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Abstract

We use an information-theoretic approach to describe changes in lending relationships between federal funds market participants around the time of the Lehman Brothers failure. Unlike previous work that conducts maximum-likelihood estimation on undirected networks, our analysis distinguishes between borrowers and lenders and looks for broader lending relationships (multibank lending cycles) that extend beyond the immediate counterparties. We find that significant changes in lending patterns emerge following implementation of the Interest on Reserves policy by the Federal Reserve on October 9, 2008.

Key words: federal funds market, lending, payment, networks, clustering, map equation

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1 Introduction

The federal funds market is an important part of the U.S. financial system. Banks and certain other financial institutions use this market to trade funds among each other on an unsecured basis. The vast majority of trades are spot and the duration is typically overnight. As such the federal funds market is the marginal source of funding for many banks and the rate at which funds trade — the so-called federal funds rate — plays a key role in the extension of credit in the economy. Moreover, for many years the market has played a central role in terms of implementing monetary policy in the United States. Currently, the Federal Open Market Committee directs the Open Market Desk at the Federal Reserve Bank of New York to create conditions in the reserves market so that federal funds trade within a target range set by the committee. In sum, understanding the inner-workings of this market is important for questions related to bank funding, the implementation of monetary policy and even systemic risk (Afonso et al., in press; Bech and Klee, in press). Here, we focus on how the market structure responded to the unprecedented stress and disruptions that hit the U.S. financial system in the autumn of 2008 as well as the interventions by public authorities.

Analysis of the federal funds market is made more complicated by the fact that there are several hundred active participants active in this market (Soramäki et al., 2007; Bech and Atalay, 2010). Hence, it is difficult to identify patterns or changes in behavior without advanced techniques. We model the flow of payments generated by loans in the overnight interbank market as a large weighted and directed network. Each node of this network represents an individual bank. Each link represents a loan; the value of loans between node A and node B determines the weight on the link from A to B. In order to understand lending relationships we use the network clustering approach known as the *map equation* (Rosvall and Bergstrom, 2008; Rosvall et al., 2010). Given a network partition, the map equation measures the per-step description length of movements of flow on a network. Minimizing the map equation over all possible network partitions gives an optimal clustering with respect to the dynamics on the network. In the original formulation of the map equation, the flow was induced by a random walker guided by the directed and weighted links of a network. Because here the weighted and directed links already represent flow, which need not

be ergodic, we measure the description length of the raw data and do not encode the movements necessary to make the flow ergodic (Rosvall and Bergstrom, 2011). In this way, we can capture the actual payment flows associated with interbank loans and reveal clusters of banks for which there is long persistence time.

To distinguish meaningful structural change from mere noise in the data, we perform significance clustering of each network (Rosvall and Bergstrom, 2010). In the statistical analysis, we perform parametric bootstrap resampling of the networks and can assess the significance of each cluster. Our maps reveal significant, tractable changes in clustering over the most intense period of the recent financial crisis. In particular, there are dramatic changes in lending patterns following the decision by the Federal Reserve to start paying interest on depository institutions' required and excess reserve balances.¹

2 Related Literature

Wetherilt, Zimmerman and Soramaki (2010) and Chapman and Zhang (2010) identify the network structure of two types of financial networks using the maximum likelihood approach developed in Copic et al. (2006). These works determine the network structure that is most likely to generate observed flows assuming that flows within groups are more likely than flows across groups. Both studies apply the technique to small networks: Wetherilt et al. consider the sterling unsecured loan market in the United Kingdom during 2006-2008 (12 to 13 banks), while Chapman and Zhang consider payment flows through the Canadian Large Value Transfer System from (14 banks). Craig and von Peter (2010) examine interbank lending for the much larger, German banking system using a related approach in which a core-periphery structure is assumed, i.e., specific borrowing and lending relationships are assumed that apply to core versus non-core banks, and the an assignment of banks to the core is selected which minimizes errors.² Both Chapman and Zhang (2010) and Craig and von Peter (2010) consider pre-crisis data. Chapman and Zhang find that a relatively

¹See <http://www.federalreserve.gov/monetarypolicy/reqresbalances.htm> for a discussion of the interest on reserves policy.

²For a larger network, like the one considered in Craig and von Peter (around 2,000 banks), it is not be feasible to examine all possible clustering combinations. The added structure imposed by Craig and von Peter allows for a greedy algorithm.

stable, core-periphery structure emerges endogenously in the Canadian payment system with five core banks. Craig and von Peter find a relatively stable core size from 1999 until the middle of 2006 at which point the core size fell sharply from around 45 banks to 35 banks. Wetherilt et al. (2010) identify a large increase in the core size and overall connectivity in the sterling unsecured loan market following Lehman’s default.

