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Too-connected-to-fail institutions and payment system's stability: assessing challenges for financial authorities

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Too-connected-to-fail Institutions and Payments System's Stability: Assessing Challenges for Financial Authorities[1,2]

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Abstract

The most recent episode of market turmoil exposed the limitations resulting from the traditional focus on *too-big-to-fail* institutions within an increasingly systemic-crisis-prone financial system, and encouraged the appearance of the *too-connected-to-fail* (TCTF) concept. The TCTF concept conveniently broadens the base of potential destabilizing institutions beyond the traditional banking-focused approach to systemic risk, but requires methodologies capable of coping with complex, cross-dependent, context-dependent and non-linear systems.

After comprehensively introducing the rise of the TCTF concept, this paper presents a robust, parsimonious and powerful approach to identifying and assessing systemic risk within payments systems, and proposes some analytical routes for assessing financial authorities' challenges. Banco de la Republica's approach is based on a convenient mixture of network topology basics for identifying *central* institutions, and payments systems simulation techniques for quantifying the potential consequences of *central* institutions failing within Colombian large-value payments systems.

Unlike econometrics or network topology alone, results consist of a rich set of quantitative outcomes that capture the complexity, cross-dependency, context-dependency and non-linearity of payments systems, but conveniently disaggregated and dollar-denominated. These outcomes and the proposed analysis provide practical information for enhanced policy and decision-making, where the ability to measure each institution's contribution to systemic risk may assist financial authorities in their task to achieve payments system's stability.

Key words: payments systems, *too-connected-to-fail*, *too-big-to-fail*, systemic risk, network topology, simulation, central bank liquidity.

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[2] Results are intended for academic and research purposes; they may not be used to infer credit quality or any type of assessment for any financial institution. [Original version: March 2011. This version: March 2011].

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Abbreviations

BF	Brokerage Firm (please refer to Table 1)
BR	Banco de la República (Colombia's central bank)
CB	Commercial Bank (please refer to Table 1)
CDS	Credit Default Swap
CF	Financial Corporation (please refer to Table 1)
CFC	Commercial Financial Corporation (please refer to Table 1)
CHAPS	Clearing House Automated Payment System
CHIPS	Clearing House Interbank Payments System
CI	Credit Intermediaries (banking institutions, please refer to Table 1)
CPSS	Committee on Payment and Settlement Systems
CUD	Colombia´s large-value payment system
DCV	BR's depositary for clearing and delivering of TES
Deceval	Private depositary for clearing and delivering stocks and TES
ECB	European Central Bank
FIFO	First-In-First-Out
FRBNY	Federal Reserve Bank of New York
IMF	International Monetary Fund
LLR	Lender-of-Last-Resort
LTCM	Long-Term Capital Management
MF	Mutual Fund (please refer to Table 1)
NCI	Non-credit Intermediaries (non-banking institutions, please refer to Table 1)
NT	Network Topology
OMO	Open Market Operations
PFM	Pension Fund Manager (please refer to Table 1)
PoQ	Payments on Queue
PS	Payments System
QRA	Queue Resolution Algorithm
RTGS	Real-Time Gross Settlement system
SEN	BR's Electronic Negotiation System (TES only)
TBTF	Too-big-to-fail
TCTF	Too-connected-to-fail
TES	Colombia's central government local bond
TLF	Transitory Liquidity Facility
VaR	Value at Risk

Introduction

The most recent episode of market turmoil exposed the limitations resulting from the traditional focus on *too-big-to-fail* (henceforth referred as TBTF) institutions within an increasingly systemic-crisis-prone financial system. It is clear now that financial stability may not only be endangered by massive banking institutions, but also by non-banking participants significantly and intricately linked within the payments system. This has encouraged the appearance of the *too-connected-to-fail* concept (henceforth referred as TCTF), and has fostered an ongoing debate on financial authorities' (i.e. central banks, regulators and supervisors) role facing systemic shocks, either during market's disruption or tranquil periods.

Acknowledging the TCTF concept broadens the base of potential destabilizing entities beyond the traditional banking-focused approach to systemic risk, but requires methodologies which cope with complex, cross-dependent, context-dependent and non-linear systems. A current trend for assessing the complexity and cross-dependency of financial and payments systems is based on network topology (hereafter NT), whilst context-dependency and non-linearity tends to be overlooked.

Hence, despite providing a comprehensive picture of systems' stability and resilience, NT is not suitable for approaching some of financial authorities' key practical concerns: If a systemic relevant institution fails, what is the intra-day and end-of-the-day dollar-value of the liquidity required by each institution within the system? Is the legal framework for customary and last-resort liquidity facilities appropriate for all the system´s participants? Is there any single institution or type of institution that conceals systemic risk? What is the market's liquidity level which may intensify dependence between institutions?

Therefore, based on a convenient mixture of NT (Becher et al., 2008; Soramäki et al., 2006) and payments systems simulation techniques (Leinonen and Soramäki, 2004), Banco de la República (BR) developed a robust, parsimonious and powerful approach for identifying and assessing systemic risk within Colombia's financial markets. First, NT basics are used to identify TCTF institutions according to the *centrality* concept. Afterwards, based on the observed transactions of an estimated payments system's typical day, the simulation procedure replicates Colombian large-value payments systems' queue resolution and multilateral settlement algorithms in order to quantify the potential consequences of the collapse of a TCTF institution.

Unlike econometrics, other customary approaches and NT alone, results consist of a remarkably rich set of quantitative outcomes which capture the complexity, cross-dependency, context-dependency and non-linearity of the payments system, but conveniently disaggregated and dollar-denominated. These outcomes and the proposed analysis provide financial authorities with practical information for enhanced policy and decision-making, where the ability to estimate each institution's contribution to systemic risk may assist financial authorities in their task to achieve payments system's stability.

This paper is divided in four sections. The first –next- section briefly covers the development of the TBTF concept for detecting and assessing systemic risk, ending with the recent appeal for the TCTF concept. The second analyzes the rationale behind the surge of connectedness as an alternative concept for detecting and assessing systemic risk. The third section is dedicated to familiarize the reader with some key features of Colombia's payments system; to present the chosen approach, and to analyze the results.

Finally, the fourth section makes some concluding remarks that may be useful for financial authorities.

1 The *too-big-to-fail* concept for systemic risk

Traditional assessment of systemic risk has focused on those market participants considered as TBTF, where that label may be granted to an institution when, due to its size, its inability to meet its obligations could result in the inability of other system participants or of financial institutions in other parts of the financial system to meet their obligations as they become due. Basically TBTF institutions are those exceeding an asset-size cutoff (Saunders et al., 2009), which is a convenient and straightforward metric readily available for any regulator or central bank, even accessible for any market participant or a fairly informed ordinary man.

Despite more complicated definitions may focus on the volume of financial services (e.g. deposits, loans) provided by an institution within the financial system (IMF et al., 2009) or other less forthright metrics, the TBTF concept for identifying systemically important institutions is rather uncomplicated, and may explain why customary tools for crisis prevention and management are designed specifically for large bank runs (e.g. lender of last resort –LLR-, deposit insurance). Moreover, because it focuses on standard accounting data (e.g. assets, investments, deposits), financial authorities have found this approach as practical. This type of supervision may be depicted as micro-prudential, since, as defined by Brunnermeier et al. (2009), it focuses on factors that affect the stability of individual institutions.

Financial history documents supervisors and central banks' reliance on the TBTF-based approach for detecting and assessing systemic risk. Quantitative evidence validates that the larger the institution, the closer the scrutiny by regulators and the less likely they are left to collapse[7] (Heffernan, 2005; Gup, 1998). In fact, as will be presented next, some of the most relevant episodes of systemic instability throughout history include the failure or near failure of a large banking or non-banking institution.

Regarding early episodes of large banking failures, it is worthwhile describing U.K. and U.S. cases in the late 19th and the wake of the 20th centuries, respectively. In 1866 England experienced the collapse of Overend Gurney and Co. Ltd., a financial institution involved in banking and bill broking, with a balance sheet ten times the size of the second largest, which precipitated the failure of a considerable number of other banking and non-banking institutions. Despite Bank of England refused to rescue Overend, which was finally declared insolvent due to losses resulting from bills of dubious quality and lending with poor collateral, Bank of England's actions during the episode[8] stated that it would intervene as LLR in situations of severe panic related to large banking institutions (Heffernan, 2005). In 1890 Baring Brothers, a large international merchant bank founded in 1762, also failed due to non-performing loans granted to Latin American countries, but

[7] Based on Gup (1998), who provides a summary of bank failures and near failures comprising 70 institutions from Belgium, Canada, France, Germany, Italy, Japan, Netherlands, Sweden, Switzerland, U.K. and U.S., from 1974 to 1997, authors calculated that regarding episodes involving large banking institutions (24), 22 ended without liquidation or closure (91.7%); episodes involving medium banking institutions (8) always ended without liquidation or closure (100%); and episodes involving small institutions (38), 15 ended without liquidation or closure (39.5%).

[8] In order to face the episode the Bank of England was allowed to suspend the 1844's Bank Act (also known as Peel's Act). Under this act Bank of England's discretionary ability to issue notes was restricted to a statutory £14 million above its holdings of gold bullion (Chancellor, 2000).

was finally rescued with private funds from the Baring family. Both cases, Baring Brothers and Overend, were the result of assets' mismanagement.

In the United States, resulting from the stock market crash of October 1929, 608 banks (with $550 million of deposits) failed during November-December 1930. As in the case of Overend Gurney and Co. Ltd. in the U.K., a large banking institution, The Bank of United States, failed. According to Friedman and Schwartz (1963), because it was the largest commercial bank by volume of deposits ever to have failed up to that time in the U.S. and due to its name, the systemic consequences of the failure of The Bank of United States in December 11th 1930 were substantial. Some other large failures followed. Ultimately, the banking crises transformed a recession into the Great Depression (Krugman, 2009).

After these large bank-related failures institutions' size gradually emerged as a critical concept for supervision and regulation purposes. This was the result of a dramatic change in the character of the contractions in late 1930, when several large bank failures led to the first of what were to prove a series of liquidity crises involving runs on banks and bank failures on a scale unprecedented in U.S. history (Friedman and Schwartz, 1963).

The first case of U.S. regulators using a TBTF policy to identify, assess and contain systemic risk originating in a large financial institution came in the 1980s with the Continental Illinois bank[9] (Heffernan, 2005). Continental Illinois was the seventh largest and the largest correspondent bank in the U.S. at that time, with assets about $41.4 billion. Regulators claimed that 66 banks, with assets about $5 billion, had investments in Continental Illinois that accounted for 100% of their equity capital, whereas other 113 banks, with assets of more than $12 billion, had investments that accounted within the 50%-100% range of their equity capital. After the Comptroller of the Currency announced in congressional testimony that the government would not let any of the eleven largest banks fail (Gup, 1998), Continental Illinois was rescued in 1984, nationalized in 1989, and taken over by Bank of America Corp. in 1994. It is worth mentioning that Continental Illinois' near failure resulted from its reliance on overseas funding and on oil and gas collateralized loans –both experiencing a severe downturn by mid 1980s-, and from its direct exposure ($1 billion) to large participations in high-risk oil loans from Penn Square Bank, a bank that was allowed to fail in 1982 because it wasn't considered a major bank.

In the U.K. one of the most famous cases of a size-related policy for assessing and containing systemic risk belongs to the Bank of England's rescue of Johnson Matthey Bankers in 1984 after it had to write-off half of its loan portfolio. Johnson Matthey Bankers was a banking institution pertaining to one of the five London gold price fixers (Johnson Matthey), which was one of the largest non-banking institutions in the City. According to Heffernan (2005), this is a rare case in which the TBTF doctrine was extended to protect large non-banking arms of a financial institution. As with Baring Brothers, Overend, Penn Square Bank and Continental Illinois, Johnson Matthey Bankers case is due to mismanagement of assets (e.g. non-performing loans).

The first legendary application of the TBTF concept for non-banking institutions was the effort by the Federal Reserve Bank of New York (FRBNY) to organize a consortium of investment banks in order to avoid the failure of a massive hedge-fund in 1998: Long Term Capital Management (LTCM). LTCM is a well-known case because it is a rather

[9] According to Kaufman (2002), other U.S. banks that were extended assistance via de LLR facilities under the TBTF criteria were the Franklin National Bank [1974], the First Republic Bank [1987], MCorp [1988] and the Bank of New England [1990]. Nevertheless, Kaufman agrees with Heffernan (2005) when concluding that the only genuine TBTF case was the Continental Illinois episode.

clear example of a large non-banking institution compromising financial stability (i.e. assets and liabilities amounted to $129 billion and $124.5 billion just before its collapse, respectively, and loans and derivatives positions estimated at $1.4 trillion), and because the intervention took place despite hedge funds were not regulated by the FRBNY, and albeit fund's portfolio wasn't even located in the U.S., but in Cayman Islands. As put forward by Lhabitant (2006), controversy followed LTCM's rescue because, for the first time, despite being a privately owned fund, with no widows or orphans to protect[10], a hedge fund was deemed TBTF, a status hitherto reserved for countries and large banks. Moreover, as stated by Freixas et al. (2002), additional relevance from LTCM comes in the form of private sector's embracing the TBTF concept for rescuing the hedge fund.

Despite public funds were not used to bail-out LTCM, FRBNY's struggle to coordinate the $3.6 billion rescue of a 124.5 billion-assets hedge fund drew attention to other large non-banking institutions. Two of these large non-banking institutions that immediately concentrated attention were The Federal Home Loan Mortgage Corporation (Freddie Mac), and The Federal National Mortgage Association (Fannie Mae). As early as in 2003, taking into account that the combined balance sheet of these two institutions was about $1.5 trillion, Heffernan (2005) stressed the systemic risk posed by them under the TBTF concept, and emphasized on the incapability of the private sector for implementing a rescue analogous to the one orchestrated by the FRBNY for LTCM.

Recent developments confirmed that worries about the systemic importance of large non-banking institutions such as Freddie Mac and Fannie Mae were not unfounded. The first global financial crisis of the twenty-first century began –silently- in 2006, but became noticeable by the late spring of 2006 when housing prices began to decline (Krugman, 2009). As a consequence of a weak housing market the earliest negative announcements began to appear during 2007[11], and got worse during 2008[12]. Without any doubt, the involvement of large financial institutions characterized the severity and extent of the crisis.

Nevertheless, troubled large institutions (e.g. AIG, Bear Sterns, Lehman, Fannie Mae and Freddie Mac) appeared rather late in the crisis, and their entrance resulted from their direct or indirect exposure to the U.S. subprime-mortgage market. Moreover, the 2005-2006 U.S. housing slump was not novel in recent history, with a few sharp declines in U.S. housing prices (e.g. 1989-1993 home prices fell by over 13%), and even in other major financial markets (e.g. Japan during the 1990s); as acknowledged by Pozen (2010), prior to 2008, no housing slump in any country has ever led to a global financial crisis. As suggested by Bullard et al. (2009), a relatively small portion of the home mortgage market triggered the most severe financial crisis in the United States since the Great Depression, whilst Haldane (2009) judges the subprime crisis as a rather modest shock by global financial standards.

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[10] In fact the entry terms were rather tough: $10 million minimum investment, three-year lock-up, 2% management fee and 25% performance fee (Lhabitant, 2006).

