with the rest of current DSGE models, this model does not go very far in evaluating the financial stability aspect of banking system resilience. The financial sector is represented by a continuum of absolutely identical, infinitely-living intermediaries assumed to possess a superior investment technology as compared to households. These intermediaries never interact with one another, only with households and producers. The model does not acknowledge the interconnectedness of the financial intermediaries. All this effectively equates to having a single intermediary. The systemic distress occurs whenever the intermediary defaults on its debt to households. The frequency of the distress is driven by the exogenous shocks to the productivity of capital and household preferences besides the liquidity and capital requirement. The model is calibrated, but the frequency of the distress is not listed among the calibration parameters and appears to not be matched to how often the distress occurs in reality. This model describes financial crisis in a very stylized way and, consequently, is of very limited use in assessing the financial stability aspect of resilience.

To summarize, these macroeconomic models provide us with insights into the effects of regulation on the economy's productivity and growth when looking at the economic services provided by banks. The primary model weaknesses are their lack of realism in modeling the banking system and failure to allow for adequate assessment of the impact regulation has on the system's actual stability. The stability aspect must be analyzed with other models, such as the credit risk and network models discussed above.

iii. Quantifying the Tradeoff Between Financial Stability and Economic Contribution

While it is appealing to analyze the tradeoff between the financial stability of the banking system and its contribution to the general economy's productivity and growth in a single model, there is presently no model that incorporates both aspects of resilience in a detailed and realistic way. Models suited to measuring financial stability of the banking system tend to ignore the

²² Simply put, the difference between "calibration" versus "estimation" is that calibration typically involves a very limited number of data points, while estimation tends to be based on many more data points. Consequently, one can derive some idea regarding the precision of the estimated values of the parameters, i.e. standard errors, if the model is "estimated." This is typically impossible for a "calibrated" model.

long-term effect of regulation on banks' provisioning of economic functions and their impact on the economy's productivity and growth. DSGE models, being the standard tool for quantifying the impact of banks' economic functions on the economy's productivity and growth, do a poor job modeling the financial stability of the banking sector. Thus, one must use several models, targeting the two aspects of resilience separately, for the tradeoff analysis.

To quantify the tradeoff, we suggest relying on the cost-benefit framework described by Schanz, et al., (2011) and BCBS (2010). This approach evaluates the costs and benefits of regulation by measuring the impact on GDP. On the benefit side of regulation, we must map the regulation requirements into the probability of a systemic event. This can be done using the credit model or one of the network models described above. The GDP loss per a systemic event can be estimated using observed losses for past crises. The change in the probability of the systemic event, together with the GDP loss per systemic event, are used to compute the amount of GDP saved by the increase in the capital or liquidity ratio. On the cost side, tighter regulation increases lending spreads and is mapped to the loss of GDP, as discussed above.

While the above mentioned framework provides a stylized way to quantify the tradeoff, in reality, the actual tradeoff between stability and economic growth is much more complicated. In the next section, we provide some detailed discussion on the subject.

4. Understanding the Tradeoffs Between Stability and Economic Growth

As described in the previous two sections, our definition of and measurement approaches to banking system resilience are meant to encompass both the stability and the economic function aspects of the concept. This normative approach implies that there is a potential tradeoff between these two aspects. This tradeoff is especially pertinent to the discussion regarding the consequences—intended or unintended—of regulation. This discussion is especially pertinent given the extent to which regulation of the banking sector has been altered following the 2007–2008 crisis. It is generally agreed that these new regulations have increased the stability of the banking system and have improved its ability to absorb shocks. However, like most regulations, financial regulations can have complicated and unintended consequences. Given that one of the most cited objectives of these regulations is to increase the overall resilience of the banking system, it is important to assess whether or not these rules are indeed enhancing overall resilience, taking into account both their intended and unintended consequences. In this section, we review the literature that analyzes these regulatory effects, and we discuss how our definition and proposed metrics may help provide a more detailed and holistic assessment.

The post 2007–2008 crisis regulations (some of which are international standards and others country-specific) are far-reaching and cover many areas of the banking system. For example, they affect capital adequacy ratios, leverage, liquidity reserves, trading activities, executive compensation, reporting, and consumer financial protection. Given the complexity, it is beyond the scope of this paper to discuss the impacts all these regulations have on banking system resilience. Instead, we highlight the regulations that impact the two primary, essential economic functions that banks provide, namely credit extension and liquidity provision.

