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Looking Deeper, Seeing More: A Multilayer Map of the Financial System

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This brief introduces a multilayer map to show how risks can emerge and spread across the U.S. financial system. The three layers in the map represent short-term funding, assets, and collateral flows. Risk is transformed and moves from one layer of the map to the next through transactions among large market players. This brief uses the difficulties faced by Bear Stearns and its two failed hedge funds during the financial crisis as a case study to illustrate how the multilayer map can shed light on potential vulnerabilities and paths of contagion. The map requires detailed data to illustrate the full scope of interconnections in the financial system.

The 2007-09 financial crisis showed the need for a more sophisticated way to monitor the financial system. Risks emerged and spread in unanticipated ways. The Financial Crisis Inquiry Commission noted that a "tangle of interconnections" played an important role in the spread and magnitude of the crisis.[2] Today, focusing on risks from a single type of financial institution or product is no longer adequate. Regulators need information about the many exposures that market participants have to each other.[3]

This brief presents the financial system as a multilayer map, building on earlier OFR papers that analyzed single layers.[4] The three layers in the map show flows of short-term funding, assets, and collateral. The layers are linked by large banks, hedge funds, central counterparties (CCPs), and other market participants.

The multilayer map reveals potential channels of contagion that are not visible in single-layer maps. A risk to an activity in one layer can become a risk to activities in other layers. For example, a large bank or dealer facing a shortfall in funding might reduce its lending to several hedge funds (funding layer), and the hedge funds might respond by liquidating assets (asset layer), resulting in a drop in asset prices that affects collateral values (collateral layer).

The multilayer map provides a new way to analyze the role of financial institutions as potential sources of stability or instability. It also identifies the types of data that could be useful for a fuller analysis of threats and vulnerabilities. Policymakers could use the map to monitor the stability of the financial system as a whole.

The multilayer map is more than conceptual. The case study in this brief shows that the map can illustrate how the 2007 collapse of two Bear Stearns hedge funds that had invested mostly in mortgage-linked securities and the subsequent troubles of Bear Stearns itself affected the entire financial system.

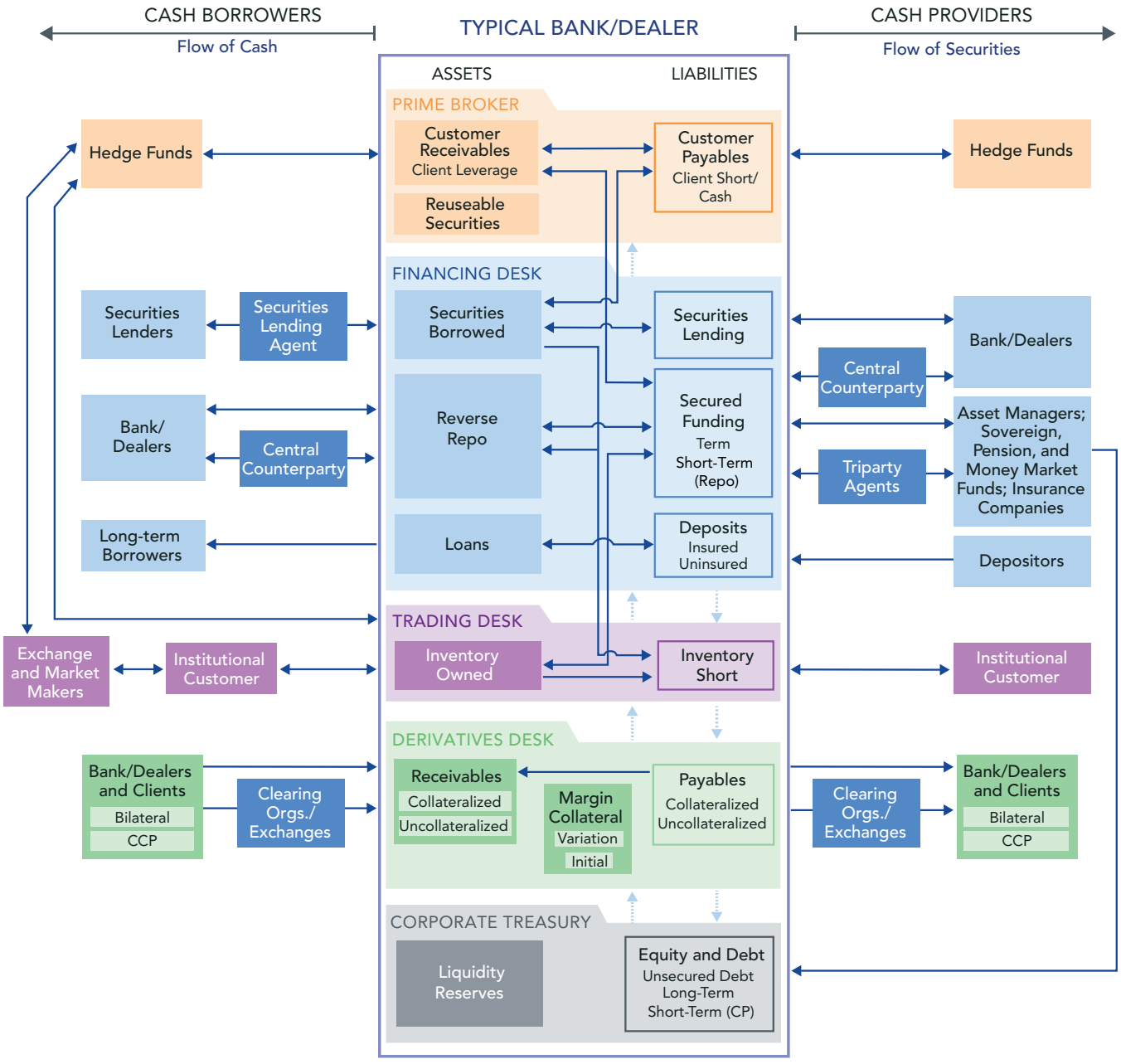
The Financial System: A Network of Networks

As in earlier OFR papers, this brief analyzes the financial system as a network. Network analysis is a relatively new tool for studying the financial system. Epidemiologists have long used network analysis to track and contain the spread of contagious diseases. More recently, intelligence experts have used it to analyze terror networks.

