The Economics of Collateral

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Abstract

In this paper we study how the use of collateral is evolving under the influence of regulatory reform and changing market structure. We start with a critical review of the recent empirical literature on the supply and demand of collateral which has focussed on the issue of 'collateral scarcity'. We argue that while limited data availability does not allow a comprehensive view of the market for collateral, it is unlikely that there is an overall shortage of collateral. However, it is quite possible that there may be bottlenecks within the system which mean that available collateral is immobilized in one part of the system and unattainable by credit-worthy borrowers. We then describe how these problems sometimes can be overcome by improved information systems and collateral transformation. We discuss how collateral management techniques differ between banks and derivatives markets infrastructures including, in particular, CCPs. In order to assess the impact of alternative institutional arrangements on collateral demand, we introduce a theoretical model of an OTC derivatives market consisting of investors and banks arrayed in several regions or market segments. We simulate this model under alternative forms meant to capture the implications of moving to mandatory CCP clearing and mandatory initial margin requirements for non-cleared OTC derivatives.

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1 Introduction

With the on-set of the financial crisis in 2007-2008 market participants sought safety by demanding more and better collateral to support their transactions. In particular, in the face of difficulties in trying to issue unsecured debt on capital markets many banks have responded by shifting their funding toward secured debt such as covered bonds (CGFS 2013). This change in behavior has persisted and has been reinforced by changes in prudential regulation standards (e.g., Basel 3) and by structural initiatives to increase the use of centralized trading platforms and CCPs. This has given rise to a lively, recent interest by credit market analysts in the prospect of a "scarcity of collateral" that might inhibit credit expansion and economic growth. There have been a variety of attempts to estimate the extent of this scarcity, but there is little agreement on the numbers and the appropriate estimation methodology. One of the most important regulatory initiatives affecting the use of collateral is OTC derivatives reform mandated by G-20. As monitored by the Financial Stability Board, this agenda is being pursued through legislation in the major jurisdictions (Dodd-Frank in the US and EMIR in Europe) and regulatory rule making.

In trying to assess the importance of a possible collateral shortage the first step is to become more precise about what is meant by collateral. A general definition is that collateral is an asset that serves as security against counterparty risk. Desirable assets for this purpose are both safe and liquid. In effect, high quality collateral has some of the characteristics of money, and indeed for many applications requiring posting of collateral this is done using 'cash'. However, for the purposes of providing protection against counterparty risk over a period of time, liquidity is not necessarily absolutely necessary so that agents may prefer to preserve their liquidity and post other assets instead.

Assets that are considered safe by collateral recipients typically include sovereign debt. But the sovereign debt crisis has pointed out that not all sovereign debt is considered totally safe. If there is a tight supply of sovereign debt viewed as default risk-free by all participants, there will naturally be an interest in expanding the list of acceptable collateral to include asset categories that are somewhat less safe than the safest sovereign issue. Acceptability is therefore a question of degree, and the degree of safety will be reflected in the terms and conditions of the contracts supported by collateral. This may be done through the 'haircut' applied to the collateral. For example, in supporting a loan of \$100 by posting a bond with a value of \$110 there is a 10% haircut.

But in expanding the list of acceptable collateral to include risky assets, then there is a problem of assessing the risks in the proposed asset type. In this regard not all receivers of the collateral will be equally well equipped. Stated differently, risky assets are information sensitive, and the information sets available to alternative counterparties may differ. This implies that there may be a specialization in relationships. That is, some intermediaries may specialize in supporting certain types of clients because they have a comparative advantage in assessing the collateral that such clients are able to provide.

Suppose an agent does not have the collateral that is required to participate in a particular market. One possible response is to turn to an intermediary to facilitate the trade. This may involve trading with the intermediary who enters as a principal and who in turn may lay off the risk by a second, opposite trade in the market in question. This will involve the investor posting his available collateral to support the initial trade and the intermediary posting a different sort of collateral in the second trade used to offset his market exposure. Alternatively, the original agent may borrow the necessary collateral from the intermediary and then use this to support the market trade. The latter is what is usually understood as 'collateral transformation'. But there is similarity between to two, and in some circumstances they will be equivalent.