The main difference between our approach and the maximum likelihood approach is that clustering arrangements in the latter are based solely on each node’s direct connections and all links are undirected — meaning that no distinction is made between the borrower and lender. This approach can be appropriate for identifying changes in direct lending relationships, but it may not detect broader dependencies that exist through intermediate banks, nor does it help identify how funding shocks might propagate through the network. Under the map equation approach, both the direction and weights of all network linkages are utilized and direct and indirect linkages matter. Bank A will not tend to be clustered together with bank B if the lending relationship is unidirectional unless there is a broader lending cycle which connects the two banks through other banks. We argue that this approach may be preferred for identifying areas of funding risk.

3 Data

We look at payment flows generated by overnight loans during second half of 2008. Unfortunately, overnight loans are not specifically identified in payments data available to the Federal Reserve and hence we extract an estimate of these payments from Fedwire data using the Furfine algorithm (Furfine, 1999). The same approach is used in Ashcraft and Duffie (2007), Bech and Atalay (2008), Bartolini et al. (2010) and Afonso, Kovner and Schoar (2011) among others. However, an important caveat is that the approach involves working with estimates of unknown quality. In fact, preliminary attempts by researchers at the Federal Reserve Bank of New York have been unable to quantify how large the type I and type II errors are. Henceforth in the paper, the use of the words “data”, “loans” and “federal funds activity” refers to these federal funds estimates.

Based on the estimates of overnight loans, there were almost 900 banks that were active in the

market during the second half of 2008, but many of these banks were not active every day. Hence, using only a single trading day's data to construct lending networks may tend to produce networks that are too sparse to reflect interesting counterparty relationships in the periphery. Instead, we aggregate the data over multiple days. The number of days chosen reflects a trade-off between being long enough to identify lending relationships and being short enough not to conceal structural changes. Specifically, we choose the two-week maintenance periods that the Federal Reserve applies for computing reserve requirements for banks. Reserve requirements are the amount of funds that banks must hold in reserve against specified deposit liabilities.³ If banks fail to meet their reserve requirements then charges will be applied by the Federal Reserve. Maintenance periods start on a Thursday and end on a Wednesday. Banks that lend to each other within the two weeks will be connected in our networks and weights on links will reflect the amount of activity.

For the purposes of illustrating changes in lending relationships we show every maintenance period starting July 3, 2008 and ending December 31, 2008. The collapse of Lehman Brothers occurred during the maintenance period from September 11 to September 24, 2008, labelled Sep 24 in the diagrams. The Interest on Reserves policy began at the start of the maintenance period which ran from October 9 to October 22, 2008 and is labelled Oct 22 in the diagrams.

4 Method and Results

Details of the clustering algorithm are available in Rosvall and Bergstrom (2008); see also Garratt et al. (2011) for an application to international claims and liabilities between countries. A full description of how to construct the alluvial diagrams we use to show structural changes in lending are found in Rosvall and Bergstrom (2010). The alluvial diagrams in Fig. 1 show the progression of change in clustering using the 13 two-week maintenance periods that cover the second half of 2008. Each column in the alluvial diagram represents the clustered network of a period, labelled by the last day of the period. Each block in a column represents a cluster in the network and the height of each block represents the total value of loans that pass through banks in the cluster. Confidentiality concerns prevent us of identifying individual members of the clusters. Consequently, each cluster

³See <http://www.federalreserve.gov/monetarypolicy/reservereq.htm>.

is named by an anonymized 3 character code of the bank with the highest transaction volume in the cluster, e.g. “KA8”, and followed by “,...” if there are more than one bank in the cluster.

Clusters are stacked in order from largest to smallest. Darker shading represent nodes that are assigned with statistical significance, while lighter shading represent nonsignificant assignments. Significantly identified clusters are separated by thick (white) vertical spaces. Changes in the clustering structure from one time period to the next are represented by the mergers and divergences that occur in the streamlines linking the blocks from one period to the next.

We perform two exercises to illustrate the changes reflected in the clustering analysis. First, we highlight groups of banks that were together, either as part of a larger cluster or as their own cluster, at the start of the sample period and ask: How are these banks clustered in the future? Second, we highlight banks that were clustered together on a certain date and ask: Which clusters did they come from and where do they go?