Network analysis looks at relationships in key areas of the financial system instead of focusing primarily on the balance sheet of a single company. It can be used to study the resilience of individual counterparties and their impact on the broader system.

The financial network map in **Figure 1** shows the relationships among market participants. It highlights the central role played by a typical large bank or dealer.

Figure 1. Financial Network Map Showing Relationships among Market Participants



Note: Key market participants and bank/dealer desks involved in funding are displayed in dark colors; others are shaded lightly.
Source: Authors' analysis

These types of companies are labeled in the map as "Bank/Dealers." Each node in the map represents a market participant. Banks, CCPs, hedge funds, pension funds, insurance companies, exchanges, and institutional customers are nodes. A link between two nodes represents a relationship, such as a loan, derivative, or other type of financial contract or obligation.[5]

Most network research has analyzed the financial system as a single-layer network within one market or involving one type of transaction.[6] However, transactions differ among companies and within them. Also, money or collateral do not simply flow from one entity to another. Market participants transform short-term funding, assets, and collateral as cash, and securities flow throughout the financial network. One layer cannot adequately represent all of these transformations.

Multilayer maps can capture more information.[7] They portray the financial system as a network of networks. For example, a multilayer map can help identify a large market participant that is a node in more than one market layer. Such a company could be a source of strength to the financial system, if managed well. If not, it could be a source of weakness. The failure of one of these nodes in a layer can lead to failures of dependent nodes in other layers. This phenomenon can happen repeatedly, leading to a cascade of failures. For that reason, multilayer networks are more fragile than single-layer networks. Connections between the layers can amplify the scope and magnitude of stress in a single layer.

Maps of multilayer networks show three stages of damage following a major shock. The initial stage is a fast, sharp decline in network nodes. Next is a lengthy plateau period when damage spreads slowly through the network. The final stage is a rapid, cascading collapse of remaining network nodes.

Mapping the Three Layers

This section describes independent network maps for three key financial activities: funding, assets, and collateral. The three maps are shown in **Figures 2, 3,** and **4**. Each map replicates **Figure 1**, but with key market participants or bank/dealer desks displayed in dark colors to highlight their roles in each layer.

To illustrate each layer map, the analysis focuses on Bear Stearns and two large hedge funds run by its asset management unit, the High-Grade Structured Credit Strategies Fund (High-Grade Fund) and the High-Grade Structured Credit Strategies Enhanced Leverage Fund (Enhanced Leverage Fund). The High-Grade Fund was launched in 2003 and quickly attracted more than $1 billion of investor capital. The Enhanced Leverage Fund was launched in 2006 with nearly $800 million from investors.[8]

Bear Stearns is a good example because it was involved in all three layers. The failure of the two hedge funds in 2007 and the subsequent forced sale of Bear Stearns itself less than a year later were important events in the financial crisis, as discussed later in this brief.

Funding layer

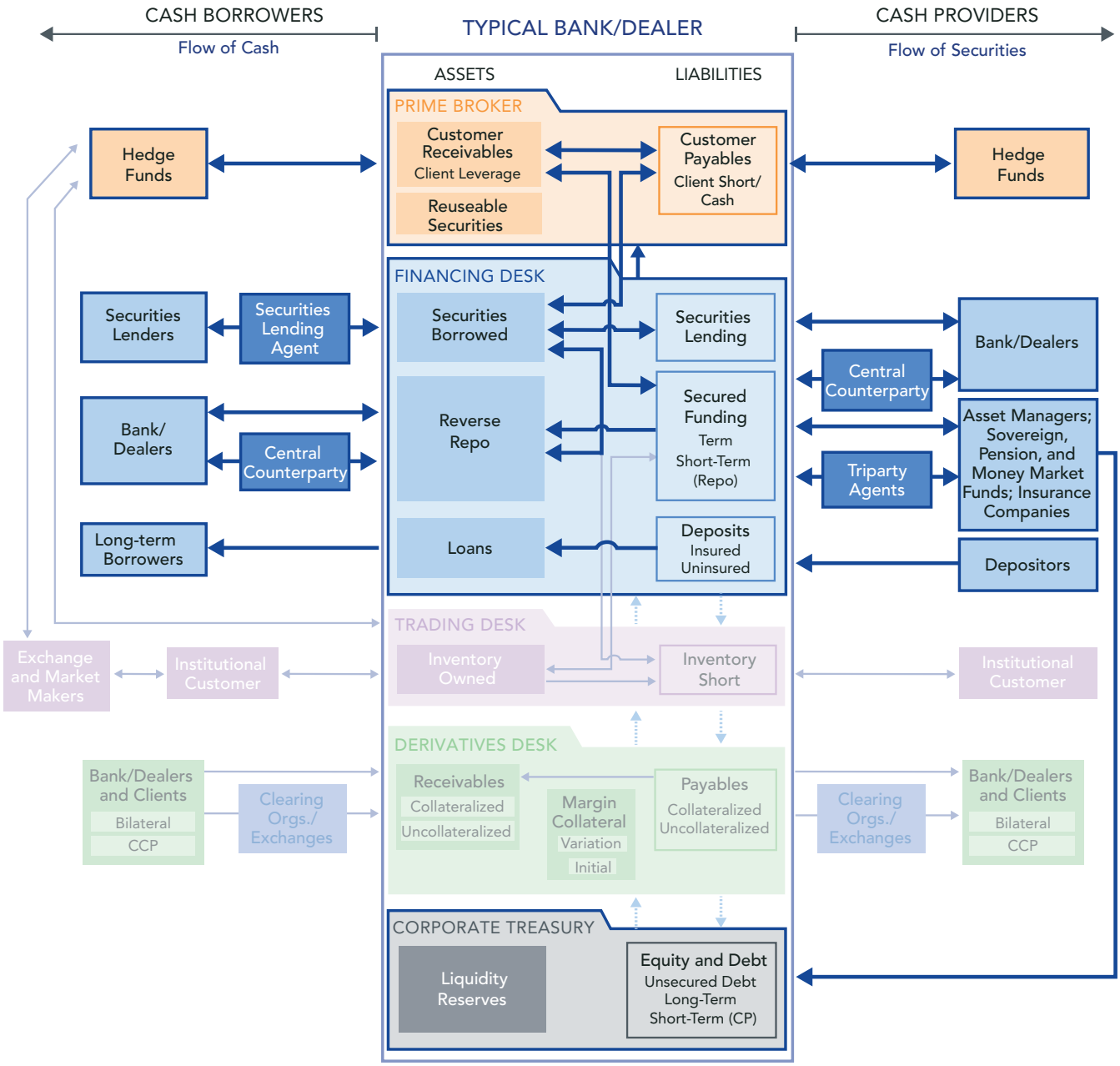
The funding map shows how funding moved through a large bank or dealer such as Bear Stearns before the crisis (see **Figure 2**).[9] At the center is the bank/dealer's financing desk, where the bank/dealer accesses overnight or short-term funding, including secured funding through repurchase (repo) agreements. On the right side of the map, asset managers, depositors, and others provide cash to the bank/dealer.