[11] HSBC Holdings announced higher delinquencies than expected –priced- in a subprime portfolio [March 5th]; New Century Financial, the second-largest subprime lender, declared bankruptcy [April 22nd]; BNP Paribas suspended calculations of three money market funds exposed to subprime debt and halted redemptions [August 9th]; Bank of England announced liquidity support and a government guarantee for Northern Rock's existing deposits [September 14th and 17th]; Freddie Mac announced 2007 Q3 losses [November 20th]; Bear Stearns announced expected 2007 Q4 write-downs [December 20th] (Acharya et al. 2009).

[12] Not only major financial institutions announced losses (Lehman Brothers, Bear Sterns, Citibank, Merrill Lynch), but also recognized valuation models' weaknesses (AIG [February 11th]); purchases and nationalizations were made public (Northern Rock by the U.K. government, Bear Sterns by JP Morgan [March 16th], Merrill Lynch by Bank of America [September 15th]); closures were decided (Indymac [July 11th]); rescues were announced (Fannie Mae and Freddie Mac, by the U.S. Treasury [July 13th], AIG by the U.S. government [September 16th]); and, finally, bankruptcy materialized (Lehman Brothers [September 15th]).

After the crisis literature has converged to declare the obsolescence of the current model of supervision and systemic risk assessment. Banks, which have been considered as the main focus of systemic risk detection and assessment because of their size (e.g. assets, deposits, loans), were not the main source of systemic risk as before (i.e. via non-performing loans, mismanagement of assets, balance mismatch). The financial system has changed dramatically since the Great Depression: though banks still play a large role, many functions that defined their traditional domain are increasingly performed by securities markets and non-bank market participants (Kambhu et al., 2007), namely unleveraged institutional investors (e.g. mutual and pension funds) and highly leveraged institutions (e.g. hedge funds); this is, non-banking participants make up the so-called "parallel banking system" or "shadow banking system" mentioned by Krugman (2009) and Acharya et al. (2009).

But the most recent global financial crisis is not the only example of the importance of the "shadow banking system". Besides its extraordinary size, LTCM episode exhibited other particularities that financial markets, central banks and supervisors were not familiar with at that time. Concerning LTCM, Brown et al. (2009) asserts that the hedge funds industry poses systemic risk because (i) hedge funds are able to be highly leveraged, which allows them for obtaining high returns, but also may end in low or negative capital when facing severe declines in their investment portfolios; (ii) they tend to follow similar investment strategies; and (iii) there is a lack of transparency in their exposures and the counterparty risk they generate.

About leverage, Chancellor (2000) documents that the effective leverage within LTCM was reported to exceed $100 of debt for every dollar of equity, which served to build a loans and derivatives position estimated at $1.4 trillion. This leverage may also explain why during May and June 1998 LTCM experienced a 16% decrease in its market value due to a widening of spreads in the mortgage-backed securities market, followed by an additional 52% decrease in August after the Russian crises exploded, which ended in its September 23rd bailout after experiencing losses about 83% in that month only (Brown et al., 2009).

Concerning the use of similar strategies within the hedge funds industry, supervisors were suspicious that if LTCM was allowed to fail, it wouldn't be the only hedge fund to do so. Despite there are several sorts of hedge funds, they all share a common feature: they provide liquidity to the aggregate of those who demand liquidity. Therefore, as Brown et al. (2009) warns, it is quite natural that hedge funds follow similar strategies because they all take the other side of the liquidity demand and so end up with returns and positions that are correlated. Such correlation may result in additional systemic risk because problems in a single non-small or several non-large hedge funds may seriously erode the market value of the whole industry's portfolios via declining market liquidity and "liquidity spirals[13]". Furthermore, because hedge funds' strategies had been highly profitable since their inception, other industries were mimicking them, extending correlation and systemic risk to other parts of the financial markets; that was the case of Salomon Brothers' $1 billion losses in analogous arbitrage positions during 1998's third quarter.

Vis-à-vis the lack of transparency in their exposures and the counterparty risk they generate, LTCM was not only large by on and off-balance positions, but it was an

[13] "Liquidity spirals" refers to the internal amplifying process whereby a falling asset leads to more sales (deleveraging), which further drives down asset prices, financial intermediaries' profit and loss statements, and balance sheets net worth (Brunnermeier et al. 2009). In the case of hedge funds, "liquidity spirals" may be particularly harsh due to the leverage they are allowed to work with, which forces hedge funds to unwind large positions when facing losses or margin calls.

important –and obscure- source of counterparty risk for global markets. As documented by Brown et al. (2009), LTCM's off-balance positions comprised $1.3 trillion notional values of derivative positions, where six banks worldwide acted as counterparties of $1 trillion approximately. According to Lhabitant (2006), LTCM's own estimate was that its 17 largest counterparties, in closing out their positions with LTCM, would have incurred in aggregated losses between $3 billion and $5 billion, with some individual institutions losing as much as $500 million. Despite this direct losses figures were non-trivial, the FRBNY's eagerness for orchestrating the rescue resulted from the potential indirect consequences of LTCM failing. As put forward by Greenspan (1998) when defending the Federal Reserve's role before the U.S. House of Representatives, "the act of unwinding LTCM's portfolio in a forced liquidation would not only have a significant distorting impact on market prices but also in the process could produce large losses, or worse, for a number of creditors and counterparties, and for other market participants who were not directly involved with LTCM."

Nevertheless, LTCM and the most recent global financial crisis are not the only cases where institutions' size is not enough to explain the episode in full. On June 26th 1974 the failure of a small German bank, Bankhaus Herstatt, almost resulted in the U.S. clearing system's collapse. Despite its size (around 50.000 customers and DM 2.0 billion in assets), its closure by the German supervisory institution and Bundesbank's cease to clear for its account, caused an overseas chain reaction that began when Chase Manhattan, its correspondent bank in the U.S., decided not to honor $620 millions in payment orders and checks drawn on behalf of Herstatt's account. As documented by Davis (1995), the immediate consequences were that the U.S. clearing system nearly collapsed, the Clearing House Interbank Payments System (CHIPS) computer was switched off and the banks had to barter checks. This episode, where a small and "outside" institution almost resulted in the collapse of the U.S. payments system, encouraged the formation of the Basel Committee on Banking Supervision (Manning et al. 2009; Alexander et al., 2006).

Consequently, evidence demonstrates that focusing exclusively on the institutions' size averts authorities from effectively detecting and assessing the systemic risk lurking beneath the nowadays highly complex and interconnected global financial system; this is, regulation and supervision were too institution-centric to see through to the systemic risk (IMF, 2009). Hence, several authors (Chan-Lau, 2010; Clark, 2010; Acharya et al., 2009; Saunders et al., 2009; Zhou, 2009; Brunnermeier et al., 2009; Trichet, 2009) recognize the inevitability of using a broader set of concepts in order to detect and assess systemic risk.

2 An increasingly systemic-crisis-prone financial system

The simplest definition –from the Merriam-Webster dictionary- of a system could be: "a regularly interacting or interdependent group of items forming a unified whole". Three main concepts comprise this definition: (i) items, (ii) interactions (interdependence) and (iii) the whole, which could be conveniently exchanged for the purpose of this paper with (i) institutions, (ii) payments[14] and (iii) the financial market. Despite being obvious that none of these concepts exists in isolation, supervision has mainly focused on the institutions only, where the best example is the reliance on the institutions' size and other accounting metrics or ratios for detecting and assessing the risk within the whole system.

[14] Some authors (Chan-Lau, 2010b) regard balance sheet claims as connections. As will be addressed in the next chapter, this document embraces payments as the primary source of connectivity.

Financial markets constitute one among many other systems exhibiting a complex organization and dynamics, where the large number of mutually interacting parts self-organize their internal structure and dynamics with novel and sometimes surprising macroscopic emergent properties (Sornette, 2003); that is, the financial system is a complex adaptive system (Haldane, 2009). Thus, the micro-prudential approach to financial markets' systemic risk, which focuses on closely analyzing the system's components (institutions), is not only insufficient, but highly unsafe; as demonstrated by recent periods of financial turmoil (i.e. LTCM, the subprime crisis), the connections between components are as important as the components themselves.

Recognizing the importance of the interdependence between participants may significantly complicate the analysis. The smaller the number of items and connections, the easier it is to understand and analyze the system. The financial system exhibits a myriad of participants, which maintain numerous connections (i.e. they engage in payments) with several other participants, whereas the characteristics of the institutions and their payments are dynamic, with episodes of extreme shifts in their individual and collective behavior. Therefore, as suggested by Landau (2009), the structure of financial systems, which is based on the interdependence between multiple actors and counterparties, is complex.

Nevertheless, despite this type of complexity makes difficult to observe, understand and analyze the financial system, it is not an undesirable feature at all. Complex systems, characterized by numerous participants and connections, may take advantage of the existence of internal self-regulatory and self-repairing processes which could make the system robust to random shocks.[15] That is, the existence of numerous participants allows for significantly different holdings and strategies across the financial system, where such heterogeneity permits a proper and efficient risk dispersion through the system.

Unfortunately, this type of advantageous complexity has been gradually fading due to a rather undesirable feature of today's financial markets: homogeneity. A complex system's robustness depends on the diversity of its participants: if all participants develop the same task, with the same tools and strategies, and with identical objectives, connectivity may not serve the purpose of risk dispersion, but amplification. Based on Haldane (2009) and Rebonato (2007), authors conclude that contemporary financial systems have experienced a sharp decrease in diversity resulting from three main reasons: (i) pursuit of returns; (ii) deregulation and disintermediation; and (iii) uniform risk assessment tools.

As documented when analyzing LTCM's case, not only hedge funds followed similar strategies within the industry, but other financial institutions, eager to achieve the extraordinary returns exhibited by hedge funds during the first half of the 1990s, imitated their strategies; that was the case of the investment bank Goldman Sachs. More recently, the decline in interest rates on U.S. Treasury bonds during the first half of the 2000s stimulated an unanimous appetite for alternative debt securities, where the exposure to high-yield subprime mortgages was extensive to all sorts of financial institutions[16]. Such lack of diversity explains why rolling averages of correlations across financial markets' sectors averaged in excess of 0.9 throughout 2004-2007 (Haldane, 2009) and why

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[15] Elton's (1958) seminal work on invasions by animals and plants concluded that complex food webs –with numerous species- are likely to contain predators or parasites that control invaders, whereas simpler webs are more vulnerable to population explosions; that is, in complex systems there are always enough enemies and parasites available to turn on any species that starts being unusually numerous.

[16] Historically low interest rates set by the Fed on short-term Treasuries encouraged the growth of subprime mortgages: volume of subprime mortgages rose from $120 billion in 2001 to $600 billion in 2006; this is, from under 6% to 20% of all mortgages originated (Pozen, 2010).

unprecedented simultaneous write-downs were common among major investment banks during the subprime crisis[17]. Even central banks –particularly risk adverse agents- are reported to have increased their weight on return since the late 1990s, where their preference for asset-backed securities, especially mortgage-backed securities, has also augmented, along with the increasing use of derivatives (Borio et al., 2008).

In addition to the pursuit of returns, but inexorably related to it, is the second reason for decreasing diversity within financial markets: deregulation and disintermediation. The banking industry during the 1980s and 1990s exhibited a dynamic resulting from a broader range of activities banks were allowed to engage in, and an unprecedented level of liquidity that facilitated capital markets taking on bank's intermediation activity.

According to Rebonato (2007) disintermediation pushed banks to undertake trading activities in order to compete with non-banking institutions and, because of deregulation, they were allowed to do so for the first time since the Great Depression; these new activities took the form of bond, equity, currency, commodities, derivatives and securitized mortgages' trading. By the mid 1990s all these activities, specially high-yield complex financial instruments, had become an increasingly important source of revenue for all financial markets' participants, making institutions' strategies and holdings similar to each other.

This deregulation and disintermediation process resulted also in a key characteristic of recent episodes of systemic risk: the system has changed from bank-based to market-based systemic events, where the emphasis shifts from funding liquidity to market liquidity (Kambhu et al., 2007; Hendricks et al., 2006; Kohn, 2006), with actual tools for crisis management designed specifically for –not very likely[18]- large bank runs (e.g. LLR, deposit insurance), but insufficient to cope with new –non-banking- sources of systemic risk. This unforeseen shift from funding to market liquidity results in <u>insufficient liquidity facilities</u>.

Furthermore, as a consequence of the increasing importance of market-based systemic events, current liquidity risk management practices should be examined. Despite liquidity risk management is carried out by financial institutions, it is not designed for assessing and mitigating persistent (i.e. long-lasting) or systemic (i.e. non-idiosyncratic) liquidity shocks (IMF, 2009b). Therefore, financial institutions and the regulators should be aware of the existence of a <u>defective liquidity risk management framework</u>, and should work on its enhancement.

Regarding the existence of uniform risk assessment tools, the widespread use of rather similar methods for risk measurement poses an additional threat to financial system's diversity. As acknowledged by the IMF (2007), from a systemic perspective, it is important to ensure that there are market participants either sufficiently disparate in their holdings and strategies, or able to take large opposing positions during periods of turmoil. In this sense, the extensive use of identical risk assessment tools, such as Value at Risk (VaR) or other enhanced versions of it (e.g. Conditional VaR), promotes similar risk strategies, which result in similar "diversified" portfolios and similar "rational" decisions across different banking and non-banking institutions. Even if VaR were a perfect risk

[17] Brown et al. (2009) reports that exposures on subprime-backed assets resulted in Morgan Stanley, UBS and Merrill Lynch, losing $15, $20 and $30 billion, respectively.
[18] Kambhu et al. (2007) stress that the financial system today does not seem highly prone to contagious runs on very large banking firms.

assessment tool[19], its universal usage in the financial industry results in an undesirable self-defeating mechanism during periods of market chaos, where decreasing prices and increasing volatilities are amplified by a destabilizing positive feedback effect; this is akin to the case against “portfolio insurance” strategies, which Sornette (2003) regards as a major factor contributing to the crash of October 1987.

IMF (2007) also documents that diversity of risk management models can be a stabilizing influence. In addition to this, it is important to mention that this issue is not exclusive to risk management tools: the use of similar asset allocation techniques may also engender positive feedbacks, either during tranquil or stressful periods; accordingly, from a systemic perspective, diversity of asset allocation models may also be desirable.

Therefore, as Haldane (2009) asserts, the financial system is complex and homogeneous, with the former resulting from the participation of numerous institutions, and the latter from the lack of diversity when comparing institutions’ strategies and exposures, where the sum of both features results in a *robust-yet-fragile* system. The financial system is robust because, on average, the financial system is able to absorb a random shock on behalf of the existence of numerous institutions and connections between them; but it is –at the same time- fragile, since a targeted shock (an *attack*) to a hub (a TCTF institution) may not be absorbed, but amplified.[20]

In addition to the fragility resulting from complexity and homogeneity, financial innovation has made institutions and their interrelatedness even more obscure. Complexity not only emerges from the structure or interrelations between participants. Financial innovation, regarded as a source of risk diversification and efficiency during tranquil times (e.g. structured products, credit derivatives, options), may increase the system’s dimensionality and complexity during markets’ unrest.[21]

Haldane (2009) highlights that financial innovations such as securitization (e.g. CDS or other structured products) resulted in participants growing in size and interconnections multiplying, where the precise source and location of underlying claims became opaque, transforming risk into uncertainty in the Knightian sense.[22] Lehman fall provides good evidence on the subject: Braithwaite (2011) documents that not only competitors were not able to know who was exposed to Lehman, but they were unable to map their own exposures with ease, particularly because Lehman was not a single institution –but about

[19] Most of VaR shortcomings for effectively assessing risk are widely know (e.g. non-normality, kurtosis, skewness) and have been partially addressed using different VaR techniques (e.g. Extreme Value Theory, jump-diffusion models, GARCH, historical simulation). Nevertheless, severe shortcomings are still poorly addressed, such as long-term scaling, measuring dependence –and diversification effects- during extreme events, capturing persistence (cumulative losses) in price changes, among others.