Two illustrations of the first exercise are shown by orange and green streamlines in Fig. 1. Banks highlighted in orange in the top panel of Fig. 1 formed part of the largest cluster until the Oct 22 maintenance period.⁴ However, in the maintenance periods subsequent to October 8th these banks separate from the main cluster, and combine into several smaller clusters. Fig. 2 provides a more detailed description of the changes in flow patterns that led to this change. Banks highlighted in orange during the Oct 5 maintenance period were included in the UC5,... cluster reflecting the fact that these banks had sufficiently strong cyclical lending relationships with the other banks in this giant cluster. However, during the Oct 22 maintenance period the flows between these banks and the other members of the cluster became weaker and more unidirectional, as reflected in panel C. Consequently, these banks were clustered into smaller subgroups over the Oct 22 maintenance period. Panel A shows a weak cyclical relationship between clusters IB6,..., DC8,..., HQ3,..., and XG9,..., which strengthened in the Oct 22 maintenance period leading to their merger in that maintenance period. Finally, Panel B shows the inclusion of cluster KA8,... into the large UC5,... cluster in the Oct 22 maintenance period. This results from a strengthening of the bilateral flows

⁴The orange-highlighted banks are grouped together within the largest cluster in all maintenance periods prior to Oct 22 for presentation purposes only. There is no special relationship between these banks within the larger cluster up to that point.