The bank/dealer's prime broker, shown in orange in the center at the top of the map, provides short-term funding to hedge funds and other customers. The bank/dealer's corporate treasury, shown in grey at the bottom, issues equity and debt, including commercial paper.

Before the crisis, Bear Stearns depended heavily on short-term funding, largely commercial paper and repo funding provided by asset managers and other cash providers (shaded blue on the right side of the map). Its leverage, measured by total assets relative to equity, was nearly 40-to-1 — high for a commercial bank but typical for an independent investment bank before the financial crisis.

Bear Stearns' hedge funds are examples of hedge funds on the cash borrowers' side of the funding map (shown on the top left). The two funds combined held $18 billion in assets at the end of 2006, 10 times their investor capital, through repo borrowing from prime brokers. The newer Enhanced Leverage Fund further

Figure 2. Funding Map for a Typical Bank/Dealer and Related Entities



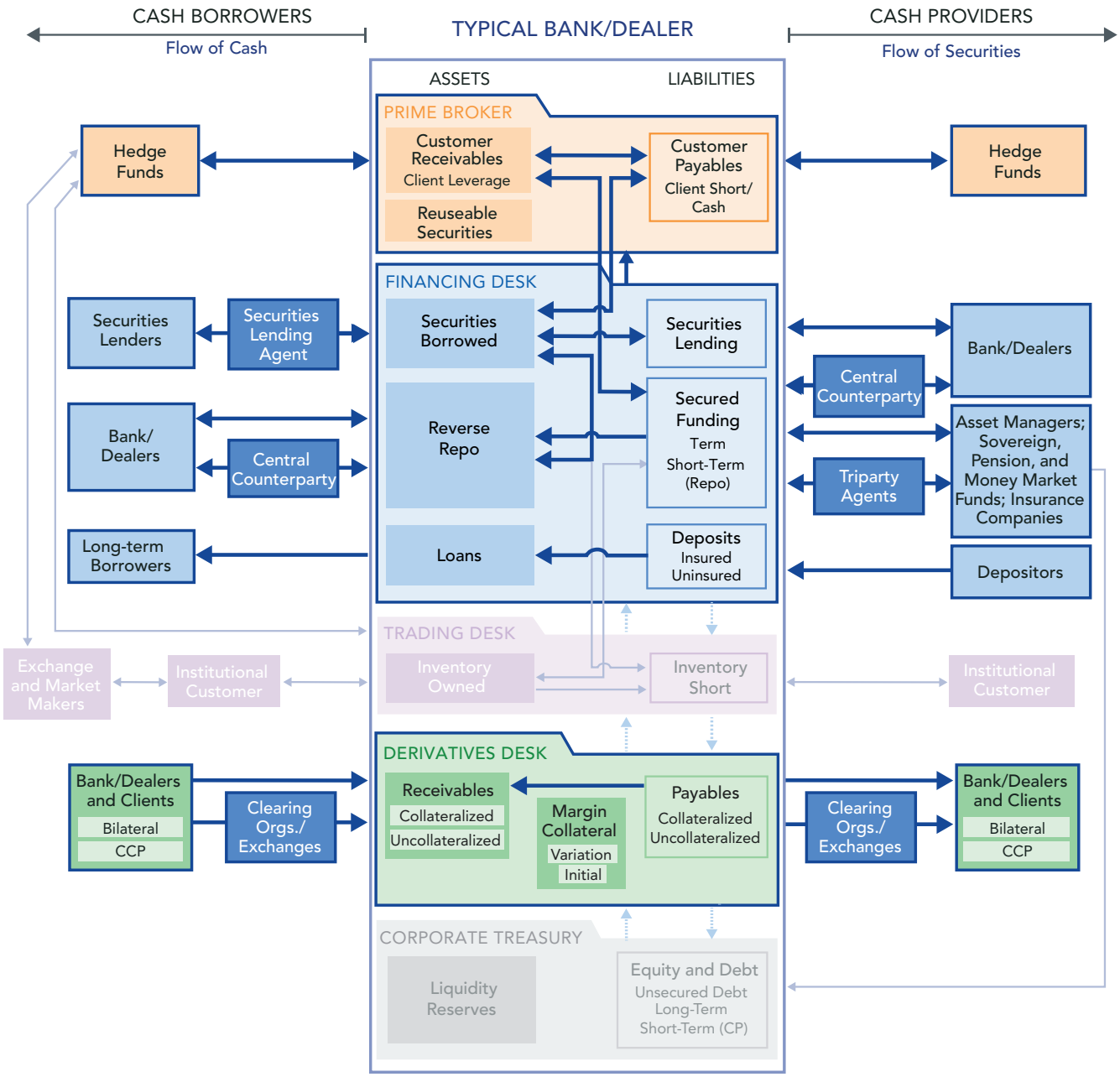
Note: Key market participants and bank/dealer desks involved in funding are displayed in dark colors; others are shaded lightly.
Source: Authors' analysis

boosted its leverage ratio to more than 27 times investor capital through total return swaps with a bank/dealer.[10]