[20] As Haldane (2009) argues, such *robust-yet-fragile* feature is a result of the system’s complexity and homogeneity, but also a consequence of the fat-tailed distribution of institution’s connectivity. About the latter, on average, a shock will be aimed to a non-TCTF institution, making the system robust to random shocks; however, if the shock is non-random but consists of a shock targeted to the tail of the distribution that contains TCTF institutions, the system will be seriously affected. This issue will be addressed in the next chapter.

[21] For example, months before the crisis the IMF’s Global Financial Stability Report focused on how credit derivatives helped to make the banking and overall financial system more resilient, and to mitigate and absorb shocks to the financial system (IMF, 2006); four years –and a global crisis- later, the same report focused on how credit derivatives took center stage as difficulties in financial markets intensified and on how they played a key role in counterparty risk (IMF, 2010).

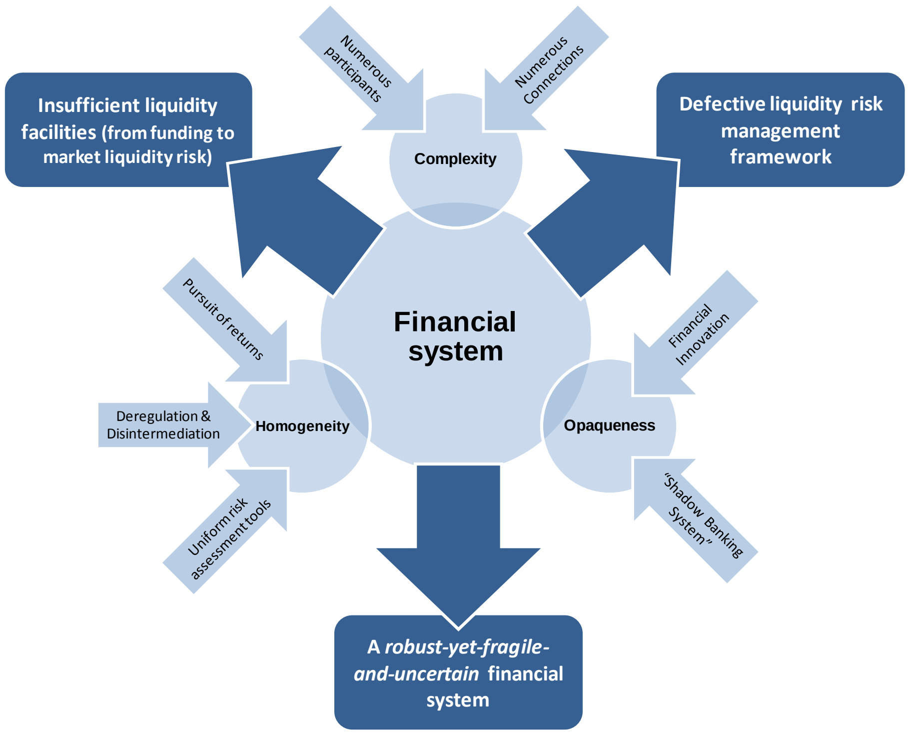
[22] According to Knight (1921), who provided an early definition of uncertainty and risk, the former corresponds to those cases in which we are unable to quantify the probabilities of various outcomes, whereas risk applies to situations where those probabilities can be known. Financial innovation, specially credit derivatives and securitization, obscured the way market participants relate to each other, resulting in counterparty risk becoming almost unknowable, thus uncertain.

10.000 institutions-, so no one could be sure what Lehman was. [23] In this sense, opaqueness in the linkages between participants make the financial system *robust-yet-fragile-and-uncertain*.

Moreover, this uncertainty, where the true counterparty exposure is difficult to define and assess, distorts asset pricing and encourages rational but –extremely- hazardous behaviors from market participants, such as herding. As a direct consequence of the opaqueness resulting from financial innovation, and due to the fact that its optimal to imitate when lacking information (Sornette, 2003), it is likely that during periods of turmoil market participants will have the "rational" incentive to imitate others' behavior, reinforcing the destabilizing positive feedback effect previously mentioned; this is, making the financial system even more fragile.

Finally, it is possible to conveniently characterize financial system's issues and challenges as follows: the sum of complexity, homogeneity and opaqueness results in a robust-yet-fragile-and-uncertain system, where the existence of a defective risk management framework and the absence of liquidity facilities able to cope with the shift towards market liquidity risk make the financial system highly prone to systemic crisis. This is summarized in Figure 1.

Figure 1
An increasingly systemic-crisis-prone financial system: issues and challenges



Source: authors´ design.

[23] Bear Sterns is also a good example. According to Acharya et al. (2009), while the market was learning about who was exposed to Bear Sterns by mid-June 2007, it was still unclear what the magnitude of this exposure was and who was at risk through counterparty failure. Kohn (2006) documents that uncertainty about counterparty risk –and market prices- was also experienced during 1987 stock market crash and the LTCM episodes, which he judges as the first two market-based (non-banking related) systemic events.

Models oriented to detecting and assessing systemic risk within the financial system's complexity and homogeneity framework previously described are rather new. Current regulation is focused not on systemic risk, but rather on the individual institution's risk (i.e. micro-prudential), whereas regulation encourages financial institutions to distribute their risks in an unfettered manner around the system and to unregulated entities, which leads to excessive systemic risk (Acharya et al., 2009).

3 A macro-prudential approach is required: the *too-connected-to-fail* concept

The most recent global financial crisis, along with LTCM episode and October 1987 stock market crash, helped achieving some degree of consensus regarding the call for models or techniques able to properly and efficiently detecting and assessing systemic risk. In this sense, taking into account that financial markets are a complex system, where connections matter as much as the participants that originate them, TCTF concept has emerged along with the traditional TBTF concept. Some authors agreeing with this statement are Chan-Lau (2010), ECB (2010), Clark (2010) and Zhou (2009).

Akin to the TBTF concept, TCTF could be straightforwardly defined. Based on a customary definition of systemic risk (CPSS, 2001), an institution may be labeled as TCTF when, due to its degree of connectedness –either direct or indirect-, its inability to meet its obligations could result in the inability of other system participants or of financial institutions in other parts of the financial system (i.e. the whole financial infrastructure) to meet their obligations as they become due.

Nevertheless, identifying a TCTF institution is not as straightforward as with a TBTF, where the latter relies on observable concepts and metrics such as the assets' value or the volume of financial services (e.g. deposits and loans) provided by a single institution (Figure 2).

Figure 2
TBTF and TCTF: a comparison

	TBTF	TCTF
Scope	Individually analyzing and inspecting financial institutions → default risk	Aggregately analyzing and inspecting the financial system → systemic risk
Focus	Financial institutions.	Payment systems and instruments (infrastructure)
Metrics	Assets, Deposits, Loans.	Centrality, connectedness.
Advantages	• Based on observable accounting data. • Easy to track. • "Easy" to forecast.	• Captures complexity of financial systems. • Identifies concealed sources of systemic risk. • Recognizes the increasing role of non-banking institutions ("shadow banking system")
Disadvantages	• Institution centric. • Focus on banking institutions. • Unreliable accounting data. • Unable to capture connectedness • Model risk.	• Requires models able to capture cross-dependency, context-dependency, non-linearity, complexity. • Define connection: claims? payments? • Model risk.
Key cases	• Overend Gurney and Co. Ltd. (U.K., 1866) • Baring Brothers (U.K., 1890) • The Bank of United States (U.S., 1929) • Johnson Matthey Bankers (U.K., 1984) • Continental Illinois (U.S., 1984)	• Herstatt Bankhaus (GER, 1974) • LTCM (U.S., 1987) • AIG, Bear Sterns, Lehman, Freddie Mac, Fannie Mae (U.S., 2008)

Source: authors´ design.

Identifying a TCTF institution is intricate. Among the main sources of intricacy it is worthwhile stressing that measuring an institution's connectedness is (i) complex and cross-dependent by nature (i.e. it cannot be measured in isolation) and (ii) extremely context-dependent and non-linear (Landau, 2009; Haldane, 2009).

Regarding the first source of intricacy for identifying a TCTF institution (i.e. complexity and cross-dependency), standard econometric approaches are not suitable for the task because the properties and behavior of the institution cannot be analyzed on the basis of its own properties and behavior alone, as these may be affected by institutions that have links to it, and also by other institutions that have no direct links, but are linked to its neighbors (ECB, 2010). A key concept when defining whether an institution fits the TCTF concept or not is *centrality*, which refers to the importance of the participant for the system as a whole.

About context-dependency, because of the numerous participants and connections within the financial market, a minor change in the initial conditions of the system (e.g. liquidity, regulation, macroeconomic environment) may critically affect the result of the analysis. This is, the TCTF label is particularly dynamic, where an institution may become TCTF (or non-TCTF) with an otherwise trivial alteration of the status-quo. Despite this may appear to be odd, Greenspan (1998) acknowledged that "the plight of LTCM might scarcely have caused a ripple in financial markets or among federal regulators 18 months ago – but in current circumstances it was judged to warrant attention".[24] Sensitivity to initial conditions is intuitive in the financial markets' case since, for example, abundant liquidity allows institutions to process payments independently from each other, whilst reduced liquidity makes institutions' ability to make payments become coupled with the ability of other institutions to make payments (Kambhu et al., 2007).

Similarly, as with context-dependence, the non-linearity features of complex systems set additional hurdles for identifying TCTF institutions. Non-linearity refers to the disproportionate effect of a shock in the overall properties of the system, which are not easily captured by standard econometric tools. For the subject under study, for example, there is some degree of consensus about the lack of correspondence between the subprime crisis (i.e. the shock) and the global financial crisis (i.e. the outcome), where the former is rather modest when compared to the extent of the whole episode (Bullard et al., 2009; Haldane, 2009).

Regarding these two sources of intricacy, Natural and Social Sciences have faced similar challenges. For the first one (i.e. complexity and cross-dependency), network topology (also referred as network analysis or theory, NT) has been a widely accepted and highly convenient approach, since it allows for analyzing systemic risk by looking at how resilient the system is to contagion and what the major triggers and channels of contagions are (Tumpel-Gugerell, 2009), taking into account the size of flows, interdependencies with other systems/markets, and the degree of substitutability (Manning et al., 2009).

For the second source of intricacy (context-dependence and non-linearity), simulation models are useful tools because they can be calibrated to replicate a specific environment (Arjani et al., 2007), and because it allows for assessing the impact of altered liquidity levels and payment flows in terms of payment queues, liquidity requirements (e.g. overnight lending) and the value and number of unsettled transactions (Leinonen and Soramäki, 2005).

[24] Regarding context-dependency, Pozen (2010) also documents that the bankruptcy of Drexel Burnham Lambert in 1990 –the most powerful bond house in the world at the time- had rather limited systemic effects.

At the end, because the system is *robust-yet-fragile-and-uncertain* due to its complexity, homogeneity and opaqueness, where the existence of context-dependency and non-linearity further hinders the use of typical approaches to systemic risk, the use of a combination of network theory and simulation techniques may be a comprehensive and convenient framework for identifying and assessing systemic risk.

4 Colombia's payments system's stability under the *too-connected-to-fail* concept

A payments system (PS) is a set of instruments, procedures and norms for the transfer of funds among participants in the system (CPSS, 2001). Accordingly, the effectiveness and stability of financial markets depends on it functioning properly. Considering how important settlement and large-value payment systems are to financial stability, the central banks in most countries now own and operate these systemically important systems, which use real-time gross settlement (RTGS) as the primary method of settlement.[25]

The systemic importance of a PS depends on the functions it fulfills within the economy. According to CPSS (2001), a systemically important PS has at least one of the following characteristics: (i) it is the only PS in the country or the main PS in terms of the aggregate value of the payments; (ii) it primarily handles payments of large individual value; and (iii) it is used to settle financial market transactions or to settle other payment systems.

This chapter is dedicated to introducing the approach developed by Banco de la República (Machado et al., 2010) for identifying and assessing systemic risk within Colombia's financial market. The approach is based on an application of NT and simulation techniques to BR's large-value PS (henceforth referred as CUD), which is the only large-value PS in the country and is used to settle all financial market transactions and to settle other PS, thus a systemically important SP by CPSS's (2001) standards.

Different from other approaches based on network topology, the chosen approach relies on payments as connections. Balance sheet claims between institutions as sources of connectedness (Chan-Lau, 2010b) are deemed by the authors as impractical for the purpose of this document because (i) it is not clear whether off-balance positions are being captured or not when using claims, whilst payments comprise all transactions between payments system's participants; (ii) unlike claims, relying on payments allow for considering liquidity as a key factor in systemic risk; (iii) as acknowledged by Tumpel-Gugerell (2009), a particular institution might not only be systemically relevant because other institutions are financially exposed to it, but also because other market participants rely on the continued provision of its services; and (iv) as emphasized by Kodres (2009), failure or insolvency are not the only sources of systemic shocks, but mere failure-to-pay or non-payment of transactions can gridlock the entire financial system.

4.1 A brief introduction to Colombian large-value payments system

The Colombian PS comprises a centralized network infrastructure in which BR's CUD operates as a hub that maintains communication with all other participants (i.e. securities

[25] The RTGS mechanism is characteristic of payments systems managed by central banks, where clearing and settlement are processed immediately and simultaneously in the accounts the institutions have with the central bank. In 2008, the World Bank surveyed 142 central banks about their PS and found that 112 of the large-value PS settle their operations according to the RTGS scheme and 108 of these PS (96%) are operated by the central bank (World Bank, 2009).

depositaries, low-value payment systems, the Foreign Exchange Clearing House, the Chamber of Central Counterparty Risk), where the participant that generates most activity and volume is BR's own securities depositary (DCV), which is exclusively dedicated to clearing and delivering the most liquid fixed-income securities in the local market: central government's local public debt bonds (TES). All financial institutions –and some special official entities- are allowed to participate directly in the CUD, which is in charge of the clearing and settlement of all their payments; the most relevant types of financial institutions participating in CUD are briefly described in Table 1.

The CUD started in September 1998 and, since then, it has operated as a RTGS system, with its monthly volume representing as much as 1.71 times the GDP (September and October 2009). During 2009, 160 institutions directly conducted transactions in the CUD, where Commercial Banks (CB) and Brokerage Firms (BF) were the most active with about 75% of all operations.

Table 1

Main Colombian market's financial institutions directly participating in CUD (2009)

Class	Institution type	Main purpose [c]
Credit Institutions (CI) [a]	Commercial Bank (CB)	Provision of deposit and loans, including mortgages. [18]
	Commercial Financial Corporation (CFC)	Provision of deposit and loans focused on goods and services commercialization (e.g. leasing). [26]
	Financial Corporation (CF)	Provision of deposit and loans focused on medium term industrial financing; akin to an investment bank. [3]
Non-Credit Institutitons (NCI)	Mutual Fund (MF)	Provision of investment vehicles with the purpose of investing in securities and other assets according to the risk profile of the investor. [26]
	Brokerage Firm (BF)	Provision of brokerage services with the purpose of buying and selling securities (e.g. stocks, bonds, currencies); allowed to trade for its own account. [32]
	Pension Fund Manager (PFM)	Provision of investment vehicles with the purpose of investing for retirement. [6]
	Special Official Institution (SOI)	Official (government owned) financial institutions with special objectives; due to its main features, they were excluded from the analysis. [b] [10]

[a] Financial cooperatives pertain to Credit Institutions, but due to its low connectedness and size they were excluded from the analysis; CIs are the only institutions able to receive LLR liquidity.
[b] SOI type comprise ten government owned institutions, where the largest is Fogafin, the deposit insurance agency. Their involvement in the CUD is rather low, thus they were excluded from the analysis.
[c] Only the main differencing feature appears; the number of institutions as of 2009 appears in brackets.
Source: authors' design.