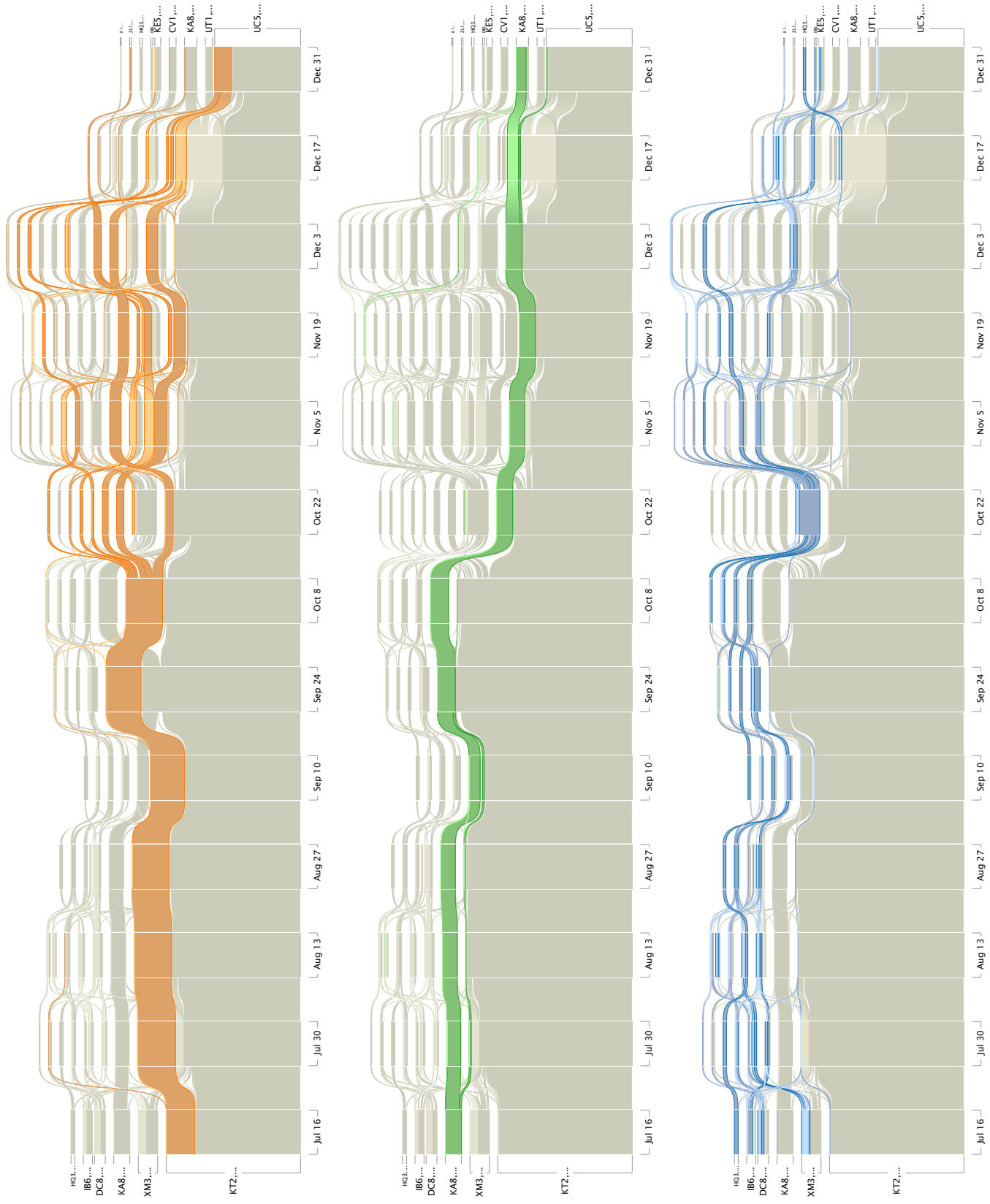


Figure 1: Mapping change of payment flows driven by federal funds market activity from July 2008 to December 2008. From top to bottom, the alluvial diagrams highlight three structural changes: Banks that segment in October (orange), a group of banks that intermittently separate from the largest cluster up until October 8th and are consistently included in it afterwards (green), and banks that combine to form a single cluster in early October (blue).

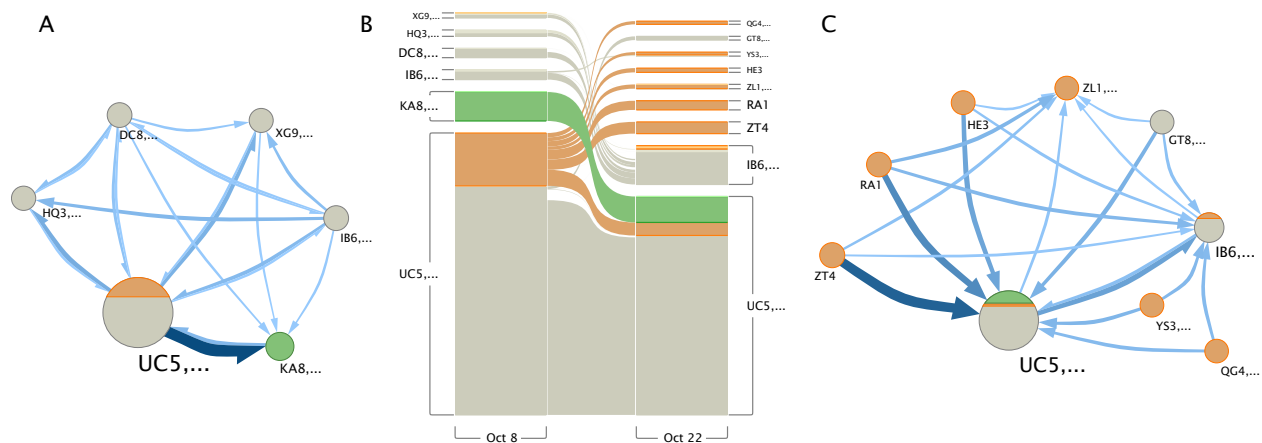


Figure 2: Mapping change of payment flows driven by federal funds market activity in late September and October 2008. For every two-week period of 2008, we partitioned close to 900 banks connected by more than 2000 transaction links into clusters of banks; each period is labelled by its last day. The maps in panels A and C show the most important clusters in two consecutive maintenance periods: September 25–October 8, and October 9–October 22. The size of the nodes represent the total value of loans that pass through banks within each cluster, and the size and color of the arrows represent the total payment flows between the clusters. To illustrate the structural change, the diagrams highlight in orange all banks that split off and in green all banks that merge with the main cluster during October.

between the two groups of banks over two maintenance periods.

Returning to Fig. 1, the banks highlighted in green and identified by the label KA8,... in the bottom panel of this figure were clustered together by the algorithm over the Jul 16 maintenance period. If we follow these banks over time we see that in five out of seven of the maintenance periods preceding the Oct 22 maintenance period, these banks are clustered together in a single module reflecting the existence of strong lending cycles between these banks. However, from the Oct 22 maintenance period onwards, these banks are absorbed by the largest cluster. This means that the borrowing and lending behavior of these banks is no longer highly concentrated amongst its members, but rather significant borrowing and lending activity is occurring within the broader collection of banks included in the largest cluster.

The bottom panel of Fig. 1 highlights in blue a cluster of banks that formed in the Oct 22 maintenance period and tracks them back in time to the beginning of the sample period and forward to the end. The interesting observation here is that this clustering seemed to be unique over the sample period. Namely, there was no other period in which anything approximating this

relatively large and significant cluster formed. The banking groups highlighted in blue on the Oct 22 maintenance period came from several smaller clusters that coexisted in the previous maintenance periods. Interestingly, this change in behavior was very short-lived. In the following months, these banks dispersed again into separate clusters.