Collateral layer

Collateral can also be presented in a layer map (see **Figure 3**). All flows of secured funding are met by collateral flows in the opposite direction. The collateral map can capture risk management features based on haircuts and quality. (A haircut is the discount on the value of an asset pledged as collateral.) These risk management features are not apparent when considering collateral flows as simply the opposite of funding flows. A recent OFR working paper used a collateral map to explain the effect of a CCP changing margin requirements (see the dark blue box on the right side in **Figure 3**).[11] In a collateral stress event, an increase in margin requirements by the CCP causes secured funding investors to increase their haircut requirements

Figure 3. Collateral Map for a Typical Bank/Dealer and Related Entities



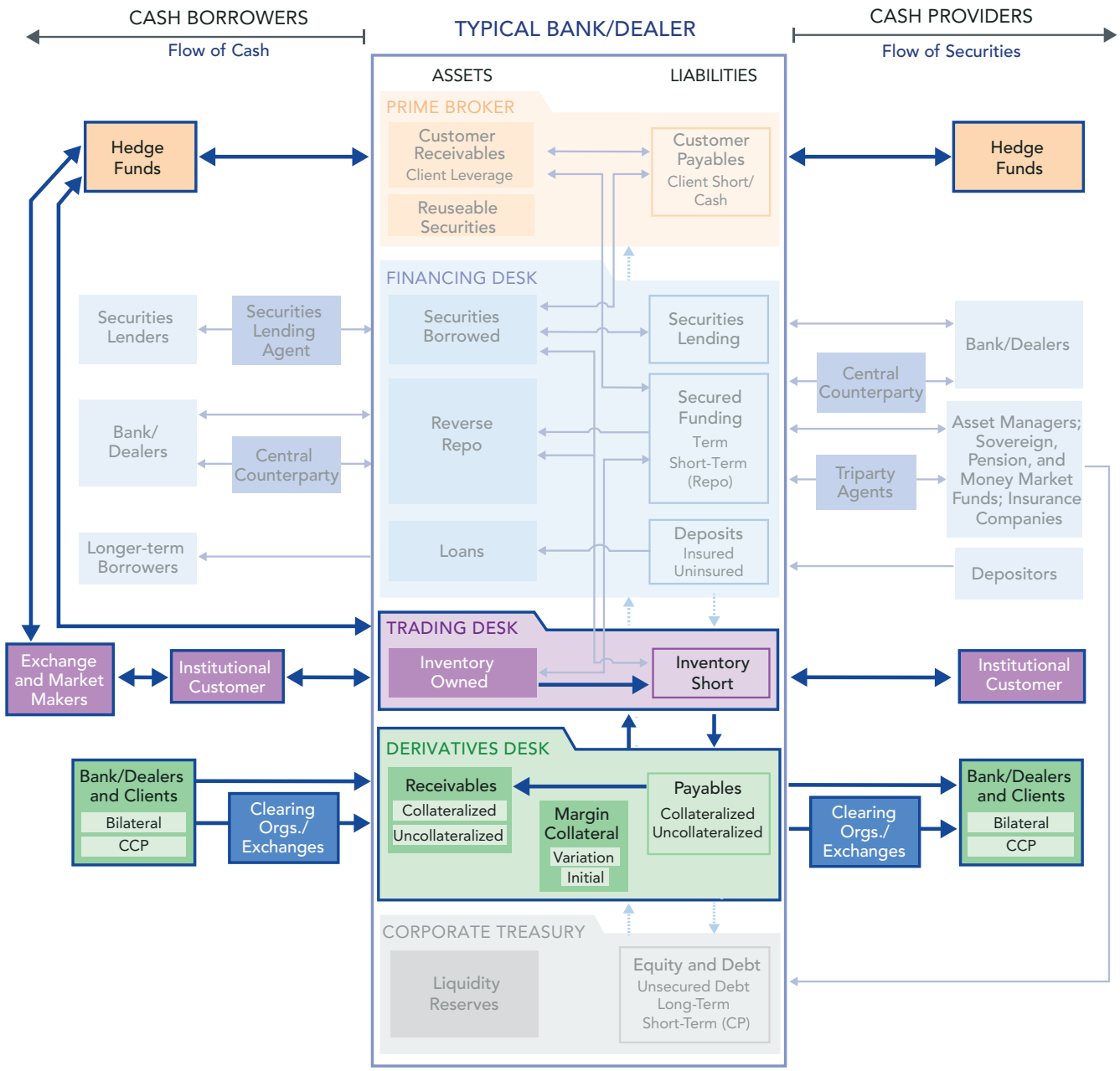
Note: Key market participants and bank/dealer desks involved in collateral are displayed in dark colors; others are shaded lightly.
Source: Authors' analysis

or withdraw the funding provided against the asset. The bank/dealer is then forced to turn to unsecured sources of funding or sell assets to fund the additional haircut. This behavior can result in a further decline of the asset's collateral value, which can lead to a fire sale for that given asset class.

Collateral enters the bank/dealer through the left side of the map. The prime broker unit handles collateral from hedge fund customers. The derivatives desk handles collateral for futures, forwards, swaps, and options through exchanges, clearing organizations, or directly with other bank/dealers and clients. The financing desk handles collateral from securities lending and repo deals. The financing desk is also the engine for collateral transformations — it is where collateral is reused and upgrades are managed.

The collateral map shows channels for collateral flows and transformations. On the right side of the map,

Figure 4. Asset Map for a Typical Bank/Dealer and Related Entities



Note: Key market participants and bank/dealer desks involved in the asset layer are displayed in dark colors; others are shaded lightly.
Source: Authors' analysis

repo collateral can move to an asset manager or other cash provider as a bilateral flow or be held by a triparty agent. Collateral can also move to a CCP.

Bear Stearns, like other investment banks, managed billions of dollars of repo collateral, receiving collateral from hedge funds through its prime broker and posting collateral against loans in the triparty repo market.