As previously mentioned, the CUD, unlike other countries' PS (e.g. CHAPS Sterling in the U.K.), is a direct participation system where any type of financial institution can maintain deposits and conduct transactions with other participants without the need for an agent or intermediary. For this reason, the CUD has a large number of direct participants (160) representing all types of institutions, banking and non-banking. In comparison, according to Becher et al. (2008b), CHAPS Sterling in the United Kingdom is characterized as having more than 4,000 institutions that participate indirectly through 15 members or direct participants,[26] who act as agents for the others to make their payments.

When institutions participating in the PS experience temporary liquidity problems, they can make use of BR's resources through different facilities. Within its expanded inflation targeting scheme, in which the stability of the financial system plays an essential role, BR's liquidity facilities can be grouped according to their objective, namely: (i) for macroeconomic liquidity, through Open Market Operations (OMO); (ii) for the ordinary operation of the PS, through intra-day repos, which may be converted into overnight repos; and (iii) for financial stability, which is achieved when BR fulfills its LLR function.

Regarding OMO, they are BR's main monetary policy instrument, as is the case with most central banks that use an inflation targeting approach. OMO transactions (via selling or purchasing TES) are conducted by OMO agents, which by the end of May 2010 accounted for 97 institutions, where CBs, CFCs and CFs are the most active.

About the second facility, BR introduced two instruments to complement OMO and to ease PS's liquidity pressures: the intra-day repo and the overnight repo. Intra-day repos first became available in January 2001 and are used by institutions to cover their liquidity shortages during the trading hours. The overnight repo facility has been in place since May 2001, and it materializes in two ways: (i) after an institution fails to fulfill an intra-day repo, and (ii) when a CB does not have enough funds to clear checks.

Concerning the third facility, BR can act as a LLR to minimize contagion and to keep the financial system stable. As asserted by Meltzer (1986), under special conditions, this function allows central banks for providing the resources an institution needs to deal with a transitory liquidity problem. In Colombia this is known as Transitory Liquidity Facility (TLF), and is reserved exclusively for Credit Institutions, which are firms dedicated to the provision of deposit and loan products, namely CBs, CFCs and CFs.

4.2 Network topology and payments simulation for identifying and assessing systemic risk

The periods and the institutions to be evaluated and analyzed were defined in order to assess the systemic risk and potential threat to the stability of the PS and the financial markets. Three periods representative of CUD transactions were selected based on the concept of liquidity and TES market activity, which follows the need for effectively capturing different volatility and liquidity scenarios for the Colombian financial market, allowing for a better assessment of the dynamics of PS stability. Afterwards, based on the selected scenarios, the four institutions of greatest systemic importance within the CUD were selected.[27]

Pursuant to the foregoing, the month of June 2006 was selected as the period representative of high volatility in the PS, corresponding to the most recent acute stress in the TES market; akin to 1987's crash, LTCM's and the most recent global financial crisis, June 2006 was characterized by a run on local market liquidity, where the non-banking financial institutions, namely BFs and MFs, were particularly threatened. This period

[26] According to Becher et al. (2008b), four of the 15 direct members of CHAPS Sterling conduct most of the transactions.
[27] Selecting the four institutions of greatest systemic importance follows practical reasons. An objective threshold for deciding the number of systemic relevance is not addressed in this document.

witnessed a sharp drop in the price of TES (local market's benchmark) and low market liquidity, with characteristics quite similar to those observed in August 2002.[28]

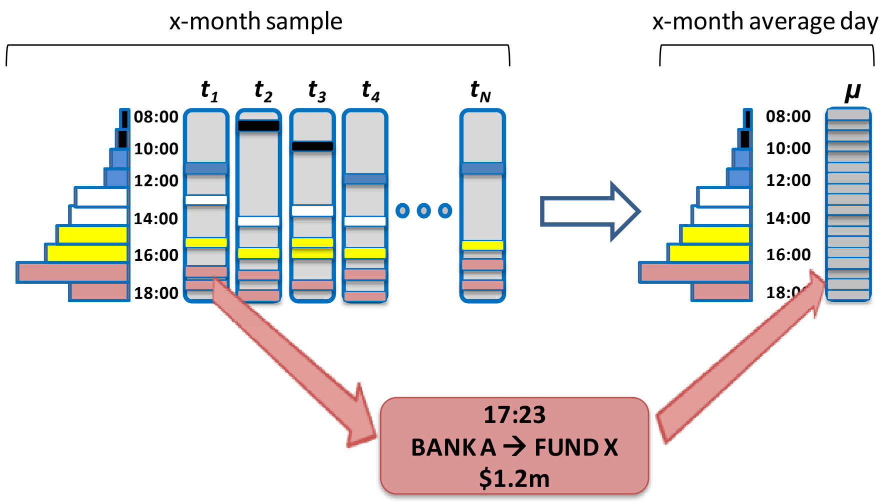
Contrasting with June 2006, four months before was a period characterized by high liquidity and low volatility in Colombian financial markets, where the TES market exhibited the peak of a prominent boom. Thus, February 2006 was chosen as a period representative of tranquil times, with abundant liquidity and confidence among the market participants.

September 2009, the month when the CUD registered the largest trading volume since its creation, was selected as well. In all, 215,776 transactions were conducted during that month for a volume representing 170.7% of GDP, with a daily average of 9,808 transactions.

The NT and payment simulation is applied to a single day of transactions. Therefore, a method to construct a typical day of operations in the CUD was designed once the periods had been selected. This process involved taking monthly samples (i.e. February and June 2006, and September 2009) of CUD transactions to discern the principal characteristics of the transactions in each period. Then, an "average day" of transactions (μ) was estimated with the bootstrap method.[29] In order to preserve the main statistical properties of the sample (i.e. intraday-seasonality) the database was divided in several time-of-the-day buckets, and the bootstrap procedure was applied independently for each bucket until approximating the average volume of transactions per bucket, and the overall average volume of transactions per day, as depicted in Figure 3.

Figure 3

Estimating an "average day" of payments transactions



Source: authors´ design.

[28] Based on the fixed-income index (IDXTES) developed by Reveiz and León (2008), August 2002 corresponds to a return of -2.82% (-10.5 standard deviations) and June 2006 to -2.26% (-8.4 standard deviations).

[29] A bootstrap procedure involves resampling, with replacement, from the existing data set (Dowd, 2002); in this case the set is the database of payment transactions taking place during the specified month.

Using an "average day" estimated in this way, rather than any particular single day, allows for a more robust characterization of the stability of the PS network in different scenarios, as it preserves the conditions found during the period (i.e. liquidity, intra-day seasonality), while mitigating the impact of infrequent but large operations on the part of certain non-financial participants (e.g. Ministry of Finance). However, this step may be skipped and a single day of data may be used if deemed appropriate.

Based on the "average day" of transactions for each period, an overall index based on (i) each institution's share of the total traded value and (ii) each institution's share of the total number of connections during the three scenarios was constructed[30]; these two measures are traditional (*in-degree* and *out-degree*) measures of *centrality*, a concept which refers to the importance and location of the participant or node in the network (ECB, 2010; Soramäki et al., 2007). This index serves as a primary approximation to the notion of systemic risk based on the idea of TCTF. Table 2 shows the results of the index for the ten foremost connected (*central*) institutions. These ten institutions, which represent 6.3% of the CUD participants, account for 47.4% of the traded value and 25.8% of the connections. Among the top ten institutions of major systemic importance according to the *centrality* concept there are seven CBs, two BFs and one FC.

Table 2

Ten foremost connected (central) institutions [a]

3-period average

Institution	**Traded Value**		**Number of Connections**		**Aggregate**	
	Share	**Index [A]**	**Share**	**Index [B]**	**[A+B]**	**Overall Index**
INST1	8,4%	100	3,5%	100	200	100
INST2	7,1%	85	3,1%	87	139	70
INST3	6,6%	78	2,8%	78	127	63
INST4	4,9%	58	2,6%	72	107	53
INST5	5,0%	60	2,5%	70	106	53
INST6	3,7%	44	2,7%	77	101	50
INST7	2,3%	27	2,7%	77	89	44
INST8	3,6%	43	2,2%	63	88	44
INST9	2,8%	33	2,0%	55	74	37
INST10	3,1%	36	1,8%	51	72	36

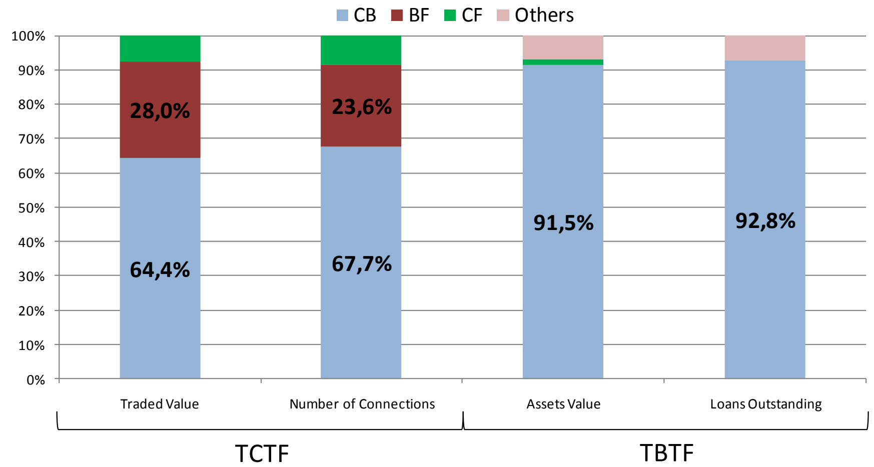
[a] The ten foremost connected (*central*) institutions represent 47.4% of the total traded value and 25.8% of the total connections.
Source: authors´ calculations.

As indicated in Figure 4, pursuant to the notion of TCTF (left side of Figure 4), the CBs are the institutions of greatest systemic importance within the ten foremost connected

[30] In this index, the institution with the largest share of total value or total connections obtains a score of 100. The following institutions, by linear interpolation, obtain a score between 0 and 100. The aggregate corresponds to the sum of the index obtained for each institution in both categories, which is then used to calculate a general or overall index. Participants such as the Ministry of Finance were excluded from this analysis; their characteristics demand a special study to assess their systemic impact.

institutions (64.4% and 67.7% of traded value and number of connections, respectively), although the BFs are significant as well (28.0% and 23.6%, respectively).

Figure 4
Ten foremost relevant institutions: TCTF and TBTF
3-period average



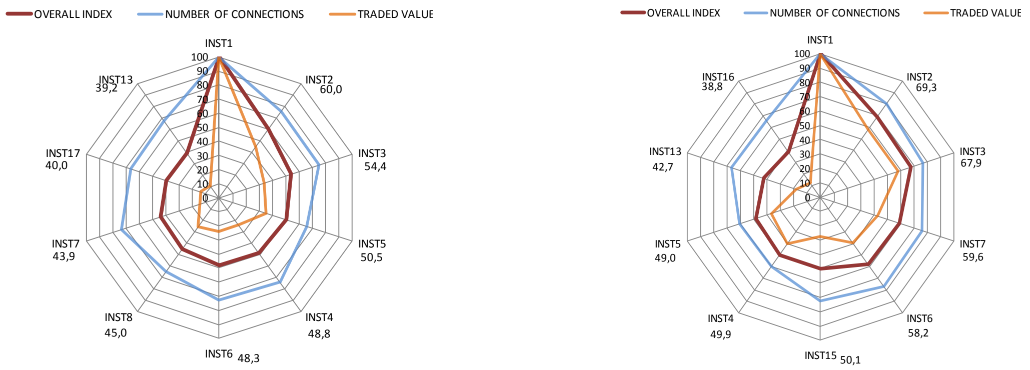
Source: authors´ calculations.

Pursuant to the TBTF concept, which is customarily measured according to the asset value and the loans outstanding[31] (right side of Figure 4), CBs are practically the only institutions that may be regarded as systemically relevant (91.5% and 92.8% of assets value and loans outstanding); the remaining share of asset value loans outstanding pertains to Fogafin (the deposit insurance agency) and other SOI. This stresses the importance of considering connectivity as a measure of systemic risk.

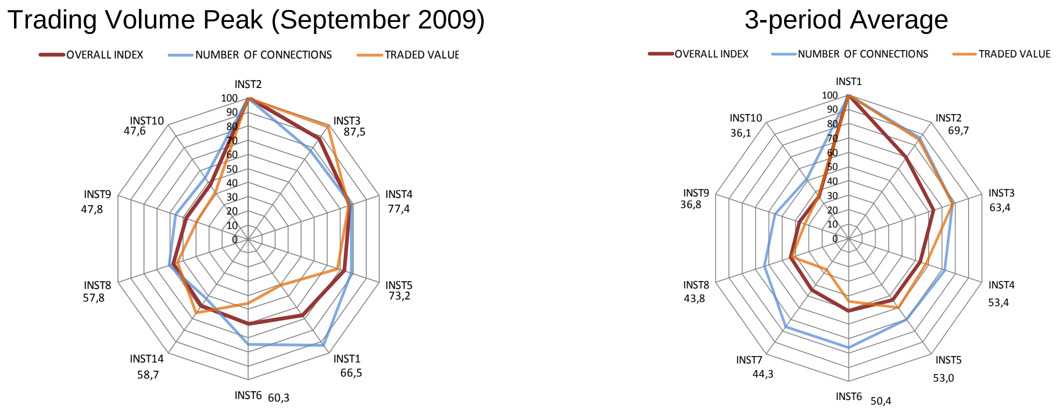
Figure 5 portrays the make-up of the index of systemic importance for the top ten institutions in the three periods and an average of these. The average's first seven institutions appear in all the selected periods. This suggests the institutions with more systemic risk, pursuant to the notion of *centrality*, are relatively stable over time.