One of the most important new regulations is the enhanced requirements for capital adequacy and liquidity. In response to the financial crisis, the Basel Committee on Banking Supervision designed new global standards, referred to as "Basel III," to address both firm-specific and broader, systemic risks. Compared with the old standards, among other revisions, Basel III raises the level of minimum capital requirements, introducing the minimum common equity to risk-weighted ratio requirement of 4.5%, and establishes a capital conservation buffer of 2.5%, effectively bringing the total common equity requirement to 7%. An additional capital surcharge of 1% to 2.5%, and possibly more, has been proposed for Global Systemically Important Banks.²³ Basel III also introduces minimum global liquidity standards consisting of both a short-term liquidity coverage ratio and a longer-term, structural net stable funding ratio. Basel III suggests promoting the build-up of capital buffers in good times that can be drawn down during stress periods, including both a capital conservation buffer and a counter-cyclical buffer to protect the banking sector from periods of excess credit growth. Complementary to Basel III are regulations in the form of stress testing. In the United States, the Comprehensive Capital Analysis and Review (CCAR) and Dodd-Frank Act Stress Test (DFAST) are conducted annually to assess whether or not institutions have sufficient capital to absorb losses and to support operations during adverse economic conditions. Stress testing for sufficient liquidity, the Comprehensive Liquidity Assessment Review (CLAR), is underway at the largest institutions.

²³ The global systemically important banks are to be placed into five "buckets" based on the banks' global systemic importance and assigned the capital surcharge of a 1%, 1.5%, 2%, 2.5%, and 3.5%, respectively. The highest bucket will initially remain empty to provide a disincentive for the banks to increase their global systemic importance.

The rationale for these regulations is twofold. On the one hand, higher capital and liquid assets holdings increase the capability of banks to absorb losses as well as to provide funding during shocks. On the other hand, higher capital and liquid assets holdings can potentially mitigate the moral hazard problem,²⁴ since the banks' own resources are the first used during times of severe losses, and, thus, banks will be more careful in their investing and monitoring activities. Additionally, these requirements help promote market discipline, as they encourage investors to monitor their investments in the banks more closely. Both improvement in the ability to absorb losses and more sensible risk-taking by banks lead to an increase in the banking system's financial stability. However, the enhanced stability may come at the cost of less credit to the general economy, reducing the banking sectors' contribution to economic growth and social welfare.

These costs can manifest themselves in a number of ways. Increased capital levels may increase the cost of bank credit, leading to higher borrowing rates for customers; a reduction of RWAs by banks to try to meet higher minimum capital ratios may lead to less credit economy-wide.

When banks must increase their capital ratio in order to satisfy a new requirement, they must either increase capital or decrease asset holdings, especially riskier assets. In the short-run, it may be difficult to satisfy the new regulatory requirements by issuing new shares. Increasing retained earnings is another option, but that may take time. Elliot (2009) argues that, over time, banks should be able to raise new equity sufficient to maintain their loan volume. However, a higher equity ratio can increase the weighted cost of capital for banks, since equity financing is more expensive than debt financing due to higher required returns as well as the difference in tax treatment. If the cost of funds for banks increases, the higher cost will be passed on via an increase in the borrowing rate for customers, which decreases the amount of credit extended to the economy.

Another way for banks to raise their ratios of regulatory capital to risk-weighted assets is to reduce their RWAs. This can be achieved either by shrinking the balance sheet or by shifting composition from riskier assets toward safer assets. These actions could lead to a quantitative restriction on bank credit or perhaps credit rationing. The consequence could be felt acutely by those whom rely more on bank credit, such as small and medium enterprises and average households. Such a move would likely impact the economy negatively due to weaker consumption and investment.

The requirement to hold more liquid assets may also raise the cost of bank credit. To meet the new liquidity requirements, banks must use some combination of increasing the maturity of their liabilities, shortening the maturity of their assets, and shifting to higher quality assets. Banks may also meet these requirements by raising capital of long or perpetual maturity to replace short-term liabilities. These actions tend to reduce bank profits and increase the overall cost of capital, as longer-term liabilities are more expensive and shorter-term, safer assets yield less. In response, a bank might choose to raise the interest rate charges on loans in order to maintain profitability.