The two large Bear Stearns hedge funds posted collateral with prime brokers at the largest investment banks to support as much as $16 billion of repo loans. The investment banks lending to the two hedge funds through their prime brokers were often the same banks selling mortgage-related securities to the funds through their trading desks.[12]

Asset layer

The third layer of the map represents the flow of assets and cash between asset managers and securities markets.

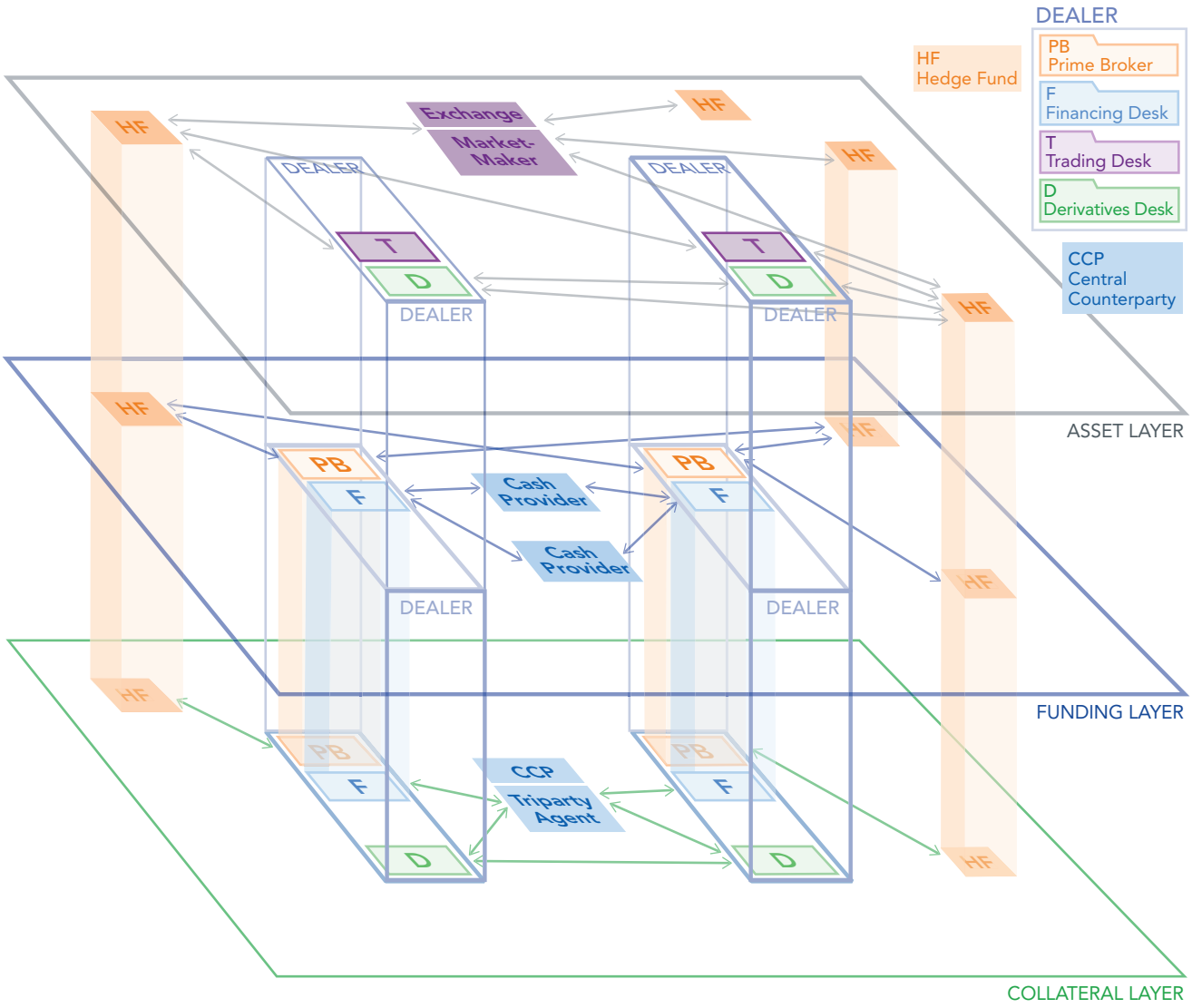
The map includes mutual funds, hedge funds, the trading and investment arms of insurance companies and pension funds, and exchanges. The trading desk provides market-making for institutional customers and hedging for internal risks by going long and short on internal inventory (see the purple trading desk box in **Figure 4**). Exchanges and market-makers are key nodes in this network (shaded purple on the left in **Figure 4**). Exchanges exist for equities and commodities. For other assets such as foreign exchange rates and credit instruments, the principal market-making activity occurs through the trading desks of bank/dealers such as Bear Stearns before the crisis.

The asset layer provides information about the sources of price shocks, which can affect the liquidity and solvency of market participants. It also provides information on price discovery, which the funding map and collateral map do not provide.

Building a Multilayer Map

Single-layer maps help illustrate flows within markets. However, many market participants play a role in more than one financial activity, as shown by the example of Bear Stearns and its hedge funds. For that reason, layering the activity-specific maps provides a more complete map of the financial system.

Figure 5. Three-dimensional Multilayer Network



Source: Authors' analysis

The financial system and its funding, collateral, and asset layers are presented as a three-dimensional multilayer network in **Figure 5**. As shown in the three single-layer maps, some financial entities, such as the bank/dealer, participate in more than one layer, thereby connecting the layers.[13] The multilayer approach establishes a framework for mapping the financial system across participant types and activities.

Most financial networks consist of a core of tightly connected nodes and a sparse, loosely connected periphery of nodes linked to one or a few of the core nodes.[14] Core nodes are in the center of each layer. They are bank/dealers in the funding layer, CCPs and triparty repo agents in the collateral layer, and exchanges and market-makers in the asset layer. Peripheral nodes in the funding layer are suppliers and users of bank/dealers as intermediaries. In the asset layer, peripheral nodes are buyers and sellers, such as hedge funds and asset managers. The representative core and peripheral nodes for each layer are shown in **Figure 5**.