In this paper we study the economics of collateral. We start with a critical review of the literature on "collateral scarcity" and the impact of reforms on collateral supply and demand. Using aggregate data several analysts suggest that the total amounts of high quality assets outstanding are sufficient to meet likely demands for collateral. However, this conclusion depends on the assumption that collateral can circulate freely within the financial system. Changing risk appetites or regulatory constraints can lead to the immobilization of assets and a fall in the velocity of collateral circulation. As a result some agents are likely to be unable to access required types of collateral or can do so only through complex and costly transactions.

We then describe collateral management and transformation in more detail. We relate this to the operations of securities funding, focussing particularly on securities lending, repurchase agreements (repo) and the tri-party repo markets in particular. We compare the methods of collateral management provided by financial intermediaries and by CCPs and other financial market infrastructures. This analysis suggests that large banks have enjoyed a number of significant advantages in collateral management and otherwise managing counterparty exposures. However, these advantages are being eroded by increased regulatory constraints, and this is creating an opportunity for CCPs and other non-bank competitors to increase their scope as providers of collateral transformation services.

Finally, to assess quantitatively the impact of alternative market structures and regulatory regimes, we introduce a theoretical model that allows for central counterparty clearing at alternative points within the system. This model builds upon the framework that was introduced by Duffie and Zhu (2011) to assess the potential netting benefits of CCPs and which has become the workhorse in the recent literature. Our particular version uses a spatial network to capture the idea of specialization of intermediaries in different segments of secured lending. This framework can be interpreted in different ways. For example, we might take the spatial dimension literally, and different regions may represent different monetary zones. Then the differences in collateral types across regions may reflect currency denominations of alternative assets (dollars, euros, etc.). Or the regions could correspond to different industry segments, and collateral types may reflect differences in intermediaries' abilities to assess assets within these segments (e.g., real estate assets versus commodity assets). This framework is explored to characterize costs and benefits of alternative structures and clearing arrangements in terms of demand for collateral, costs of collateral transformation and benefits in exposure reduction. Our analysis suggests that centralized clearing with CCPs specialized along geographic or product lines can greatly increase the numbers of margin movements thus increasing operational risks and placing greater demands on participants' liquidity.

2 Literature review

At early stages of the recent financial crisis there emerged a wide-spread view that weaknesses in risk management and regulation allowed risks to be transmitted and magnified through the nexus of connections between banks, institutional investors and markets which became known as the shadow-banking system. Non-transparent over-the-counter (OTC) derivatives markets were viewed as being central to these problems. In reaction, G-20 leaders meeting in Pittsburgh in September 2009 agreed that,

> *All standardized OTC derivative contracts should be traded on exchanges or electronic trading platforms, where appropriate, and cleared through central counterparties by end-2012 at the latest. OTC derivative contracts should be reported to trade repositories. Non-centrally cleared contracts should be subject to higher capital requirements.* (G-20 2009)

Since then particularities of OTC markets and the implications of central counterparty clearing have become the subjects of active interest both among practitioners and increasingly in the academic literature.