These potential negative impacts of bank capital and liquidity regulations on long-term economic growth have been generally recognized. However, there is less agreement on the magnitude of these impacts and the resulting tradeoff. In a report prepared for The Clearing House Association, Oxford Economics (2013) critically dissects several recent papers that evaluate the effect recent regulation has had on lending rates and economic growth. These studies can be broadly classified into two groups: "official" impact studies by organizations such as the International Monetary Fund (Elliot, Salloy, and Santos, 2012), the Organization for Economic Co-operation and Development (Slovik and Courneade, 2011), the Bank of England (Miles, Yang, and Marcheggiano, 2011), and the Bank for International Settlements (BCBS, 2010; MAG, 2010); and studies undertaken by groups linked to the financial industry, such as the Institute for International Finance (IIF, 2011). Generally speaking, the "official" studies tend to show that recent regulation has modest impacts on lending and growth, while the industry-connected studies show somewhat larger effects. These differences can be attributed to key differences in the assumptions underlying the effect of regulatory changes on bank behavior and the cost of credit, with some differences also due to varied methodological techniques (e.g., whether the studies use an economic model to estimate output effects).

Oxford Economics also conducted its own analysis to assess the impacts of new capital and liquidity regulations. Using various assumptions, they show that the estimated decreases in GDP reported in "official studies" may be understated. Overall, their results highlight the uncertainty around the potential macroeconomic effects of regulatory reform proposals for banks, and they illustrate the need for such proposals to be carefully calibrated in order to prevent unnecessary damage to economic growth.

²⁴ In economics, moral hazard refers to a situation where the party that is responsible for the risk-taking (or more generally any action) does not bear the full cost of the risk-taking (the action). Consequently, the party may be willing to take on more risk, to the detriment of other involved parties.

In addition to the “official” and industry-sponsored studies on the long-term impacts, there are also a number of studies that focus on the impacts in the short-run. For example, Kashyap, Stein, and Hanson (2011)²⁵ review some of the literature on the link between capital requirements and the supply of credit in the short-run. Using theory-based calibrations, they conclude that the change in loan rates is small and ranges from 2.45 basis points to 4.5 basis points per one percentage point increase in capital requirement. The paper makes the important point that, although the credit cost increase can be very small, it may shift the bulk of credit away from the banking sector to the shadow banking sector, which is heavily unregulated.

It is important to note that Schanz, et al., (2011) and Miles, et al., (2011) attempt to calculate the benefits as well as the costs of regulatory changes. This is important, as a cost and benefit analysis is essential in assessing the overall impacts of the new capital and liquidity regulations on banking system resilience. The general approach in these papers is to estimate the GDP losses associated with banking system crises and then to estimate the present value of these losses using a discount factor. The probability of crises is then estimated and linked to the capital and liquidity ratio, as is the reduction in this probability as a result of regulation. After all these steps, the benefits from regulation can be calculated and compared to the costs of regulation.

A critical input to these analyses is the estimated probability of crisis and how it is related to capital and liquidity levels. Schanz, et al., (2011) use an early version of the network model type in constructing the probability of crisis with very simplistic assumptions. For example, they assume a bank fails if its capital ratio approaches the Basel II minimum of 4%. The model is calibrated using 2007 data for the five largest U.K. banks, with a systemic crisis defined as the joint default of at least two of these banks. Miles, et al., (2011) also uses a simplistic approach for deriving the probability of bank crisis. They assume that the percentage fall in the value of risk-weighted assets moves in-line with any permanent fall in the level of GDP. They think of a banking crisis — at least of the sort that higher capital can counter — as a situation where many banks come close to insolvency: the point where the fall in the value of their assets is close to being as large as (or is greater than) the amount of loss-absorbing equity capital they have. While the economic reasoning is intuitive, the estimated probability of crises is based on limited empirical studies, and the estimate of how this probability is impacted is assessed more based on heuristics than by rigorous empirical analysis.

In addition to affecting the credit extension function of banks, the new regulations may also potentially distort the asset market and lead to unwanted consequences on liquidity provisioning, another important economic function of banks. For example, the implementation of a liquidity requirement necessitates specifying qualified liquid assets. Northcott and Zelmer (2009) argue that if liquid assets are too narrowly defined, it can distort the functioning of the eligible asset. This scenario occurs if banks must effectively immobilize eligible assets in order to meet requirements, reducing market liquidity for them. Furthermore, a narrow definition of liquid assets may increase the risk of forcing banks to purchase government debt. By contrast, a broader definition of liquid assets may sustain the liquidity of additional assets, since banks may be more willing to trade them, knowing that they meet the liquidity standards.