Nodes can be differentiated by the direction of flows among suppliers, users, and intermediaries in each layer. For the funding layer, the supplier is the cash provider and the user is the hedge fund. In the asset layer, the peripheral nodes act as both asset suppliers and users, and can be defined either as sellers and buyers of assets, or as providers and users of liquidity. For the collateral layer, the collateral supplier receives funding, while the user receives collateral. In some cases, peripheral nodes might interact directly in bilateral swap transactions.

Some financial entities cross layers, while others operate only in a single layer. An entity that spans layers may have a different role in each layer. For example, a hedge fund is a buyer or seller of assets in the asset layer, and a user of funding in the funding layer. The way a financial market participant crosses layers, its position in the core or periphery of each layer, and its function as a provider or user can be a blueprint for new categories of financial institutions based on the level of activity in different layers.

A multilayer map can help policymakers monitor financial entities active in more than one layer and calibrate regulations to address new categories. It can also help track how a financial entity changes roles in different layers.

A multilayer map can support analysis of systemically important financial institutions (SIFIs). Regulators currently measure a SIFI's size and dominance in various activities. They could use multilayer analysis to gauge a SIFI's importance across the layers of funding, collateral, and assets. The degree to which a financial entity acts as a core node and crosses layers in a multilayer network map can help show its systemic importance. These connections can lead to more fragility in the financial system.[15] A SIFI that can transmit a market shock or disruption from one layer to another arguably poses more systemic risk. This reasoning suggests that systemic risk in the banking sector is not simply a matter of banks' size, it is also about their span across the layers.

Bear Stearns in the Multilayer Map

The multilayer map offers a new way to illustrate what happened in the financial crisis to Bear Stearns and its hedge funds, which were active in all three layers of the map (see **Figure 6**).

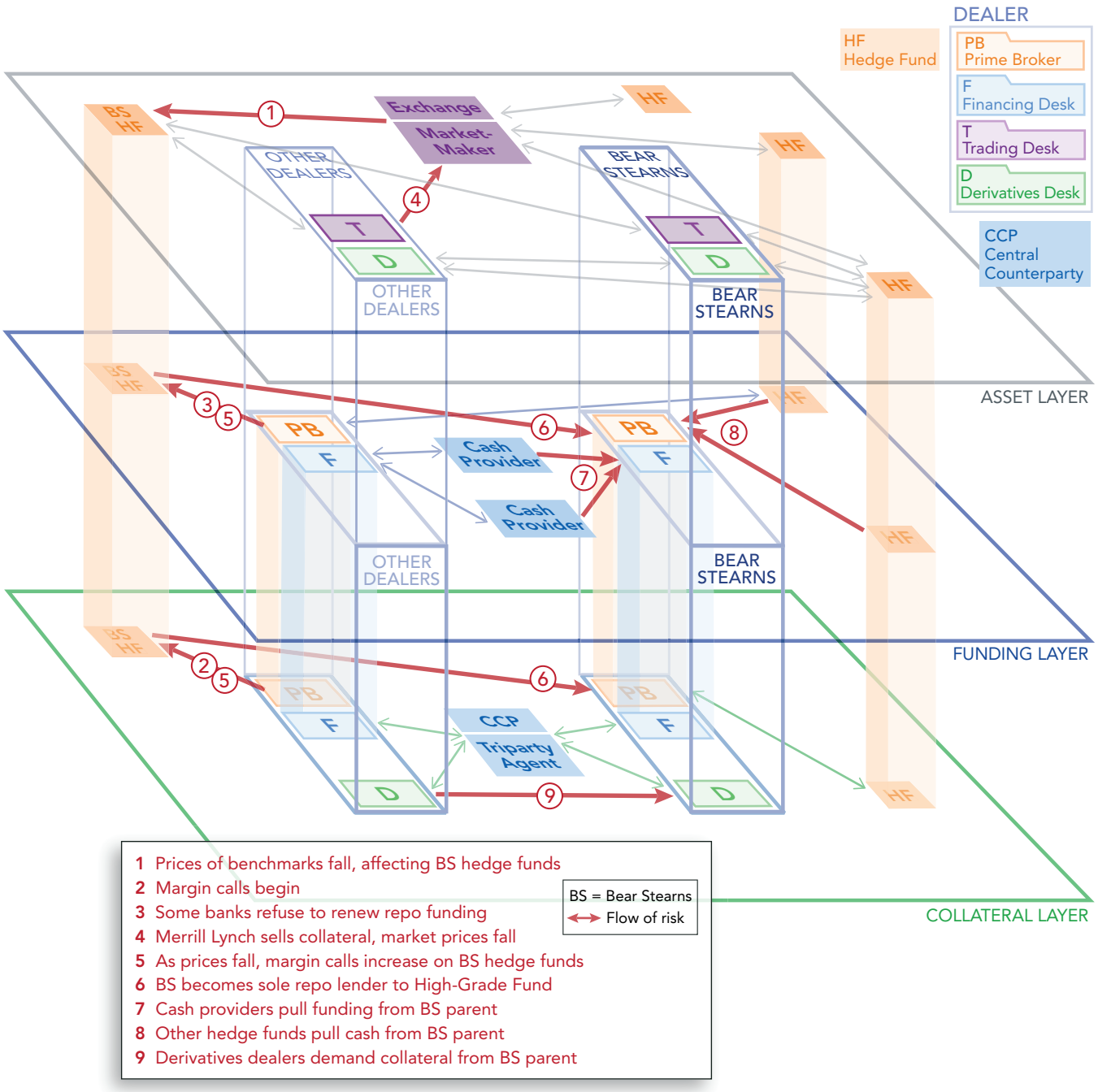
Problems for Bear Stearns' hedge funds began in the asset layer but quickly spread to the other layers, affecting other market participants. Soon after the Enhanced Leverage Fund opened in 2006, the benchmark index for its holdings began falling on exchanges where such indices trade (see ① in the asset layer in **Figure 6**). Investors withdrew money from both of the Bear Stearns hedge funds. By the late spring of 2007, the funds had few options other than to sell assets. Lenders marked down the value of their assets and demanded more collateral, which is known as a margin call. ② Some lenders refused to roll over repo funding, in other words, to renew funding as it expired. ③