Since a basic characteristic of CCPs is that they require participants to post collateral as initial margin, one of the immediate concerns among practitioners about the mandated move toward centralized clearing was the difficulties and costs that would be incurred in supplying collateral to support their derivatives transactions. In many bilateral OTC derivatives transactions banks have accepted a trade with a client without collateral or with collateral coming in form that would be convenient for the client, e.g., by encumbering assets that the client holds in the normal course of business. The prospect of moving these trades to centralized clearing seemed to mean that many such investors would be called upon to hold assets in more liquid, lower-yielding forms in order to be able to supply collateral to support their derivatives trades. Given the enormous size of the OTC derivatives market the quantitative implications seemed daunting. According the BIS OTC derivatives survey of major reporting dealers the gross notional outstanding OTC derivatives stood at \$632 trillion at the end of 2012. Even if initial margins might be set at a very low rate, say 1 per mil, this would suggest a demand for liquid collateral of some \$632 billion. However, it was quickly recognized that notional open interest might not be the right basis for estimating the impact of centralized clearing because many agents hold outstanding OTC contracts with different counterparties with opposite market risk exposures. If both of these were cleared through a single CCP these could offset each other. This led a number of analysts to try to refine the estimate of net impact of a move to central clearing taking into account the likely compression effect that might be achieved in practice. For example, Morgan Stanley and Oliver Wyman (2012) estimated that starting from an initial OTC derivative collateral demand of \$450 billion, the additional collateral needed to back outstanding trades would be \$3100 billion but that netting would able to offset an amount of \$2500 billion. Building on this they estimated net new collateral requirement to be $700 billion. Given suitable assets in the banks estimated as $240 billion, this leaves an estimated collateral shortfall to be around $460 billion. The detailed methodology and data used in arriving at this estimate are not explained. As such, it is difficult to know precisely what this represents and how reliable an estimate this is. However, taking this estimate as given, we might ask whether $460 billion is a big or small number. That is, would it be very difficult for the relevant participants to acquire the additional collateral needed?

One approach to this issue is to take a high-level macroeconomic view and see what the total available supply of suitable assets is. For example, at the end of 2011 the total amount of US Treasury securities outstanding stood at some $10.4 trillion (as reported by the Federal Reserve in the Financial Accounts of the US). So making some 4 percent of Treasuries accessible for use as collateral for derivatives transactions may not seem beyond the capability of the financial sector. Furthermore, the collateral shortfall might be further mitigated by the inclusion of some corporate debt ($8 trillion outstanding at end 2011) and perhaps some mortgage debt ($9.7 trillion). Also, given the fiscal outlook, the availability of US Treasury debt is likely to grow, going forward.

This approach is sometimes used by policy makers to argue that there is no shortage of collateral that could be mobilized to meet increasing demands. For example, Benoît Coeuré (2012) notes that based on official data the stock of assets acceptable as Eurosystem collateral was 14.3 trillion euros in 2011 while the amount of collateral submitted to support official ECB liquidity provision was only 2.5 trillion euros. This suggests that there was available a large supply of high quality assets that could be committed as collateral in response to increases in demands for collateral. He argues that the market price of collateral naturally plays a role in allocating scarce collateral supplies to increasing collateral demands. Such demands come from a variety of sources including "money markets, the longer-term wholesale funding markets, in an increased use of CCPs as mandated by the G-20, and a larger recourse to central bank liquidity." Implicitly he acknowledges that some of these demands may result in the immobilization of collateral assets, in particular through the central bank asset purchase programmes, which would tend to exacerbate collateral scarcity. For this reason there is a public interest in structural reforms that would increase the elasticity of collateral supply.

A more elaborate attempt to estimate a possible scarcity of collateral within the euro zone is carried out by Levels and Capel (2012a, 2012b). In estimating the supply of collateral they consider two classes based on criteria derived from Basel 3 categorizations and the Eurosystem collateral framework for purposes of liquidity provision and official asset purchases. Only euro denominated assets are considered. High quality collateral consists of cash, central bank reserves and certain classes of marketable securities issued or guaranteed by sovereigns, other public sector entities (PSEs) and central banks. Quasi-high quality collateral is made up of assets subject to a 15% haircut and includes riskier classes of marketable securities issued or guaranteed by sovereigns, other PSEs and central banks. They estimate eligible assets to be 13.2 trillion euro in 2011. After taking into account haircuts they estimate supply of high quality collateral to be euro 6.44 trillion and euro 1.45 trillion for quasi-high quality collateral. They also estimate the expected increase in supply of collateral based on

European Commission's estimates of financing needs of sovereigns. After haircuts they expect the growth in high-quality government debt over the period 2012-14 to sum up to euro 1.1 trillion.