Malherbe (2014) shows that liquidity requirements may even go in the opposite direction of their original intention. In short, he argues that a liquidity requirement may reduce the future need to raise cash, deterring market participation, impairing market liquidity, and perhaps even causing a liquidity dry-up. More specifically, the paper presents a model in which cash holding imposes a negative externality, because it worsens future adverse selection in markets for long-term assets.²⁶ The intuition, from a buyer's point of view, is that the more cash a seller is expected to have on hand, the less likely he is trading to raise cash, and the more likely he is trying to unload the assets that he considers overvalued.²⁷ When agents decide to hold cash, it decreases the expected quality of their future sales. This depresses the market price, which imposes an externality on other agents. Moreover, the lower the expected market price, the more appealing it is to hold cash. This scenario may result in widespread hoarding behavior, which, in turn, causes the market to break down.

Another example of the unintended consequences of regulation on market liquidity is the impact of the “Volcker Rule,” one of the key pieces of Dodd-Frank legislation. The rule prohibits banks from making certain principal investments considered speculative in nature. The rule also narrows the distinction between market making and proprietary trading and effectively bans banks that are market makers from engaging in the latter.

The rule's intent is reasonable, as it tries to limit excessive risk-taking by banks. However, like many regulations, the Volcker Rule has some unintended consequences. Perhaps the most significant for investors is banks dramatically decreasing their bond

²⁵ Research sponsored by The Clearing House Association.

²⁶ The notion of adverse selection originates in insurance and refers to a situation where someone's demand for insurance is positively related to the chance of using the insurance, while the insurer is not aware of this relation for this particular person and, thus, cannot account for it in the price of insurance. The term has been adopted in economics and is widely used for similar situations where asymmetric information of market participants affects market performance.

²⁷ Using economic slang, we might call such assets a “lemon.”

inventories, as they de-lever their balance sheets and wind down their proprietary trading activities. This has decreased liquidity and caused transaction costs to increase in certain areas of the market. This is especially the case for the corporate bond market, which has seen dramatic reductions in corporate bonds held on dealers' balance sheets since the financial crisis of 2007–2008 and again following passage of Dodd-Frank. This dynamic has caused trading cost increases for corporate bond investors.

Clearly, the regulatory measures discussed above have complex effects, and they impact both the financial stability and the economic contributions' aspects of resilience. The beneficial influence on one aspect of resilience may come at the cost of the negative influence on the other aspect of resilience. As discussed, regulation potentially improves shock absorption, but it is also likely to decrease banks' contributions to the broader economy. Tracking and analyzing the consequences of these regulations is difficult but absolutely necessary in order to pursue the optimal balance between the costs and benefits of regulation. While considerable efforts have been put forth toward this goal, much more work remains to be done.

The approaches for measuring and modeling resilience outlined in Section 3 can be used to provide insights in this pursuit. As discussed before, one of the key inputs in the cost and benefit analysis is the probabilistic assessment of banking crisis and its relationship with capital and liquidity levels. This is an area that needs significantly more and robust empirical research, as the existing research (e.g., Schanz, et al., 2011) relies primarily on calibration with limited empirical data. This link can be built on a stronger empirical footing using the two modeling approaches we suggest in Section 3.3: the credit risk type model and the network model. In particular, quantifying the link might benefit from a better usage of a historical panel data of bank failures for empirically determining the relationship between bank failure and capital and liquidity levels.

With firmer empirical evidence, the framework outlined in Section 3.3 can then be used to inform a range of appropriate capital and liquidity requirements by comparing marginal cost to marginal revenue (measured as percentage of GDP) at different levels of capital and liquidity ratios. Depending on the specific model used, marginal costs may stay the same by construction for each percentage point increase of a given ratio. Marginal benefit, however, decreases as the capital or liquidity ratio increases, due to a non-linear relationship between the ratio and the predicted probability of a systemic event. When the capital or liquidity ratio is excessively large, the decrease in probability tends to zero, making the marginal benefit tend to zero. The optimal level of the ratio can be inferred by setting the marginal benefit to the marginal cost.

It is also important to note that existing studies on tradeoff primarily focus on specific regulations, for example the new capital and liquidity standards. Today, there has been no empirical study that assesses the cost and benefits of all the regulations in totality. Given that no single modeling framework nor measure exists to achieve the objective, we advocate taking the approach of examining a collection of the resilience attributes and utilizing a collection of economic models to provide additional insights, as we have illustrated in Section 3.