Although Bear Stearns exercised little oversight over the asset management subsidiary that managed its hedge funds, its executives became involved. They met with 10 repo lenders to negotiate more time to meet margin calls, reflecting stress through the collateral layer. All the lenders refused. Both funds were forced to sell assets at distressed prices to raise cash to meet the margin calls. One of the repo lenders, Merrill Lynch, a large bank/dealer, seized about $850 million of collateral that the Bear Stearns hedge funds had posted against their loans.[16] Merrill Lynch began to liquidate the collateral by selling the subprime securities,

illustrated in the asset layer. ④ Those sales established a market price for similar subprime securities held and used as collateral by other banks and investment funds, spreading the impact to other nodes in the asset layer. The contagion quickly spread through the collateral and funding layers, as all repo lenders similarly increased their collateral requirements or refused to roll over loans backed by subprime collateral. ⑤

The troubles at the hedge funds soon affected Bear Stearns, the parent company. Bear Stearns had no obligation to support the hedge funds, but executives were concerned about their relationships with other investment banks and their own investors. Bear Stearns became the sole repo lender to the High-Grade Fund by paying $1.8 billion to the funds' repo lenders to take over their collateral. ⑥ Bear Stearns decided not to rescue the more troubled Enhanced Leverage Fund.

Figure 6. Bear Stearns: A Case Study of Financial Contagion



After the failure of its two hedge funds, Bear Stearns itself lost the confidence of its counterparties in the fall of 2007 and the winter of 2008.[17] Repo lenders, mostly money market funds shown as cash providers in the blue boxes in the funding layer, increasingly demanded more collateral and raised interest rates. ⑦ Hedge funds that were customers of Bear Stearns' prime broker, in orange on the right of the funding layer, pulled out their cash. ⑧ Derivatives counterparties, shown in green on the collateral layer, demanded more collateral. ⑨

Challenges, Applications, and Data Gaps

Mapping a multilayer network creates new opportunities as well as new challenges for monitoring financial stability.

For example, network analysts use contagion models to track the effects of disruptions on the financial system. Multilayer maps could provide additional detail to these models. New models would need to account for how shocks spread between map layers, and how the connections and dependencies across layers amplify shocks. This detail could help in developing new systemwide stress tests, and ultimately lead to new intervention strategies for managing financial crises.

Maps of multilayer networks could also lead to revised definitions of financial market participants. In particular, policymakers may want to define companies based on their activities in different layers of the network map.

Multilayer network maps won't be useful for policymakers without good data. Analysis requires detailed counterparty exposure data for each layer of the map, representing a broader range of financial entities and markets (see **Figure 7**).[18] Although regulators have expanded their data collections since the crisis, such data are currently only partly available in various regulators' datasets.[19] To build a full multilayer network map, the datasets would need to be expanded and linked.

Building the asset layer of the map would require data about swaps, securities, corporate and government bonds, commodities, and other asset classes. Partial data are available for some assets, but many gaps remain.

Constructing the funding layer would require data about interbank exposures, and triparty and bilateral repo transactions.[20] The OFR, working with the Federal Reserve, recently completed a pilot data collection from the bilateral repo market that includes counterparty information. Data about counterparty exposures and transactions by hedge funds and money funds are needed in more detail than now available in the Securities and Exchange Commission's Form PF dataset. More data about interbank relationships and bank balance sheets are also needed in addition to what is currently available in Federal Reserve datasets and its Fedwire electronic funds transfer system used by U.S. banks.

Building the collateral layer would require data about triparty and bilateral repo transactions. It also would require information about CCPs' collateral and how collateral is reused by market participants.

All regulatory data submitted by a bank, hedge fund, money market fund, insurance company, and other financial participant would need to include a legal entity identifier.[21] The identifier is a unique code already required by swap market regulators. It can accurately link a company's activities across the funding, collateral, and asset layers.

Conclusion

As shown in the Bear Stearns example, a multilayer map of the U.S. financial system can illustrate how risks begin and spread through funding, collateral, and asset transactions. It can help in examining risks that are layer-specific, such as funding liquidity and leverage, collateral behind secured lending, and asset prices and liquidity. A multilayer map exposes new sources of vulnerability from dependency and interconnectivity across layers. Such connections can amplify and transform vulnerabilities into broader, systemic risks.

A single-layer map cannot fully capture the array of activities in the financial system, or how different nodes are affected by shocks or disruptions. Risk is transformed as it moves from one layer of the map to the next. A price shock may transform into a funding risk. Similarly, a price shock that moves to the collateral layer may be expressed as a counterparty or credit risk. Or, as a shock moves from the collateral layer, a counterparty risk may prompt a CCP to sell assets, pushing

Figure 7. Financial Participants in a Multilayer Network

	Agent	Network Node		Network Function			Primary Regulator
		Core Node	Peripheral Node	Supplier	Intermediary	User	
ASSET LAYER	Hedge Funds		X	X		X	SEC, CFTC
	Bank/Dealer Trading Desk	X			X		OCC, FED, SEC
	Bank/Dealer Derivatives Desk	X			X		OCC, SEC
	Exchanges and Market-Makers	X			X		SEC, CFTC, SRO
FUNDING LAYER	Hedge Funds		X			X	SEC, CFTC
	Cash Providers (pension funds, insurance companies)		X	X			U.S. Department of Labor, state insurance regulators, FIO
	Bank/Dealer Financing Desk	X			X		OCC, FED
	Bank/Dealer Prime Brokerage	X			X		SEC
COLLATERAL LAYER	Hedge Funds		X			X	SEC, CFTC
	Cash Providers (pension funds, insurance companies)		X	X			U.S. Department of Labor, state insurance regulators, FIO
	Bank/Dealer Derivatives Desk		X	X		X	CFTC
	Bank/Dealer Financing Desk	X		X		X	OCC, FED
	Central Counterparties (CCPs)	X			X		SEC, CFTC, FED
	Triparty Repo Agents	X			X		FED

CFTC = Commodity Futures Trading Commission, FED = Federal Reserve, FIO = Federal Insurance Office, OCC = Office of the Comptroller of the Currency, SEC = Securities and Exchange Commission, SRO = self-regulatory organizations

Source: Authors' analysis

risk into the asset layer and creating liquidity risk from the market impact of the asset sales.