Figure 5
Ten foremost relevant institutions: TCTF and TBTF

Boom in the TES Market (February 2006) | Stress in the TES Market (June 2006)



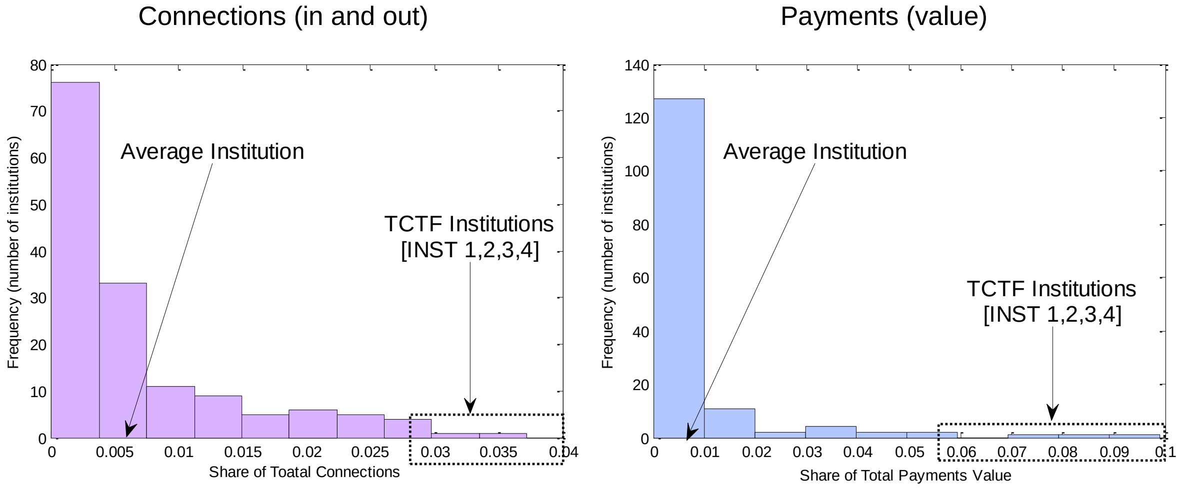
[31] Another customary measure of size is the value of deposits. It is not included because CB, CF and CFC are the only authorized institutions to take deposits from the public.



Source: authors´ calculations.

The first four institutions of greatest systemic average importance according to the *centrality* metrics were selected to carry out targeted shocks (*attacks*) on the PS (i.e. INST1, INST2, INST3, and INST4 in Table 2). The result was a sample with two types of institutions: CBs and BFs. The systemic effect of an *attack* on each of the four selected institutions will be simulated in the following sections, and the results will be presented and analyzed as an average per type of institution.[32]

Figure 6
Distribution of connections and payments per institution (%)
3-period average



Source: authors' calculation

It is worthwhile to emphasize the importance of the usage of *centrality* for deciding which institutions will be *attacked* in the NT and simulation approaches. As documented before, because the distribution of institutions' connectivity is significantly fat-tailed and skewed (Figure 6), using random shocks will tend to overlook systemic risk; TCTF entities await in the uttermost right side of the distribution. Assessing the *centrality* of institutions allows for

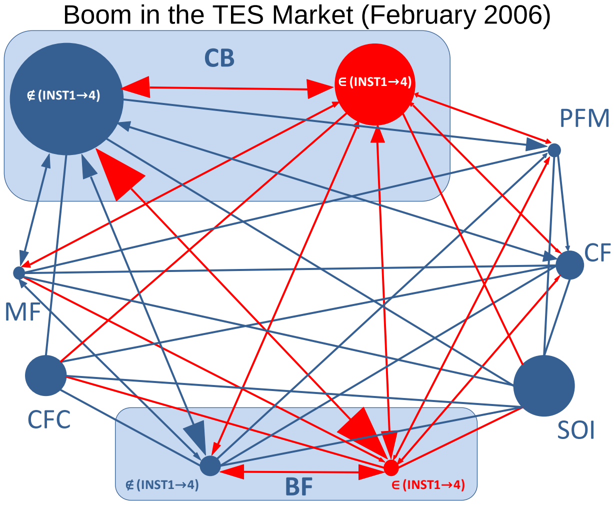
[32] Authors deem necessary to present results as an average per type of institution (e.g. CB and BF) in order to preserve confidentiality. This is also the reason not to disclose the names of the institutions or the precise composition of the top-four and top-ten systemic relevant firms by type of institutions.

selecting those entities that actually may endanger systemic stability, whilst preserving parsimony within the approach.[33]

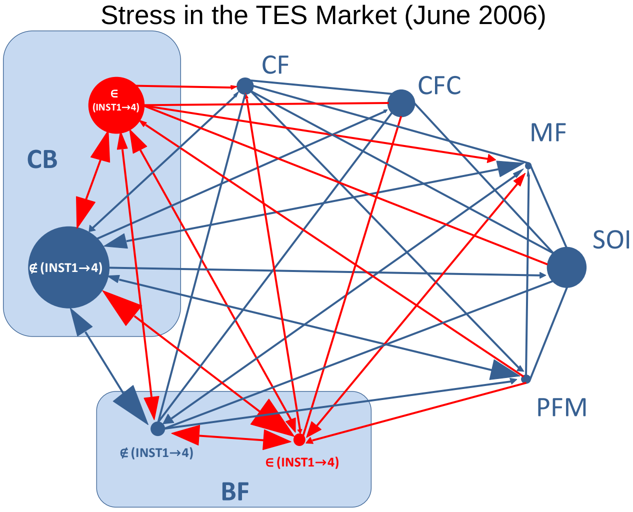
As before (Figure 4), using *centrality* as an objective metric for systemic importance based on the TCTF concept allowed for identifying institutions which would have been disregarded by the traditional TBTF concept. This is evident in Figure 7, where network theory (graphs) is used to simultaneously present TCTF and the TBTF concepts for each scenario. The size of each arrow's head represents the total value of the payments (i.e. connectedness), whilst the size of the node represents the asset size; please note that the four foremost relevant institutions under the *centrality* concept and their connections have been differentiated (in red) for illustrative purposes, where the [∈(INST1→4)] nodes corresponds to the institutions belonging to INST1, INST2, INST3 or INST4, and the [∉(INST1→4)] to those not belonging, either pertaining to the CB or BF institution types (in rectangles).

Figure 7
Colombia's financial system as a network (graphs)

Boom in the TES Market (February 2006)

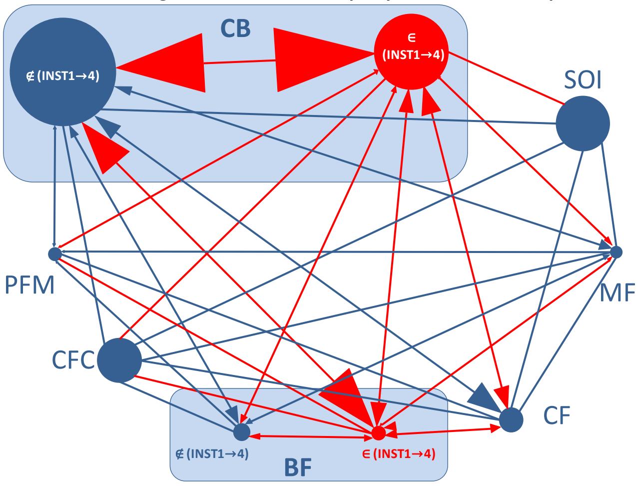


Stress in the TES Market (June 2006)



[33] Instead of using random shocks or targeted shocks based on *centrality* it is possible to shock all the institutions of the system. Nevertheless, this may be computationally inefficient and burdensome, especially in a PS where any financial institution may participate directly; this is the case in hand, where it would be necessary to shock, simulate and analyze 160 institutions.

Trading Volume Peak (September 2009)



Source: authors´ calculations.

Regarding the graphs in Figure 7 it is key to emphasize the following: (i) as expected, focusing on the size of institutions (nodes' size) would concentrate supervision on Credit Institutions (CBs, CFCs and CFs), along with government related SOIs; (ii) focusing on the size of the institutions would overlook the importance of the "shadow banking system", with BFs being institutions heavily connected to CB for the three scenarios considered; (iii) the nodes corresponding to the four foremost systemic relevant institutions [∈(INST1→4)] concentrate a significant share of the connections within the network, thus supporting their choice for illustrative purposes.

All this further supports the mainstay of the TCTF concept: using the size of the institution is insufficient to assess its contribution to systemic risk within the financial network; it is necessary to shift from micro-prudential to macro-prudential approaches, where the latter refers to the objective of promoting the stability of the financial system as a whole (Clement, 2010).[34]

4.2.1 The static approach: network topology

Network topology (also known as network analysis or network theory) is a method used in statistical physics to understand and analyze the structure and functioning of complex networks. Recent applications demonstrate its usefulness in analyzing how PSs respond to liquidity stress. The studies by Soramäki et al. (2006) and Bech and Garrat (2006) use NT to characterize the PS in the United States (Fedwire),[35] while Ianoka et al. (2004) apply it to the PS in Japan (BoJ-Net). In the Colombian case, Cepeda (2008) applies NT to the CUD to quantify the impact of failures on its stability.

A PS network is made up of a set of nodes or vertexes (institutions participating in CUD) and connections or links (payments) between pairs of nodes. The connections between nodes can be directed or not, and can be weighted (by value or volume of payments) to reflect the strength or weight of the link that is established. Accordingly, the PS is

[34] Central bank's macro-prudential role makes part of its oversight function, which has the objective of attaining an efficient and safe payments and settlement system (CPSS, 2005).
[35] The applications of Lublóy (2006) for Hungary and Boss et al. (2004) to measure systemic risk in the Austrian banking system are useful examples of the use of this method to characterize the banking system.

constructed of nodes or participants, which are the institutions that comprise the network and conduct transactions with one another.

Based on this characterization, it is possible to study the basic properties of the network, which are observed through parameters such as *average distance*, *diameter* and *connectivity* (Table 3).[36]

Table 3

Selected NT parameters

Average distance	Refers to the lowest average number of connections or links needed to connect two nodes, and indicates how close the nodes are in the network.
Diameter	Pertains to the maximum distance between two nodes, and makes it possible to determine the number of connections (payment relationships) needed for any two nodes (participants) to interact.
Connectivity	Refers to the ratio between the number of connections observed in the network and the number of possible connections in the network. It captures network density, which reflects just how interconnected the nodes are in the network.

Source: Authors' design, based on Cepeda (2008).

Calculating the stability of the PS based on NT is intended to characterize the CUD as a network, so as to estimate its stability in scenarios that involve an institution's failure-to-pay or non-payment. Initially, the parameters described in Table 3 were calculated for the CUD payment network in each of the selected periods (average days for February and June 2006, and September 2009). The next step was to recalculate the network's parameters after subjecting it to failure-to-pay by a selected node; this is a targeted shock or *attack*. This was done by eliminating the transactions originating from that institution (*out-degree*), but preserving those made by its counterparties (*in-degree*), including transactions which correspond to payments directed to the failing node.

Four failure-to-pay or non-payment scenarios were designed for each period, with each corresponding to an institution that ceases –for whatever reason[37]- to make its payments (i.e. INST1, INST2, INST3, INST4 from Table 2). These *attack* scenarios are interpreted as static in nature, since they consider all the transactions sent/received in the selected average day regardless of the order in which they were conducted, nor taking into account whether the participants had enough funds on their BR's deposit accounts to fulfill those payments. Assuming that institutions had enough funds may result in some nodes or participants remaining "artificially" connected to the network after the *attack* because they are taken as able to comply with their payments when, in certain cases, they could have exhausted their liquidity.

Afterwards, the approach consisted of evaluating the change in network's parameters (i.e. connectivity, diameter, average distance), identifying the type of network (e.g. the distribution of number of connections per node), as well as measuring the effect caused by the *attacked* institution on the traded amount and the number of disconnected institutions. As asserted by Becher et al. (2008), if the network is robust and stable, the

[36] Basic concepts of NT applied to PS's stability analysis are used in this paper. Cepeda (2008) describes and uses additional concepts and metrics.
[37] It is important to emphasize that the reason behind the non-payment or failure-to-pay of the institution is non-specified; it may be due to liquidity problems, solvency, operational risk, legal risk, etc.

attack should have little effect on other participants; that is, the properties of the network should not differ significantly compared to those in the original scenario (with no *attack*).

The results of the exercise are exhibited in Table 4, in the form of variations with respect to the original scenario. It is evident that the impact on the network varies depending on the type of institution under *attack* and the selected period. For example, the *attack* on BFs has more of an impact on the network during the boom and stress periods, while the CBs had the most impact during the period of greatest activity in the PS.

The *attack* on the BFs in the boom scenario (February 2006) had a larger average impact in terms of reducing the amount traded (8.5%) than the impact derived from the *attack* on the CBs (5.9%), which was also reflected in the decline in the number of transactions (7.4% and 4.7%, respectively). During that same scenario, *attacks* on the institutions caused no major changes in distance and diameter, although connectivity declined considerably.

Failure-to-pay by BFs in the stress scenario (June 2006) generated less of a reduction in the amount traded and the number of transactions than was the case during the previous scenario (7.1% and 7.2%, respectively), and a lower connectivity loss.[38] It is noteworthy that failure-to-pay by BFs generates a marginal loss in network stability, but does cause one participating institution to disconnect from the network; in other words, it neither receives nor makes payments within the PS.

Table 4

***Attacks'* effects on the network (CUD) – static approach (NT)**

As variations with respect to the original scenario – per type of institution and scenario

Scenario	Institution Type	Network Activity		Network Topology Criteria						
				Network Features [b]			Nodes Features [a]			
		Traded value	Number of Transactions	Distance	Diameter	Connectivity	Sending & Receiving	Sending Only	Receiving Only	Not Receiving & Not Sending
TES Boom (Feb/2006)	CB	-5,9%	-4,7%	0,01	0	-2,8%	-1	1	0	0
	BF	-8,5%	-7,4%	0,01	0	-4,5%	-1	0	1	0
TES Stress (Jun/2006)	CB	-6,5%	-4,9%	0,03	1	-2,3%	-1	0	1	0
	BF	-7,1%	-7,2%	0,01	0	-3,3%	-1	1	0	1
CUD trading peak (Sep/09)	CB	-9,1%	-6,6%	0,01	0	-3,3%	-2	1	1	0
	BF	-5,4%	-5,3%	0,02	0	-2,6%	-1	1	0	0

[a] Corresponds to the number of nodes; rounded to the next integer.
[b] As defined in Table 3.
Source: authors´ calculations.

[38] As presented in Machado et al. (2010) the stress period (June 2006) exhibits the lowest level of connectivity among the chosen scenarios (60.6%, 46.1% and 49.7% for scenarios 1, 2 and 3, respectively), which intuitively results from participants' reluctance to engage in market transactions. This explains why the connectivity loss during the stress period is –on average- the lowest.

During the period of increased activity in the network (September 2009) the average failure-to-pay by CBs results in a decline of 9.1% in traded value within the PS and 6.6% in terms of the number of transactions. The distance increases by 0.01, the diameter remains the same, and connectivity is down by 3.3%. Contrary to the previous period, there were no disconnected nodes.

The average result of the *attacks* during the three selected periods is shown in Table 5, by type of institution. CBs are the institutions with more of a direct impact on the volume traded, since their failure-to-pay would lower the average traded amount in the CUD by 7.2%, as opposed to a decrease of 7.0% by BFs. Nevertheless, the SBFs have more of a direct impact in terms of the average number of transactions, which are down 6.6% compared to the reduction of 5.4% generated by the *attack* on the CBs. As for network connectivity, the *attack* on the BFs results in an average decline of 3.5%, which is more than the reduction caused by the *attack* on the CBs (2.8%).

Network topology confirms that the TBTF concept is insufficient to identify systemic risk sources. For Colombian large-value payments system (i.e. CUD), focusing on the size of the institutions would result in overlooking the importance of BF, which appear to be of similar systemic relevance as CBs.

Table 5

***Attacks'* effects on the network (CUD) – static approach (NT)**

As variations with respect to the original scenario – per type of institution

Institution Type	Network Activity		Network Topology Criteria						
			Network Features [b]			Nodes (Institution) Features [a]			
	Traded value	Number of Transactions	Distance	Diameter	Connectivity	Sending & Receiving	Sending Only	Receiving Only	Not Receiving & Not Sending
CB	-7,2%	-5,4%	0,02	0	-2,8%	-1	1	0	0
BF	-7,0%	-6,6%	0,01	0	-3,5%	-1	0	0	0

[a] Corresponds to the number of nodes; rounded to the next integer.
[b] As defined in Table 3.
Source: authors´ calculations.