5. Concluding Remarks and Discussion

As discussed in previous sections, an optimal set of regulations may exist to maximize sustainable economic growth and social welfare by promoting a stable financial system and by simultaneously avoiding excessive limitations on banks' abilities to perform functions critical for economic growth. However, to date, neither policymakers nor academics have conducted any major analyses that consider the costs and benefits of the full set of regulations that have been implemented or will be in the near-term.

Central to these new regulations is banking system resilience — the notion that banks must be able to survive and to continue functioning during crises, a primary goal of regulation. For the purposes of analyzing the stability/growth tradeoff, we have put forward a new definition of banking system resilience. Our definition facilitates analysis of the tradeoff between financial stability and the ability of banks to provide economic services to the broader economy. In this context, resilience is both the banking system's ability to absorb shocks without relying on government support as well as the ability to perform its core economic functions, thereby contributing to sustainable economic growth.

Much work remains to be done to further understanding of banking system resilience, specifically identifying the necessary data and metrics and building the relevant models. Ultimately, we believe that one can develop a robust framework that recognizes and measures banking system resilience and monitors the tradeoffs between regulation designed to improve financial stability and economic growth. We hope this paper helps stimulate interest, discussion, and additional research, especially empirical research, all in an effort to undertake a grounded approach when developing and reviewing regulations that impact the entire financial system.

And while this paper takes a comprehensive look at the primary resilience issue above, the subject is very complex, and many issues extend beyond our immediate scope. Many questions remain. In concluding, we discuss some related areas not specifically

addressed within the main body of this report: market resilience and the shadow banking system's resilience. These subjects are important and should be recognized in the broader discussion of resilience. Future research in these areas can shed additional light on the stability of financial and banking systems as a whole, as well as regulation's impact.

Banking system resilience is related to the market resilience. The main parts of a financial system are banks, non-bank financial institutions, and financial markets. While we have not provided a formal definition of market resilience, it can be roughly understood as the ability of the financial markets to withstand disruptions and to continue functioning normally.

On the one hand, banking resilience depends upon financial market strength. Aguiar, Bookstaber, and Wipf (2014) illustrate how financial markets play an important role in financial institutions' funding liquidity. Lack of financial market stability makes funding difficulties more severe during a distressed scenario and, thus, significantly damages institutions' abilities to absorb shocks. More specifically, the financial stability of the banking system greatly depends on banks' financing capabilities, especially short-term financing. During an adverse scenario, money market funds can be the first to respond and drop the troubled institution as a counterparty for unsecured commercial paper. Following that action, repurchase agreements may require higher quality collateral. Such events can greatly decrease the financial stability of the banking system and increase banks' probabilities of default.

On the other hand, market resilience depends on banks' health and their performance as well. In general, banks are important market makers and supply liquidity in the securities market. Illiquidity can impair the ability of financial markets to work properly and to meet the economy's needs.

From the above, we see that the two main components of the financial system rely on one another to function properly. Increased resilience of either component increases the resilience of the entire financial system. Furthermore, one component can take on more lending/financing activities for the real economy when the other underperforms. For example, Mora (2010) points out that banks can help avoid financial disruptions and business liquidations during financial crises if they are not at the center of the crisis. In particular, businesses shut out of the securities markets seek to fund their operations by drawing down credit lines established with banks during normal times, and banks should have no difficulty meeting these increased credit demands with funds from depositors seeking safe assets, such as bank deposits. Similarly, when banks contract credit to the private sector, the bond markets can potentially provide more financing. Becker and Ivashina (2011) analyze this substitution between bank loans and bond issuing.

The possible measures of market resilience and banking system resilience may differ. In general, market resilience may be more observable and, thus, more intuitive, in the sense that its measures may be more easily obtained from market data. For example, Vayanos and Wang (2012) define market resilience as the speed at which liquidity recovers from shocks. Foucault, Kadan, and Kandel (2005) measure market resilience by the probability that, after a liquidity shock, the bid-ask spread reverts to its former level before the next transaction. In comparison, the banking system's resilience measures, especially unified ones, are more abstract and, thus, harder to construct. These measures can be affected easily by assumptions and modeling technique choices.