Systemic risks can occur in one layer of the financial network map. Risks can also become systemic because of interconnections between layers. Both types of systemic risks should be evaluated. However, extra attention is needed when a single-layer risk is transformed into a systemic risk. As market participants enter new activities, their layer-specific and systemic importance may change. The multilayer map is a way to identify financial market participants, financial risks, and vulnerabilities that may threaten the stability of the financial system.

Endnotes

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[2] See Financial Crisis Inquiry Commission (FCIC), *The Financial Crisis Inquiry Report* Washington: U.S. Government Printing Office, 2011, xvi (available at www.gpo.gov/fdsys/pkg/GPO-FCIC/pdf/GPO-FCIC.pdf, accessed July 13, 2016).

[3] Since the financial crisis, analysts have proposed various ways to study those connections and how they can affect the resilience of the financial system. See Sary Levy-Carciente, Dror Y. Kenett, Adam Avakian, H. Eugene Stanley, and Shlomo Havlin, "Dynamical Macroprudential Stress Testing Using Network Theory," *Journal of Banking and Finance* 59 (October 2015), 164-181; Martin Summer, "Financial Contagion and Network Analysis," *Annual Review of Financial Economics* 5, no. 1 (2013), 277-297; and Paul Glasserman and H. Peyton Young, "Contagion in Financial Networks," OFR Working Paper no. 15-21, Oct. 20, 2015.

[4] Earlier OFR working papers introduced network maps of short-term funding markets and collateral flows. See Andrea Aguiar, Richard Bookstaber, Dror Kenett, and Thomas Wipf, "A Map of Collateral Uses and Flows," OFR Working Paper no. 16-06, May 26, 2016; and Andrea Aguiar, Richard Bookstaber, and Thomas Wipf, "A Map of Funding Durability and Risk," OFR Working Paper no. 14-03, May 29, 2014. See also Paul Glasserman and H. Peyton Young, "How Likely is Contagion in Financial Networks," OFR Working Paper no. 13-09, June 21, 2013.

[5] See Matthew O. Jackson, *Social and Economic Networks* (Princeton University Press), 2010.

[6] See Leonardo Bargigli, Giovanni Di Iasio, Luigi Infante, Fabrizio Lillo, and Federico Pierobon, "The Multiplex Structure of Interbank Networks," *Quantitative Finance* 15, no. 4 (2015), 673-691; Bernardo Bravo-Benitez, Biliana Alexandrova-Kabadjova, and Serafin Martinez-Jaramillo, "Centrality Measurement of the Mexican Large Value Payments System From the Perspective of Multiplex Networks," *Computational Economics* 47, no. 1 (2016), 1-29; and Inaki Aldasoro and Ivan Alves, "Multiplex Interbank Networks and Systemic Importance: An Application to European Data," SAFE Working Paper no. 102, 2015, (available at dx.doi.org/10.2139/ssrn.2603732, accessed July 13, 2016).

[7] See Gregorio D'Agostino and Antonio Scala, editors, *Networks of Networks: The Last Frontier of Complexity* (Switzerland: Springer International Publishing), 2014.

[8] See FCIC (2011), Chapter 12, for more details about the Bear Stearns hedge funds. Other background information is in the Securities and Exchange Commission's civil complaint filed June 19, 2008, in the U.S. District Court for the Eastern District of New York, SEC v. Ralph R. Cioffi and Matthew Tannin, case #08-2457 (SEC complaint).

[9] See Aguiar, Bookstaber, and Wipf (2014).

[10] See SEC complaint (2008).

[11] See Aguiar, Bookstaber, Kenett, and Wipf (2016).

[12] See FCIC (2011), 136.

[13] See OFR, *2015 Financial Stability Report,* Dec. 15, 2015, Chapter 5 (available at financialresearch.gov/financial-stability-reports/files/OFR_2015-Financial-Stability-Report_12-15-2015.pdf, accessed July 13, 2016).

[14] See Glasserman and Young (2015).

[15] See Elizabeth Quill, "When Networks Network," *ScienceNews,* Sept. 7, 2012 (available at www.sciencenews.org/article/when-networks-network, accessed Jan. 20, 2016); and Stefano Boccaletti, Ginestra Bianconi, Regino Criado, Charo I. Del Genio, Jesus Gómez-Gardeñes, Miguel Romance, Irene Sendiña-Nadal, Zhen Wang, and Massimiliano Zanin, "The Structure and Dynamics of Multilayer Networks," *Physics Reports* 544, no. 1 (2014), 1-122.

[16] See FCIC (2011), 240.

[17] See FCIC (2011), 280.

[18] See OFR (2015), Chapter 4.

[19] See Viktoria Baklanova, "Repo and Securities Lending: Improving Transparency With Better Data," OFR Brief no. 15-03, April 23, 2015; Viktoria Baklanova, Adam Copeland, and Rebecca McCaughrin, "Reference Guide to U.S. Repo and Securities Lending Markets," OFR Working Paper no. 15-17, Sept. 9, 2015; and David C. Johnson, "Private Fund Data Shed Light on Liquidity Funds," OFR Brief no. 15-05, July 9, 2015.

[20] Some preliminary data has recently become available through a voluntary pilot program run by the OFR, the Federal Reserve System, and the Securities and Exchange Commission. See Viktoria Baklanova, Cecilia Caglio, Marco Cipriani, and Adam Copeland, "The U.S. Bilateral Repo Market: Lessons from a New Survey," OFR Brief no. 16-01, Jan. 13, 2016.

[21] For details about the LEI alphanumeric codes, see Global Legal Entity Identifier Foundation, www.gleif.org/en.