4.2.2 The dynamic approach: payments simulation

NT can be used to characterize and analyze the structure and operation of complex networks. However, in its basic form, this approach can have certain limitations. As presented so far, the *attack* involved removing a node or participant as the originator of transactions under two key assumptions: (i) other institutions are always able to fulfill their obligations (i.e. their intra-day liquidity level is not considered) and (ii) other institutions do not react to the *attack*.

Relaxing the first assumption involves acknowledging that the capacity of institutions to conduct their transactions depends on their opening balance in the CUD at the start of the day, as well as all the transactions that imply an inflow and outflow of resources for them during the day, where the opportunity of each transaction is related to the ability of each institution to fulfill its obligations. On the other hand, relaxing the second assumption would demand making additional and challenging assumptions about how information spreads throughout the financial markets and about the manner *non-attacked* institutions react upon the arrival of this information; this is the reason why this assumption was preserved.[39]

Simulation exercises may provide the central bank with additional information that is valuable for managing liquidity in the PS. In this respect, Leinonen and Soramäki (2004) suggest that simulation analysis of PS transactions makes it possible, among other things, (i) to quantify the result of a change in payment flows; (ii) to determine the result in payment queues and liquidity requirements owing to the change in payment flows; and (iii) to quantify the need for overnight liquidity or the value and number of transactions that would not be completed if additional liquidity is not available.

Therefore, simulation of a complex system provides access to information that is not available through traditional statistical or econometric approaches, neither to NT. For these reasons, the NT approach is supplemented with a simulation model of CUD's payments in order to develop a dynamic analysis that measures the direct and indirect impact of the *attack*.

This approach, which compares end-of-the-day liquidity in a base scenario (i.e. with no *attack*) to end-of-the-day liquidity in a scenario where there was an *attack* on an institution, captures the direct and indirect effects of the failure-to-pay, the latter being caused by having connections with a previously *affected* institution; this is, this approach captures the *attack's* extended (i.e. second-hand) effects, which are the mainstay of systemic risk. Afterwards, based on NT, the simulation of payments' results are used to compare the network's properties (e.g. connectivity, diameter, average distance) before and after the *attack*. Finally, the responsiveness and resilience of participating institutions was analyzed according to their financial structure and access to BR's liquidity in the event of *attacks* on the PS.

The simulation of payments uses the opening balances and CUD transactions for each of the three selected periods as the base scenario, where central bank's liquidity facilities is excluded from CUD's transactions.[40] The base scenarios are compared to the *attack* scenarios, in which failure to fulfill any payment by one of the four institutions selected

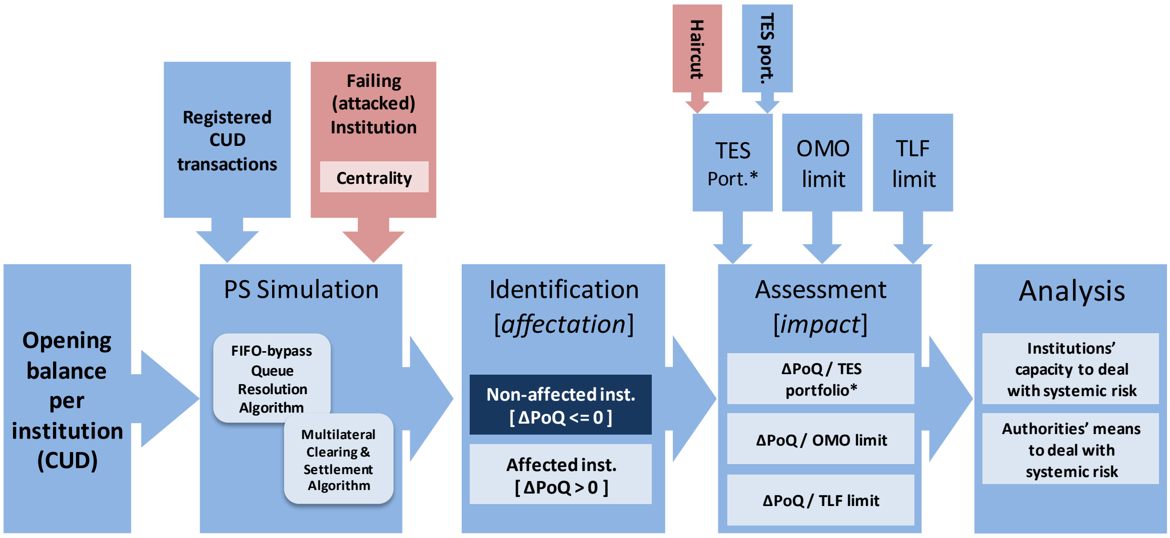
[39] Relaxing this second assumption requires a more extensive study to identify information conditions in the market (e.g. the existence of asymmetries, intra-group information management, and the response strategy by type of institution or particular entity), which is beyond the scope of this work; this assumption is common when using simulation techniques (Leinonen and Soramäki, 2004), but has been addressed by Soramäki et al. (2007). Authors consider this assumption as a rather interesting starting point for two reasons. First, it may be regarded as a stringent case in which a system's hub will act as a liquidity drain, where a major participant receives all their counterparties' payments but makes no payments to its counterparties. Second, because each source of systemic shock entails different informational dissemination and reaction dynamics (e.g. an operational driven failure may become noticeable later than a solvency issue), maintaining the non-reaction assumption serves the purpose of not specifying the source of shock. Nevertheless, authors acknowledge that the failure of a hub becoming public could have major consequences for the institutions' willingness to make payments to each other or even bank runs, which may generate an extreme disruption case.

[40] Excluding central bank's liquidity facilities from the central bank is convenient because it allows for obtaining true end-of-the-day liquidity requirements by the participating institutions, thus allowing for assessing the total liquidity required by the system and each participating institution. This will also allow for properly evaluating the sufficiency of central bank's liquidity facilities.

according to their degree of connectivity is assumed to occur from 9:00a.m onwards. The parameter for comparison will be the variation between the base scenario and the *attack* scenario with respect to the unresolved payments each institution still has on queue (Payments on Queue, PoQ) at the end of the day.

Figure 8 reproduces the dynamics of the simulation procedure. The simulation is based on the liquidity institutions have in their deposit accounts (opening balance), which is *affected* during the day by the transactions registered chronologically in the CUD. Because the objective is to replicate a RTGS large-value PS (i.e. CUD), a transaction can be carried out only if the institution making the payment has enough funds in its deposit account. If it does not, the payment is placed on the queue of outstanding payments (PoQ). PoQ will be fulfilled to the extent the institution obtains enough funds to cover all or part of them, for which a Queue Resolution Algorithm (QRA) was defined.

Figure 8
Simulation of payments process



Source: authors' design.

The selected QRA is based on the "First In First Out" or FIFO algorithm, which is the one most commonly used.[41] Every time a transaction is executed (i.e. a payment is made), the algorithm assesses if the institution that received funds has any PoQ and whether or not the new balance is sufficient to cover any of these left-pending transactions. The algorithm respects the order in which the unfulfilled transactions were placed on queue. If it is possible to settle one of the outstanding payments, it is registered as a new transaction. This, in turn, prompts the QRA to search again to determine if the institution that received funds has any PoQ, if the new balance is sufficient to settle any of the outstanding payments, and so forth.[42] This type of QRA is known as FIFO-bypass (BR, 2009).

[41] Leinonen and Soramäki (2004) document the existence of other types of algorithms, including those that give priority to smaller transactions and others that allow the originator of the transaction to assign a preference to each transaction; the latter is the case of the CUD in Colombia and CHAPS in the United Kingdom. The FIFO system was used because of its simplicity and given the difficulty of determining the priority assigned by each participant when registering transactions in the CUD.
[42] Jurgilas and Martin (2010) describe recent developments for managing liquidity in RTGS payment systems and implementing different algorithms to make the best possible use of the liquidity in such systems.

To manage the liquidity in the system more efficiently a multilateral clearing and settlement algorithm was used to net institutions' PoQ at different points in time. For this purpose five multilateral nettings were carried out during the trading day, all made during periods of peak intra-day trading. Liquidity savings are generated this way, giving participating institutions more capacity for settling PoQ and allowing for more efficient use of liquidity in the simulation.[43]

Based on the payments registered and settled using the simulation approach, the NT is applied to the simulated CUD's settled transactions with and without *attack*, and a new characterization of the network is provided. Table 6 shows a comparison of the results obtained with both approaches, where using NT on the simulations' results allows for assessing the direct and indirect (extended) impact of the *attack* on PS liquidity, where the intraday liquidity level is properly captured. As expected, the decline in network activity is more pronounced after using the simulation procedure, both in terms of volume traded and the number of transactions. This is an intuitive result since the simulation approach, unlike the basic NT approach, considers the direct and indirect effects of the *attack* and the intraday liquidity.

Table 6

***Attacks'* effects on the network (CUD) – static approach (NT) and dynamic approach (simulation + NT)**

As variations with respect to the original scenario – per type of institution

Approach	**Institution Type**	**Network Activity**		**Network Topology Criteria**						
				Network Features [b]			**Nodes (Institution) Features [a]**			
		Traded value	**Number of Transactions**	**Distance**	**Diameter**	**Connectivity**	**Sending & Receiving**	**Sending Only**	**Receiving Only**	**Not Receiving & Not Sending**
Static (NT)	CB	-7,2%	-5,4%	0,017	0	-2,8%	-1	1	0	0
	BF	-7,0%	-6,6%	0,015	0	-3,5%	-1	0	0	0
Dynamic (simul. + NT)	CB	-11,0%	-11,7%	0,019	0	-3,6%	-1	1	0	0
	BF	-12,8%	-16,8%	0,024	0	-5,0%	-1	0	0	0

[a] Corresponds to the number of nodes; rounded to the next integer.
[b] As defined in Table 3.
Source: authors´ calculations.

With the standard NT model CB's failure-to-pay yielded, on average, a decline of 7.2% and 5.4% in the value and number of transactions in the network, in that order. With NT applied to simulations' results, these *attacks* led to declines of 11% and 11.7% in value and number of transactions, respectively. Likewise, in the case of BFs results yielded a greater reduction in value (from 7% to 12.8%) and number of transactions (from 6.6% to 16.8%). As for the characteristics of the nodes, the *attack* on selected institutions with the

[43] Multilateral clearing and settlement is done pursuant to the approach used in the DCV with transactions from SEN. In the simulation procedure it is done at 12:00, 14:00, 15:00, 16:00 and 18:00 hours.

dynamic model led to a sizeable reduction in activity, as well as longer distances and less connectivity; this is more evident in the BFs case.

4.2.3 Results: assessing systemic risk and central bank's challenges

PS activity in the event of failure-to-pay by one or more institutions can be captured through the variation in the end-of-the-day PoQ of each institution that conducted transactions during the day. By means of this analysis it is possible to: (i) identify the institutions that significantly *affect* the stability of the network when *attacked*; (ii) identify the institutions that are *affected* directly and indirectly as a result of the *attack*; (iii) quantify the *impact* of an *attack* on individual and systemic liquidity; (iv) analyze institutions' resilience, which corresponds to their capacity to deal with systemic risk by making use of their own liquid portfolios (TES), as well as BR's liquidity facilities. The results are distinguished by class and type of institution, namely (i) CIs (CB, CFC, CF) and (ii) NCIs (BF, MF, PFM), which correspond to the banking and non-banking institutions, also referred as banking and shadow-banking sectors, respectively.

Accordingly, the variation of each institution's PoQ by the end of the day allows for quantifying the liquidity shortage an institution would face, and if it has the means to absorb such shortage by using its own account TES portfolio and/or BR's liquidity facilities. With this approach, an increase in an institution's PoQ means it has been *affected*, inasmuch as the opening balance and the payments received from third parties were insufficient to fully meet its payment obligations, due to the failure-to-pay by the selected institution or failure-to-pay by other institutions that were *affected* by the failure-to-pay of the former.

No change in an institution's PoQ after the *attack* would mean (i) it did not cease to receive payments as a direct or indirect result of the *attack* or (ii) in spite of not receiving all the payments as a direct or indirect result of the *attack*, it had an opening balance in the CUD or a payment structure that allowed it to retain the same level of PoQ. In both cases, for the purpose of analysis, the institution is considered as *non-affected*.

To assess institutions' resilience, which corresponds to the magnitude of the *impact* on their liquidity, three ratios were designed to show the increase in PoQ as a percentage of the following variables: (i) the market value of the TES portfolio, which is the most liquid and easy-to-collateralize security in the market; (ii) the liquidity limit in OMO for each institution, and (iii) the liquidity limit in TLF for each CI.

In the case of the first indicator, the variation in PoQ with respect to the market value of the TES portfolio comes close to the concept of potential liquidity, as it would indicate whether the sale of the TES portfolio or its use as collateral would be enough to cover the outstanding payments in the CUD. A discount factor on the market value of the portfolio of each institution was used in order to capture the effect of instability on the market and its corresponding effect on securities' prices[44]. Such discount factor pertains to the maximum haircut rate used by BR (currently 3%)[45] and results in the TES Portfolio* variable.

The second ratio consists of the maximum liquidity an institution can obtain through transitory expansion operations with BR, including OMO and intra-day and overnight repos.[46] The third indicator refers to the resources CIs may access through TLF, which are the resources provided by BR on behalf of its LLR function.[47] The last two indicators make it possible to assess whether or not the current limits set for OMOs and TLF are sufficient for BR to meet liquidity needs in adverse systemic scenarios. All three ratios allow for assessing the resilience of the institutions to the *attacks*.

4.2.3.1 Scenario 1: Boom in the TES Market (February 2006)

The results, on average, demonstrates that failure-to-pay by one of the four institutions (INST1, INST2, INST3, INST4) in this scenario *affects* 41.3% of the CUD participants; this is, 41.3% of the participating institutions observe an increase in their PoQ. The results for the boom scenario with respect to each of the four selected institutions are presented in Figure 9, which relates the variation in PoQ to the market value of the TES portfolio (horizontal axis), and the variation in PoQ to the limit for accessing BR's OMO transitory liquidity (vertical axis); please note that both axis are truncated to 200% for practical purposes.

In this sense, the situation of the institutions in the upper right quadrant is more critical with respect to the two variables under analysis, as they would be unable to meet their liquidity needs with their TES portfolio or with OMO resources; those institutions will be referred as *impacted* by the failure-to-pay of the *attacked* institution. Meanwhile, institutions located in the shaded portion would be resilient; that is, they are able to cover the increase in their PoQ after the *attacks* –either by selling or collateralizing their TES portfolio or by using its OMO quota-, thus they will be regarded as *non-impacted*.

MFs and BFs were the institutions most *affected* in this scenario. INST1 was the institution that, on average, generated the most instability in the PS, having led to an increase of the PoQ for 48.5% of the participating institutions. *Attacks* on INST2, INST3 and INST4 affected 38%, 32% and 32% of the institutions, respectively.

[44] It is worthwhile stating that during periods of financial turmoil (e.g. 2002 and 2006) the flight to quality in the Colombian market consists of shifting from TES or stocks to dollars; therefore, despite being issued by the central government and being considered as local credit risk-free instruments, TES' prices tend to fall during local crisis.