Another important component of the modern financial system is the shadow banking system, which includes money market funds, special purpose vehicles, government sponsored enterprises, and hedge funds. We have not formally discussed the resilience of the shadow banking system, because it is out of the scope of this report. However, as shadow banking is highly connected with the banking sector, we briefly discuss their relationship.

On one side, the banking sector benefits from the shadow banking system. For instance, special purpose vehicles give banks the ability to increase their balance sheet turnover and extract the maximum value from their capital. More specifically, by using special purpose vehicles, banks can unload their loan portfolios before their maturities and obtain cash, which can generate new lending or investment. On the other side, the shadow banking system relies on the banking sector for its operations. For example, hedge funds need the liquidity facilities provided by banks as well as bank loans in order to achieve high leverage.

Due to this high level of interconnectedness between the two sectors, the resilience of the banking system is intertwined with that of the shadow banking system. It is important to recognize the importance of this interconnectedness for defining and measuring banking system resilience. For example, efforts to increase banking system resilience may result in pushing certain activities to less-regulated entities. As a result, they may be counterproductive to the overall resilience of the entire system. A holistic view of banking system resilience requires simultaneous characterizations of shadow banking system resilience as well, a daunting and worthy effort beyond the scope of our study.

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Appendix A: Review of the Literature on Systemic Risk

Systemic risk is closely related to the financial stability aspect of our resilience concept—the system's ability to survive shocks. Though the literature on systemic risk spans several decades, the bulk is merely a few years old and focuses primarily on the recent post-crisis period. Many recent studies are not yet fully formalized and are migrating from working papers to academic and regulatory journals. We begin by reviewing systemic risk definitions and continue with a discussion of measures commonly used for systemic risk.

Review of Definitions

The literature on systemic risk includes hundreds of academic and regulatory policy pieces. Despite this abundance, the concept of systemic risk remains fuzzy in nature and, at present, there is no single, uniformly accepted definition. Broadly speaking, systemic risk is the risk of the collapse of an entire financial system or market, as opposed to the risk associated with an individual entity or a group of system components. The operational definitions of systemic risk in the literature can be classified into the following groups:

- The first group defines systemic risk as the risk of an extreme loss event for the system as a whole (Acharya, et al., (2012), Maltz (2013), Acharya, et al., (2014), Brownlees and Engle (2012), Hansen (2013)). This definition focuses on the financial health of intermediaries, rather than on credit conditions.
- Another similar, though different definition is the simultaneous failure of a large number of (large) financial institutions (Huang, Zhou, Zhu (2009), Schwaab, Koopman, and Lucas (2011), Amini, et al., (2012)).
- The third type describes systemic risk as a composition of (macroeconomic) shock and contagion (Martínez-Jaramillo, et al., (2010) and De Bandt and Philipp Hartmann (2002)). A subclass of this group focuses on the phenomenon of interconnectedness and contagion only (Schwaab, Koopman, and Lucas (2011), Giese (2013), Amini, et al., (2012), Adrian and Brunnermeier (2011), Vives (2010), Dia and Van Hoose (2013)).
- The fourth group simply describes systemic risk as the opposite of financial stability (Billio, et al., (2012), Bisias, et al., (2012), ECB (2009), IMF paper (2014), Schwaab, Koopman, and Lucas (2011)).
- There is also a group of definitions that focuses on financial risk that spills over into the real economy (ECB (2009), Bluhm and Krahenz (2011), Vives (2010), Adrian and Brunnermeier (2011), Hansen (2013)).
- Finally, systemic risk can also be defined as a “we know it when we see it” statement (Hansen (2013), Billio, et al., (2012), and there are more). This definition appears popular within the regulatory context.

Clearly, many of these definitions come close to our financial stability aspect of resilience. For instance, the definitions of systemic risk as the risk of an extreme loss event for the system as a whole or as the simultaneous failure of a large number of (large) financial institutions are very much in tune with our financial stability aspect of resilience.

Review of Measures

The 2007–2008 financial crisis led to the introduction of new regulations that focus on the identification and treatment of financial institutions that, in the case of their failure, can threaten the performance and stability of the entire financial system. Such institutions are designated Systemically Important Financial Institutions (SIFIs). They are subject to different regulatory requirements than other financial institutions.