5 Discussion

After an interlude of relative calm following the rescue of The Bear Stearns Companies, Inc. in March of 2008, concerns about the profitability and asset quality of financial institutions started to mount again over the summer. These tensions came to a head with the bankruptcy of Lehman Brothers Inc. Holdings (Lehman) in the early-morning hours of Monday, September 15. During the tumultuous days that followed, any hopes that the Lehman bankruptcy was the end of the trouble quickly dissipated. If not for the multitude of actions undertaken by public authorities the Lehman debacle might easily have been the beginning of the end.⁵

A byproduct of the Federal Reserve's interventions was that the level of reserve balances exploded from \$10 billion on average during August of 2008 to \$850 billion by year end.⁶ Unlike earlier in the financial crisis, the Federal Reserve was not able to sterilize the increase in reserves balances from these operations by selling U.S. Treasuries due to the sheer size of injections required, and this had implications for the federal funds market. Bech and Klee (in press, p. 1) state: "With the banking system awash in funds, the rate at which banks were willing to buy and sell these funds—the federal funds rate—dipped well below the intended policy target rate set by the Federal Open Market Committee...This situation created a tension for the Federal Reserve: while the increases in liquidity would prove to help improve market functioning, these increases were also exerting downward pressure on the federal funds rate."

These events motivated the Federal Reserve to start paying interest on required and excess reserve balances held by banks. The new policy began on October 9, 2008. However, as discussed

⁵See Bech and Rice (2009) for a description of these events and an account of the steps taken by the federal reserve and other government agencies to ease investor concerns and support U.S. banks and other companies.

⁶Federal Reserve Statistical Release, H.4.1, Factors Affecting Reserve Balances, Historical Data, Table 9. <http://www.federalreserve.gov/releases/h41/hist/h41hist9.pdf>

by Bech and Klee, in press, government-sponsored enterprises (GSEs), which are significant sellers of federal funds on a daily basis, are exempt. Bech and Klee (in press, p. 2) state: “This heterogeneity across participants [in the federal funds market] created a segmented market with different rate dynamics.” Moreover, “...a combination of financial consolidation, credit losses, and changes to risk management practices has led at least some GSEs to limit their number of counterparties in the money market and to tighten credit lines.” (p. 3)

Our maps reveal several aspects of these extraordinary events. While we must refrain from discussing individual institutions, we can identify some general trends. Our analysis suggests that the Lehman bankruptcy was less of a transformative event for the federal funds market than the implementation of interest on reserves. The orange cluster is dominated by a set of Federal Home Loan Banks and a number of small and medium sized banks. This cluster disintegrates shortly after the implementation of interest on reserves, likely due to the fact that the lending between the banks was significantly reduced as the amount of reserves supplied by the Federal Reserve increased. The blue cluster which forms only during the Oct 22 maintenance period is comprised by another Federal Home Loan Bank and a number of banks that tend to be located the same geographic region as the Home Loan Bank. We speculate that this cluster reflects the fact that the Home Loan bank may have started to intermediate funds between its members by borrowing federal funds from some and making overnight advances (i.e., collateralized loans) to others during this period. The fairly stable green cluster, which is subsumed into the large cluster after the implementation of interest on reserves, is dominated by a prominent government-sponsored enterprise and one large money center bank. The break down of the cluster may reflect the reduction (or even elimination) of the lending relationship to the particular bank by the GSE.

6 Concluding Remarks

Advanced network techniques can help stakeholders in the financial system to understand its structural features and to analyze the impact of transformative events. As illustrated here, the map equation appears to be a very useful tool for understanding funding flows. The lending flows in the

federal funds network changed in a fundamental way between September 10th and October 22nd, 2008, and the alluvial diagrams reveal this clearly.

Prior to performing this analysis, we had suspected that the Lehman bankruptcy in the fall of 2008 would have been the most important shock to the underlying flow dynamics of the federal funds market. The clustering maps raise an alternative hypothesis: that the interest on reserves policy may have had a more pronounced impact overall.

However, in evaluating such hypotheses it is important to recognize that changes in clustering of flow reflect not the instantaneous rate of change of a system, but rather the cumulative effects of such changes. The occurrence of an important structural changes tells us that the system has reached a tipping point at which the description length of one clustering configuration falls below another. Thus the underlying shifts in network flows that precipitate these structural changes may have been initiated well before the tipping point was reached. As a consequence, considerable caution is required when deriving causal inferences from alluvial diagrams. While the major structural changes observed here follow the institution of interest of reserves, this does not in and of itself imply a causal link. It is possible, for example, that these changes result instead from the cumulative effects of lending changes that were precipitated by the collapse of Lehman and accumulated over time, reaching the tipping point only after the interest on reserves policy began.

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