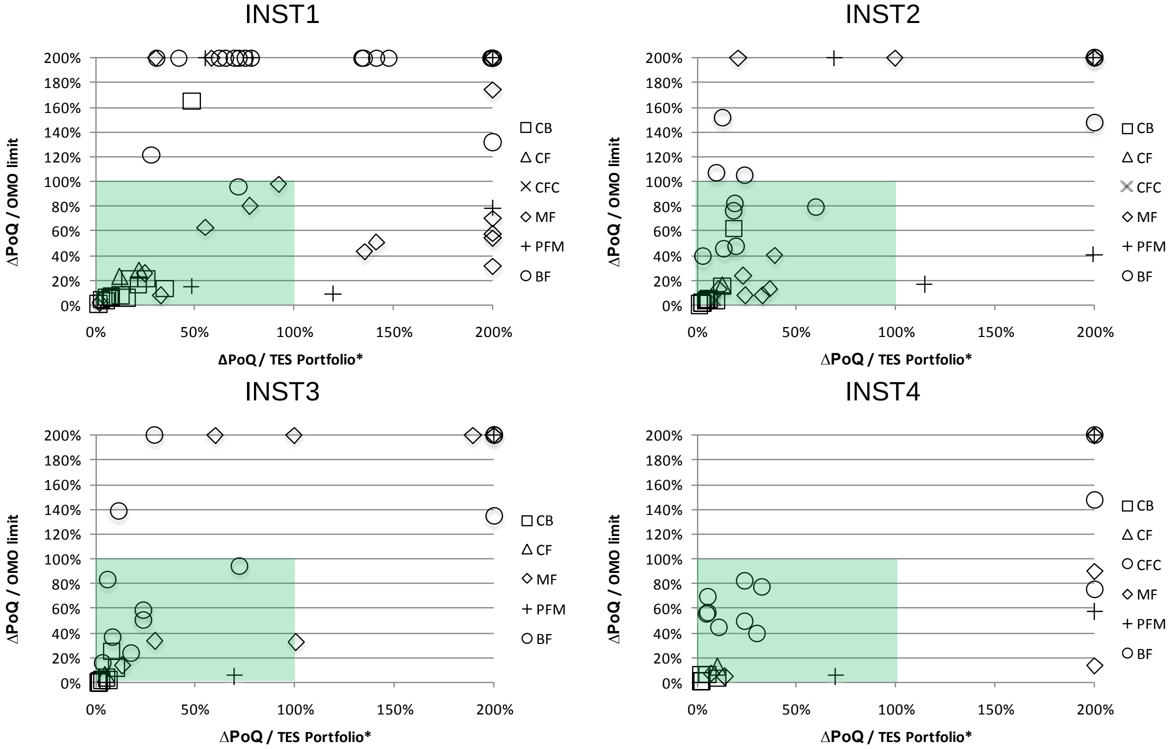
[45] This is, each institution may use (1-α) of the market value of its TES portfolio, where α is the maximum percentage of the *haircut* used by BR. This provides an approximate scenario to what a market stress episode may be and, in turn, yields more conservative results. The use of the 3% figure is fairly adequate since the worst daily fall ever in the IDXTES index (Reveiz and León, 2008) corresponds to 2.78% (August 22nd 2002).

[46] This limit is 35% of the liabilities subject to reserve requirements in the case of CIs, whereas for the MFs it is the value of their capital plus the legal reserve. In the case of PFMs and BFs, it is their technical capital. This document assumes that the limit allows all institutions access to the maximum amount of liquidity permitted. However, in reality, there are limits to the concentration of the auction per institution, among other constraints.

[47] The limit for TLF is 15% of the highest registered level of liabilities to the public within the 15 calendar days prior to the date the support was granted. As stipulated in the 1991 Constitution (Article 272), TLF may be used only by CIs (CB, FC and CFC); this constrain obeys the fact that CIs, due to their intermediation function (e.g. taking deposits and granting loans), are particularly exposed to liquidity strains.

Figure 9

***Attacks' impact* on the institutions (Scenario 1)**



Note: Results truncated to 200% for practical purposes.
Source: authors' calculations.

Notwithstanding the majority of CBs and FCs witnessed an increase in their PoQ, a look at the *impact* of the *attacks* according to the type of institution shows that they had sufficient liquidity because of their substantial TES portfolio, as well as their broad access to BR's OMO mechanism; thus, CBs and FCs are examples of resilient types of institutions. Both PRMs and MFs exhibited weaknesses with respect to the use of their TES portfolio, while BFs experienced restrictions in terms of the limit on access to OMO. PFMs and MFs reduced capacity to tackle liquidity slumps is partly due to considering their TES own-account portfolio only, which corresponds to the existing regulation about restricting the use of third parties' portfolio for accessing liquidity from BR.[48]

4.2.3.2 Scenario 2: Stress in the TES Market (June 2006)

This scenario is characterized by considerable risk aversion among market participants. Unlike Scenario 1, where the TES market was booming, this scenario features a sharp decline in the mark-to-market value of local fixed income securities, which began in March 2006.

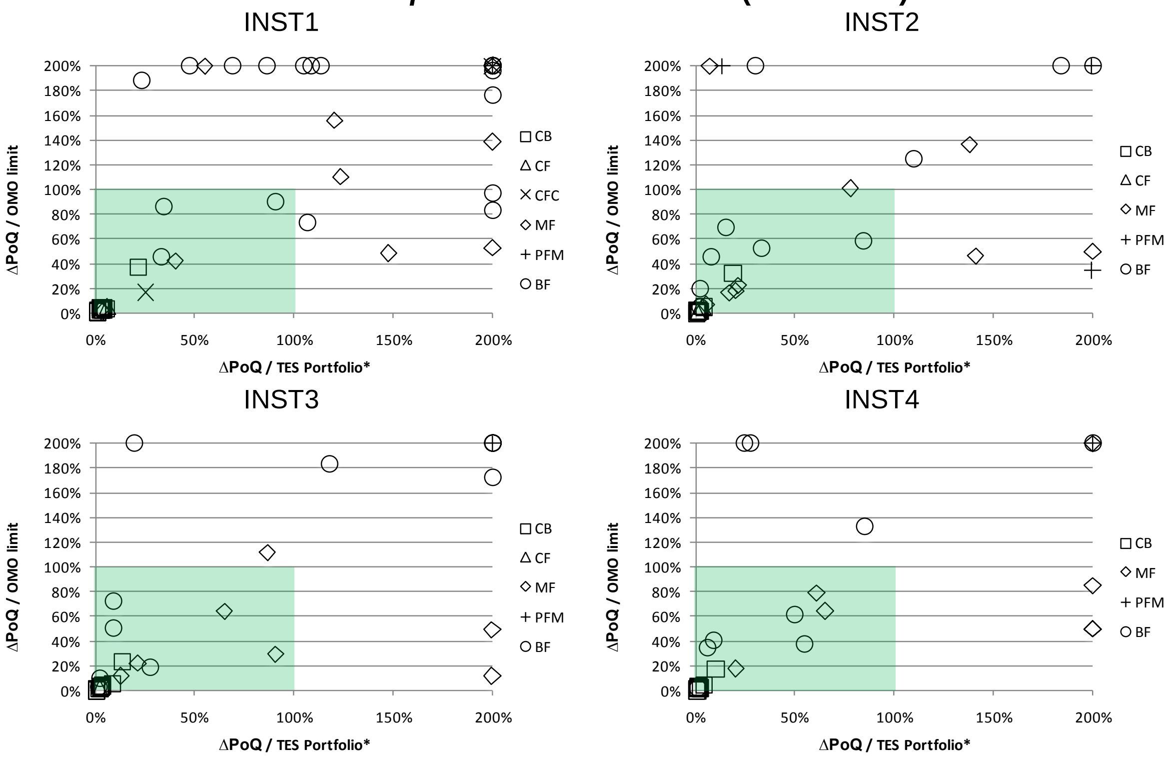
For that reason, the February 2006 and June 2006 scenarios reflect different environments in the local capital market, where TES market dropped by almost 10% in

[48] The portfolios of third parties may not be used as collateral to settle an institution's payments. This is due to regulations on separate accounting, conflict of interest and intention of the transaction between the institution and its funds. The only possibility of using them as collateral for an obligation is limited to 30% of the assets in the mutual fund and only to resolve liquidity problems specific to the portfolio in question, such as requests for withdrawals or liquidity to meet expenses.

four months. This shift from a boom to a bust environment was accompanied by reduced activity in the PS. The number of transactions within the CUD fell from 9,400 to 7,377 transactions (-21.5%), whereas the traded value decreased 36.5%. Also, with respect to the characteristics of the PS in both these scenarios, the distance between nodes increased, while connectivity declined. This suggests that the system became less robust.[49]

According to the results of the simulations, there were fewer institutions *affected* in the stress scenario (Figure 10), demonstrating the added weight exerted by factors other than the basic properties of the network. The *attack* on the selected institutions *affected* –on average- 33.9% of the participating institutions, compared to 41.3% in the boom scenario.

Figure 10
***Attacks' impact* on the institutions (Scenario 2)**



Note: Results truncated to 200% for practical purposes.
Source: authors' calculations.

INST1 and INST2 were the institutions that affected the system the most, causing 47.5% and 31.3% of the CUD participating institutions to experience an increase in PoQ, respectively, whereas INST3 and INST4 affected nearly 30.3% and 25.2% of the participants, in that order. As for the general level of *impact*, despite it may seem odd to find that the consequences of an *attack* during stressful times are less important, participants' higher risk aversion and reluctance to engage in counterparty and market risk resulted in CUD's reduced activity, and in a lower sensitivity to a systemic shock.

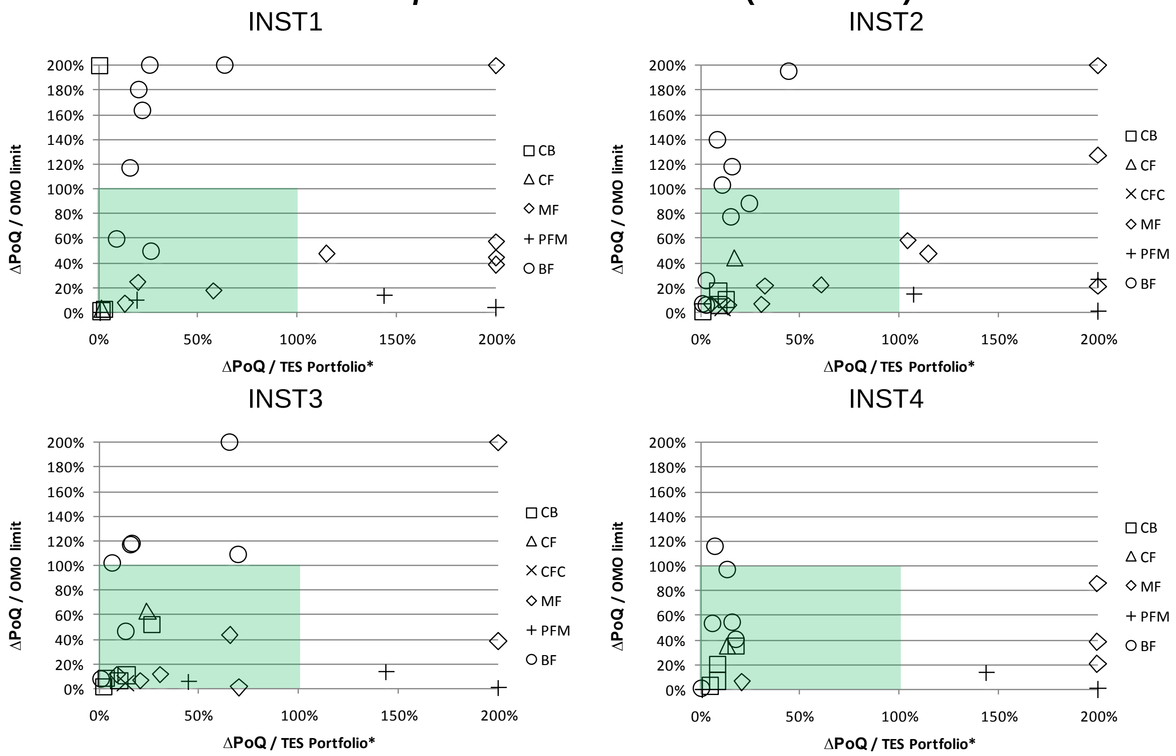
[49] The authors found that this kind of changes in the network's properties also occurred during the transition from the first half 2002's boom to the second half 2002's uproar.

4.2.3.3 Scenario 3: Trading Volume Peak in the PS (September 2009)

September 2009, the third scenario, is characteristic of a time when the volume traded in the CUD reached an all-time high. During this period the network continued to show an increase in distance, but with higher connectivity. The new properties of the network, along with the premise that failure-to-pay by a systemically important institution tends to be magnified during periods of high PS activity, should have exhibited a SP that is more vulnerable than in the two previously analyzed scenarios.

Nevertheless, the results of the simulation show that failure-to-pay by the selected institutions in this period affected only –on average- 22.6% of the institutions participating in the CUD. This is significantly lower than the 41.3% and 33.9% found in the TES market boom and stress scenarios, respectively (Figure 11).

Figure 11
Attacks' impact **on the institutions (Scenario 3)**



Note: Results truncated to 200% for practical purposes.
Source: authors' calculations.

This outcome is explained by a larger opening balance for CUD participants. In the boom and stress scenarios the average beginning-of-the-day funds in the CUD accounts corresponded to 36.4% and 24.2% of the September 2009's average.[50] In the peak trading volume scenario the additional opening balance provided the institutions and the PS with enhanced protection against the failure-to-pay of any institution, which resulted in fewer institutions being *affected* and more resilience of those being *affected*. It is

[50] Such a difference in the September 2009's opening liquidity is due to CIs maintaining larger deposits in the CUD during this period, which went from 5.95% of liabilities subject to reserve in February 2006 to 5.66% in June 2006 and 8.24% in September 2009. CIs are allowed to use their reserve requirements to meet their intra-day liquidity needs provided that their average effective reserve at the end of the bi-weekly period never drops below the required reserve.

worthwhile to stress that customary econometric models or NT alone would have disregarded this relevant feature of the system, which supports the choice of simulation models for capturing non-linearity and context-dependency.

4.2.3.4 Overall systemic risk assessment

Conveniently combining NT with the simulation approach makes it possible to identify and measure the importance of certain variables commonly overlooked by customary use of econometric models and NT. Such variables can mitigate or augment the systemic effect of an *attack* on TCTF institutions, and alter institutions' resilience and the capacity of the financial authorities to contain systemic risk.

Network stability depends not only on the basic properties of the network (distance, diameter and connectivity), usually calculated through NT alone. It is also contingent on (i) network activity (e.g. number of participants and transactions, number and volume of payments); (ii) distribution of number of connections per node; (iii) initial conditions (e.g. institutions' opening balances in the CUD); (iv) the specialty of each business (e.g. managing third parties' portfolios); (v) the financial strategies used by participating institutions (e.g. the size of their portfolio of liquid securities); (vi) the regulation in place (e.g. being eligible for LLR liquidity or not); and (vii) the participants' behavior resulting from the arrival of adverse information (e.g. knowledge of a systemic event).

The results illustrate that external factors can overshadow the influence exerted by the network's intrinsic properties. Accordingly, the limited degree of network activity in the TES stress scenario proved to be a decisive variable in mitigating the *impact* of failure-to-pay by a systemic relevant institution, while the opening balance in the CUD during the peak trading scenario was the variable that did much to offset the increase in PoQ generated by the *attacks* and to make institutions more resilient.