Similar to systemic risk, there is no specific definition of what constitutes a SIFI. Financial institutions are listed as SIFIs on the basis of attributes such as size, complexity, concentration in product areas, interconnectedness, expert opinion, etc. Characteristics can be supplemented with market-based measures of systemic risk, which have appeared in the literature during the past several years, can come from publicly available information, and can target the identification of SIFIs by focusing on the “contribution” of individual institutions to possible distress. Below, we discuss the three most prominent examples of such measures: CoVaR, MES/SES/SRISK, and DIP, along with some measures that have not gained as much traction in the literature, namely Co-Risk and OBSESS.

One of the important market-based measures was introduced by Adrian and Brunnermeier (2011). The measure focuses on the system as a whole and is based on the logic that the contribution of an individual institution to the systemic risk of the financial system should be related to the impact of that institution on the entire market. To formalize this logic, the paper introduces a notion of CoVaR for a particular institution, defined simply as the Value-at-Risk of the entire financial sector, conditional upon the institution being in distress. Consequently, the difference between CoVaR conditional upon distress and CoVaR conditional upon a

median state of the institution serves as a measure of the marginal contribution of a particular institution to the overall systemic risk. The paper names this measure ΔCoVaR and proposes a way to estimate it using quantile regression. The econometric framework uses data on market equity and balance sheets for publicly traded institutions. The computed ΔCoVaR is regressed upon lagged characteristics of financial institutions (size, leverage, maturity mismatch, etc.). The relationship is used to construct Forward- ΔCoVaR , a forward-looking measure that can be used to evaluate a buildup of systemic risk and to calibrate regulatory capital requirements.

The CoVaR framework has been actively cited and discussed in the literature since its inception. For instance, White, Kim, and Manganelli (2014) propose an alternative way to compute ΔCoVaR based on an extension of the CAViaR model by Engle and Manganelli (2004). The CoVaR approach has been compared against other measures of systemic risk (Lee, et al., (2013), Benoit, et al., (2013)). Bernard, Brechman, and Czado (2013) point out how the change in the definition of conditioning event can influence the CoVaR measure's behavior.

Acharya, et al., (2010) introduced the Systemic Expected Shortfall (SES) measure of systemic risk. SES is defined as expected undercapitalization of a bank when the entire system is undercapitalized. This measure is based on the notion of Marginal Expected Shortfall (MES), defined as the decrease in the value of equity for a given firm when the entire market is in distress. MES can be seen as the marginal contribution of an institution to systemic risk, measured by the expected shortfall of a system, i.e., the increase in the system's expected shortfall, induced by a marginal increase in the weight of the institution in the system. The paper shows that SES is a function of a firm's leverage and MES.

Brownlees and Engle (2012) consider a closely related measure of systemic risk, which they call SRISK and define as an expected capital shortfall for a given financial institution, conditional upon a crisis affecting the entire financial system. The paper shows SRISK to be a function of MES, leverage, and firm size. Formally, SRISK is almost identical to Acharya, et al.,'s (2010)²⁸ SES measure. The main contribution of Brownlees and Engle (2012) is that they estimate MES and, thus, SRISK/SES *ex ante*, employing a Generalized Autoregressive Conditional Heteroscedasticity model to measure volatilities and a Dynamic Conditional Correlation model to measure correlations. NYU Stern's Vlab website uses this methodology to compute and report systemic risk measures for U.S. financial institutions on a daily basis.²⁹

Distress Insurance Premium (DIP) is a measure of systemic risk introduced by Huang, Zhou, Zhu (2009). The paper attempts to measure the systemic risk of the banking sector with the estimated price of insurance against large default losses in the sector. Intuitively, the measure is a risk-neutral analog of expected shortfall for the banking sector. It is constructed from Credit Default Swap spreads data and equity correlations for the twelve largest U.S. banks and involves simulating risk-neutral loss distribution for a portfolio of these twelve banks. A follow up paper by Huang, Zhou, Zhu (2011) proposes to measure the systemic importance of a financial institution as the marginal contribution of the institution to the distress insurance premium of the entire banking sector. These two papers show a close resemblance to models adopted in the financial sector that measure and manage credit risk.

Apart from the three measures listed above, there are also many other market-based measures. For example, the Co-Risk measure, proposed by Chan-Lau (2009), examines the co-dependence between the Credit Default Spreads (CDS) of various financial institutions. Similar to CoVaR, it uses quantile regression to estimate the conditional VaR. The main difference is that, instead of using the return data, it utilizes a different source of information, the CDS spread data, and is, consequently, more focused on credit risk links between institutions.

Malz (2013) proposes a risk-neutral systemic risk indicator named Option-Based Systemic Expected Shortfall Statistics (OBSESS). The construction has two main steps. In the first step, risk-neutral return distributions and a single correlation value for all pairs of firms are inferred from current market prices of options.³⁰ Copula techniques are then used to obtain a joint return distribution. In the second step, returns are simulated according to the joint distribution specified in the first step. The simulated equity returns provide an estimate of the systemic risk indicators, defined as probabilities of different loss levels of the entire portfolio of financial institutions. This approach does not explicitly model defaults of individual institutions. While based on the current market information, as well as being forward-looking, the approach takes in information on the market prices of options, equities, and, as a variant, CDS spreads, along with derived information such as implied volatilities of individual stocks and indexes. It is limited by the availability and quality of such information.

²⁸ See Benoit, et al., (2013) for the theoretical and empirical comparison of the MES/SES, SRISK, and CoVaR.

²⁹ See <http://vlab.stern.nyu.edu/welcome/risk/>

³⁰ See Breeden and Litzenberger (1978) and Banz and Miller (1978).

It is important to note that the systemic risk indicators constructed in this way are also risk-neutral in nature³¹ and cannot be interpreted as physical probability. In this respect, the indicators are similar to DIP, in the sense that they both blend market expectations as well as the market's desire to protect itself against tail risk. In comparison, our model-based approach focuses on the physical probability of a systemic event, as well as on the actual expected shortfall, given a systemic event.

As mentioned, the systemic risk measure focuses primarily on the systemic risk of an individual institution and less, if at all, on the evaluation of the entire financial system. However, DIP and OBSESS approach this problem by first modeling the systemic risk of the system. This approach makes them the most closely-related frameworks to the model-based approach measuring financial stability we propose.

Appendix B: Insights from Other Disciplines

Compared to systemic risk, definitions of financial/banking resilience appear scarce in the economic literature. To better define resilience, we review resilience definitions and measurements common in other disciplines.

For example, psychological resilience is defined as an individual's ability to properly adapt to stress and adversity, and it is measured as the reported number of symptoms of individual PTSD after a disaster in Bonanno and Galea (2007).

In ecological literature, resilience is either defined as the time required for an ecosystem to return to an equilibrium following a perturbation, or as the capacity of a system to absorb disturbance and reorganize while undergoing change, so as to still retain essentially the same function, structure, identity, and feedbacks. Westman and O'Leary (1986) present measures of four components of ecological resilience to quantify the response of coastal sage scrub to fire in southern California. The four components are: (1) elasticity (the rate of recovery following disturbance), (2) amplitude (threshold of disturbance, beyond which recovery to the original state no longer occurs), (3) malleability (extent of alteration of the new stable-state from the original), and (4) damping (extent and duration of oscillation in an ecosystem parameter following disturbance). Cumming, et al., (2005) develop a quantitative measure of resilience as the likelihood of a change in the ecosystem's identity (and its magnitude), given disturbances.

In physics and engineering, resilience is defined as the capacity of a material to absorb energy when it is deformed elastically and then, upon unloading, having this energy recovered. Therefore, it is measured as the maximum energy per volume that can be elastically stored.

The National Academy of Sciences (NAS) defines "disaster resilience" as the ability of a system to perform four functions with respect to adverse events: (1) Planning and Preparation, (2) Absorption, (3) Recovery, (4) Adaption. Based on this framework, Bene (2013) argues that resilience can be measured in terms of the costs that a household must "pay" to pass through a particular shock. These costs can be broadly grouped into three categories: (1) the *ex ante* investments made as a preparedness process (anticipation costs); (2) the costs of destruction following the impact of the shock; (3) the *ex post* recovery costs, including the replacement costs of what has been destroyed and also the various costs associated with change/adaption or transformation and the cash/food/assets transfers implemented through *ex post* emergency/assistance interventions. So, in simple terms, resilience costs equal anticipation costs, plus impact costs, plus recovery costs. The quantified resilience cost then gives an indication of the level of a system's resilience.

From the above literature, we can summarize that, although the specific definitions of resilience differ in various fields, the core concept of resilience is the capacity to absorb or recover from shocks. Our definition of banking system resilience incorporates this important aspect of resilience, as well as the functioning aspect of the banking system.

³¹ Since they are constructed using the risk-neutral distribution of individual returns.

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