This situation is evident in Table 6, which includes the results of the failures-to-pay for each selected scenario. There was more of an *impact* on the PS in the boom scenario (February 2006), when 41.3% of the CUD participants were *affected*, compared to 33.9% and 22.6% in the stress and peak volume scenarios, respectively. Such outcome may be explained by high counterparty exposure resulting from a boom period, along with low levels of opening balances in the CUD and the assumption of non-reaction from other participants.

In all the periods, BFs and MFs are the institutions *affected* the most by the *attacks* to *central* (TCTF) institutions. These were also the types of institutions where the variation in PoQ most often exceeded the TES portfolio and the OMO limit (i.e. they were the most *impacted*); this is, BFs and MFs are the less resilient institutions. BFs' resilience is hampered by the existing OMO limit, whilst MFs is hindered by the level of their TES portfolio. This is due mostly to the specific nature of their business, since BFs manage large own-account portfolios, whilst MF's portfolios are mainly third parties'. Therefore, when examining the behavior of the network in the different scenarios, it's evident that although contagion depends on factors external to the properties of the network, there are other explanatory factors such as the specific nature of the business of participating institutions and their regulations.

A look at the outcome of the *attacks* during the three selected periods, according to the type of institution (Table 7), shows the *attack* on the systemically important BFs *affected* –

on average- 34.3% of the institutions, whilst the *attack* on the CBs affected 30.2%. It's important to emphasize that the TBTF concept would have missed this result, since the total assets (total investments) of the largest BF is about 16% (63%) of the CBs' average; this is also true for NT or simulation techniques based on balance sheet claims, since the balance sheet exposure of other institutions to BFs is non-large and collateralized.

CFs were the institutions most *affected* (i.e. share of CFs which experimented an increase in their PoQ), followed by the BFs and the PFMs. As in the analysis by periods, the BFs and the MFs are the institutions whose liquidity is *affected* the most. The *attack* on the systemically relevant BFs resulted in a situation where non-systemically relevant BFs exhibited, on average, a variation in PoQ higher than their TES portfolio and than their OMO limit. The situation with the CFCs and PFMs was similar.

Attacks on CBs had a similar *impact* on the MFs and PFMs. It is to note that the PFMs are less active in the CUD, and do not routinely resort to transitory expansion operations for liquidity, given the volume and liquidity of the resources they manage and the –long and immovable- maturity of the portfolios they manage. A significant share of the institutions that experienced more of an increase in their PoQ were found to be resilient; this is, they have alternatives for solving the liquidity strains generated by the *attacks*, be it through the available TES portfolio or through the OMO and TLF facilities (e.g CFCs, CFs and CBs).

Table 6

Attacks' impact on the institutions – per scenario (vertical), per type of institution (horizontal) [a]

Scenario	Criteria		Credit Institutions (CI)			Non-Credit Institutions (NCI)			Aggregate	
			CB	CFC	CF	PFM	MF	BF		
TES Boom (Feb 2006)	*Affected* institutions (mean)		55,9%	3,9%	62,5%	62,5%	46,0%	46,8%	41,3%	‡
	ΔPoQ / TES Portfolio*	Mean	7,5%	67,8%	11,1%	5410,8%	516,6%	141,6%	512,0%	‡
		Max.	48,4%	258,7%	21,8%	26605,7%	9752,3%	1497,5%	26605,7%	§
	ΔPoQ / OMO limit	Mean	10,0%	1,3%	15,8%	24,9%	137,4%	230,7%	109,7%	‡
		Max.	165,0%	2,9%	28,9%	78,7%	1734,9%	4186,7%	4186,7%	§
	ΔPoQ / TLF limit	Mean	19,2%	102,1%	37,2%	N/A [b]			61,6%	‡
		Max.	103,5%	399,3%	69,8%				399,3%	§
TES Stress (June 2006)	*Affected* institutions (mean)		56,3%	2,5%	66,7%	25,0%	35,9%	40,6%	33,9%	‡
	ΔPoQ / TES Portfolio*	Mean	3,5%	200,5%	2,5%	203,1%	727,9%	2652,0%	1079,8%	‡
		Max.	21,5%	1579,2%	5,7%	396,3%	15916,4%	191641,1%	191641,1%	§
	ΔPoQ / OMO limit	Mean	4,9%	4,3%	2,8%	35,0%	92,9%	240,5%	103,1%	‡
		Max.	37,5%	17,1%	5,7%	35,0%	978,6%	3321,4%	3321,4%	§
	ΔPoQ / TLF limit	Mean	12,7%	26,9%	12,5%	N/A [b]			20,2%	‡
		Max.	103,5%	179,4%	30,4%				179,4%	§
CUD trading volume peak (Sept 2009)	*Affected* institutions (mean)		25,0%	2,3%	33,3%	50,0%	22,9%	22,9%	20,7%	‡
	ΔPoQ / TES Portfolio*	Mean	7,6%	6,0%	18,1%	118,8%	365652,2%	16,9%	85215,7%	‡
		Max.	26,4%	13,0%	24,0%	272,5%	4384820,5%	69,3%	4384820,5%	§
	ΔPoQ / OMO limit	Mean	10,6%	2,3%	47,9%	8,4%	31,1%	85,7%	37,9%	‡
		Max.	52,4%	4,9%	63,7%	26,1%	330,2%	286,4%	330,2%	§
	ΔPoQ / TLF limit	Mean	27,0%	5,3%	108,6%	N/A [b]			21,4%	‡
		Max.	139,2%	11,6%	144,3%				144,3%	§

[a] Institutions with TES portfolio or OMO limit equal to zero were discarded. Aggregate corresponds to the arithmetic sum of each type of institution (¤); to the number of institutions weighted average (‡); and to the maximum of all types of institutions (§). TES Portfolio* corresponds to the (1-α) market value of the TES Portfolio, where α is the BR's haircut. [b] TLF is reserved exclusively for Credit Institutions. Source: authors' calculations.

Table 7

Attacks' impact on the institutions – per _attacked_ institution type (vertical), per type of institution (horizontal) [a]

***Attacked* Institution Type**	**Criteria**		**Credit Institutions (CI)**			**Non-Credit Institutions (NCI)**			**Aggregate**	
			CB	**CFC**	**CF**	**PFM**	**MF**	**BF**		
CB	*Affected* institutions (mean)		45,8%	13,4%	58,3%	55,6%	36,1%	31,8%	30,2%	†
	∆PoQ / TES Portfolio*	Mean	6,2%	5,5%	10,4%	1259,0%	190,3%	62,4%	142,1%	‡
		Max.	22,4%	12,0%	20,4%	6836,3%	2122,1%	623,1%	8239,9%	§
	∆PoQ / OMO limit	Mean	8,5%	2,0%	22,8%	13,4%	77,5%	134,6%	64,1%	‡
		Max.	57,2%	4,6%	54,2%	24,4%	547,9%	770,0%	770,0%	§
	∆PoQ / TLF limit	Mean	20,2%	4,7%	53,6%	N/A [b]			13,8%	‡
		Max.	121,3%	10,7%	122,8%				123,9%	§
BF	*Affected* institutions (mean)		47,9%	2,5%	54,2%	48,6%	43,8%	49,0%	34,3%	†
	∆PoQ / TES Portfolio*	Mean	6,2%	177,4%	9,6%	2002,5%	244407,5%	2704,3%	59089,1%	‡
		Max.	33,1%	918,9%	17,6%	19941,1%	2197286,4%	96016,7%	2288230,8%	§
	∆PoQ / OMO limit	Mean	8,5%	3,0%	16,2%	26,2%	96,7%	308,4%	124,5%	‡
		Max.	100,1%	8,6%	32,2%	68,0%	1356,8%	2478,3%	2582,7%	§
	∆PoQ / TLF limit	Mean	19,1%	84,9%	40,2%	N/A [b]			54,8%	‡
		Max.	98,4%	289,4%	75,0%				289,4%	§

[a] Institutions with TES portfolio or OMO limit equal to zero were discarded. Aggregate corresponds to the arithmetic sum of each type of institution (¤); to the number of institutions weighted average (‡); and to the maximum of all types of institutions (§). TES Portfolio* corresponds to the (1-α) market value of the TES Portfolio, where α is the BR's haircut. [b] TLF is reserved exclusively for Credit Institutions. Source: authors' calculations.

5 Concluding remarks

Systemic risk is a negative externality. Financial market's participants have clear incentives to manage their own risk (e.g. credit, market, legal, operational, etc.), but no incentives exist for them to account the effects of their actions on other institutions or the system as a whole; this is, each individual institution is clearly motivated to prevent its own collapse but not necessarily the collapse of the system as a whole (Trichet, 2009). As a social consequence of individual behavior, systemic risk has to be addressed within a comprehensive approach, capable of capturing institutions' contribution to systemic risk.

The most recent episode of market turmoil exposed the limitations resulting from using micro-prudential approaches (e.g. TBTF) to identifying and assessing institutions' contribution to systemic risk when applied to payments and financial systems, which are characterized by high levels of complexity, cross-dependency, context-dependency and non-linearity. Such limitations are not new, but have been increasingly important overtime due to the escalating homogeneity and opaqueness of financial markets, which has resulted in what the authors consider as an increasingly systemic-crisis-prone financial system.

It is rather clear that a qualitative leap towards a more broad and comprehensive analysis of financial markets and payments systems is the first step to effectively identifying and assessing systemic risk. Accordingly, this document proposes an approach consisting of applying a convenient mixture of NT and simulation techniques, where the former allowed for identifying those institutions that can be regarded as *central* for the system, and the latter allowed for assessing and analyzing the resilience of *not-attacked* institutions and of the system as a whole. Afterwards, based on quantitative assessment of individual liquidity requirements, central bank's means for containing systemic risk via its liquidity facilities are appraised and analyzed.

Results of this approach when applied to the Colombian large-value payments system (CUD) yield three main remarks. First, results confirm that customary micro-prudential approaches (i.e. institution centric) are insufficient for identifying and assessing sources of systemic risk. Second, results draw attention to an ongoing debate on the improvement of the financial systems' resilience through an adequate liquidity provision framework. Third, because this is a preliminary approach, some challenges for further research are still pending. This remarks will be discussed next.

5.1 The importance of macro-prudential approaches

Results converge to recent literature on systemic risk: although the size of the institution influences the systemic importance of the participating institutions (i.e. CBs), market activity and connectedness within the network play a key role in defining systemic relevance (i.e. BFs). This is, the connections between financial institutions are as important as the institutions themselves.

Results also confirmed the importance of developing macro-prudential approaches. Unlike traditional micro-prudential approaches (e.g. TBTF), the Colombian case displayed that BFs are systemic risk sources as important as CBs. Despite the role of BFs was previously believed as systemically important within Colombia's financial system, this document provides an innovative approach that allows for quantitatively assessing systemic importance at a disaggregate level (by institution). Furthermore, this results highlight the importance of the "shadow banking system", where too-connected institutions, regardless of their size or the value of their claims held by other participants, may endanger the safety of the payments system and financial stability.

It is important to recognize that reaching a true macro-prudential approach to systemic risk requires a coordinated supervision and regulation of the financial system. Financial authorities should work together in order to establish a comprehensive regulatory framework that aims to the efficient and safe functioning of the financial system, whereas supervision should be capable of effectively tracking individual and collective behavior for preserving such framework, where assessment and enforcement tools are key for this task. Such coordination may require designing clear institutional arrangements.

The approach also allowed for an inclusive characterization of payments systems. Their stability depends not only on the basic properties of the network (distance, diameter and connectivity). It is also contingent on (i) network activity (e.g. number of participants and transactions, number and volume of payments); (ii) distribution of number of connections per node; (iii) initial conditions (e.g. institutions' opening balances in the CUD); (iv) the specialty of each business (e.g. managing third party's portfolios); (v) the financial strategies used by participating institutions (e.g. the size of their portfolio of liquid securities); (vi) the regulation in place (e.g. being eligible for LLR liquidity or not); and (vii) the participants' behavior resulting from the arrival of adverse information (e.g. knowledge of a systemic event).

5.2 Improving financial systems' resilience is essential

Results show there are institutions (i.e. BFs and MFs) that need to make more of an effort in terms of liquidity risk management in order to be resilient to systemic shocks and to contribute to the proper dispersion of risk within the system. Likewise, according to the results, financial authorities need to consider the convenience of designing additional instruments capable of providing liquidity during systemic disruptions (or modifying those already in place) in order to improve institution's and market's resilience.

This paper's results and the emphasized importance of improving the resilience of the financial system concur with recent IMF's (2010b) request for addressing systemic liquidity risk. Some particular statements which are shared by the IMF (2010b) and the authors may outline the road to enhancing systemic risk management; they can be conveniently summarized as follows:

- Increasingly important non-banking institutions (i.e. the "shadow banking system") lack of sufficient tools for systemic risk management. The role of non-banking institutions in funding markets and in systemic liquidity should be adequately understood, and those institutions' coverage by the financial safety net should be properly addressed.
- The system has changed from bank-based to market-based systemic events, where the emphasis shifts from funding liquidity to market liquidity. Therefore, the scope of central bank's liquidity counterparties should be broad in order to reach banking and non-banking systemically important participants and support systemic liquidity when needed.

- Traditional tools for liquidity risk management address individual or idiosyncratic risk only. It is crucial to redesign liquidity risk management tools in order to capture the effect of market and funding liquidity during periods of turmoil; this is, liquidity risk management should aim to making the institution and the system resilient to systemic shocks.
- An appropriate level of reserves serves as a liquidity buffer, and could make the financial system more resilient; they are the first line of defense against systemic shocks. Therefore, the level of required reserves should take into account the implications for financial stability.
- It is advisable to build the right incentives for institutions to manage their contribution to systemic risk and mitigate moral hazard; this is, it is necessary that institutions internalize the negative effects emerging from their financial activities.

5.3 Further research is required

Because this approach consists of a rather novel application of existing techniques (i.e. NT and simulation) and a convenient set of ratios to be analyzed, some issues are worth further examining. Regarding the assumptions herein used, which are the main sources of model risk, it is important to capture the institutions' reactions in a more realistic manner, where the arrival of a failure-to-pay event by a *central* participant should prompt risk averse behavior by other participants. This is by no means an uncomplicated task since the source of the failure-to-pay (e.g. solvency, liquidity, operational, legal) will influence the way the news spread within the system, along with the type and the pace of reactions.

Other source of model risk is focusing on the CUD. Despite being the only large-value payments system in the country, most of the payments result from currencies and securities transactions taking place in other settlement and clearing systems. In order to address this additional source of complexity, the NT and simulation should not only focus on payments but also on the settlement and clearing of securities. This will increase the intricacy of the model, but will display a closer look to the reality of the financial system.

Additionally, taking into account the differences between direct participation in the payments system (as in CUD) and indirect participation (as the CHAPS Sterling in the U.K.), analyzing the different properties of each scheme in terms of stability and resilience is worthwhile. This paper's results agree with Manning et al. (2009) regarding the convenience of direct settlement in central-bank money and of broadly establishing reserve accounts and access to central bank's standing facilities, but this result is still preliminary and should be further addressed.

Finally, assessing each institution's contribution to systemic risk should serve the purpose of creating the right incentives for institutions caring about the risk they pose to the financial system. Several proposals have surged, including TCTF capital charges (Chan-Lau, 2010) and systemic liquidity risk insurance (IMF, 2010b), which should be further explored as they could induce institutions to internalize the costs associated with their contribution to systemic risk.

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