In considering demand for collateral in the euro zone Levels and Capel consider three sources of increased demand: trends in the private European repo market, changes in the OTC derivatives markets, and the new Basel 3 liquidity requirements. Overall, they estimate that the demand for collateral within the euro zone would rise by 1.8 trillion euro between 2010 and 2012. They arrive at this estimate as follows. First, using a linear trend they extrapolate the growth of the private repo market at about 580 billion euro, a figure that is about the same as an alternative estimate they obtain by treating repo demand as a function of GDP and then extrapolating GDP growth rate. Second, on the assumption that approximately 2/3 of OTC derivatives contracts would move to centralized clearing by 2012 and making an assumption that this would eliminate what they estimate to be the existing undercollateralization of OTC derivatives exposures in the euro zone, they arrive at an additional collateral value of 325 billion euro. Finally, based on a consensus of several estimates of the shortfall of liquid assets that banks face due to the new Basel 3 liquidity standards, they estimate an additional 923 billion euro of demand.

Combining their estimates of supply and demand, Levels and Capel arrive at the conclusion that growth of demand will outstrip growth of supply by about 0.7 trillion euros between 2010 and 2012. Thus collateral in the euro zone is predicted to become relatively scarcer implying that the costs of collateral are likely to rise. The methodology employed by Levels and Capel is subject to error as the authors readily admit. For example, extrapolating from BIS estimates of the global OTC derivatives market to the amount of undercollateralization of OTC derivatives positions in euro zone participants involves numerous assumptions that are not securely justified by data. Furthermore, they may have overlooked other possible sources of increased collateral demand. In particular, the official report of the Committee for the Global Financial System (2013) has identified the official sector as a major source of increased demand for collateral both for currency management purposes and as part of non-standard monetary policy (i.e., quantitative easing).

To summarize, analysis based on the limited aggregative data available suggests that the total stock of high quality assets that are widely accepted as collateral exceeds the documented demand for collateral. However, taking into account regulatory changes it seems likely that increased demands for collateral will out-strip the growth in generally accepted collateral assets. This leads to an overall qualitative conclusion that relative cost of high quality assets is likely to rise, or stated otherwise, that risk premia are likely to rise.

One way in which the effects of increasing relative scarcity of collateral might be mitigated would be in increasing the reuse of collateral by market participants. This issue has been taken up in a series of papers by Manmohan Singh. The basic approach is set out in Singh (2011) and can be understood by considering his calculation of the "velocity of collateral" in 2007 as set out in Figure 1.

Singh views the world market for collateral as being operated by a handful of global banks. The primary supply of collateral is received by these banks through customers who seek services for which the bank requires collateral to mitigate counterparty risk. Once it is in the hands of a global bank the asset received as collateral is not immobilized. Rather, the bank seeks to create value by reusing the collateral in a variety of ways. It is made available to other bank customers who use the assets for their own purposes. Some of these involve the assets being used as collateral to secure transactions with other global banks. That is, the safe assets can circulate among the global banks in a manner analogous to the way central bank reserves circulate within a banking system and support the expansion of deposits. So just as we can talk of the velocity of money (the ratio of aggregate deposits to total reserves within the banking system) we can talk of the velocity of collateral. It is the ratio of the total stock of collateral accepted by banks within the system to the stock of unencumbered assets that is initially made available as collateral to these same banks. If there were no frictions within the system, in principle, the velocity of collateral could be infinite. In reality there are frictions that mean that collateral velocity is limited. It may be that not 100% of all collateral can be reused. Furthermore, there are settlement delays which mean that banks may need to keep a cushion in order to be able to return the collateral to clients once their transactions with the bank are finished and the collateral is no longer required. Furthermore, not all the reused collateral will find its way back into the system of banks participating in the market. Some of it will find its way into the stable hands of long-term investors who thus immobilize the asset.

As can be seen in Figure 1 Singh obtains his estimate of velocity by combining data from a variety of sources and by relying on judgements and assumptions derived from a variety of authorities. He focusses on six US investment banks, eight European global banks, and one global Japanese bank. Based on financial reports of these institutions including the detailed 10-K filings for the American banks, he estimates the total collateral received by these institutions in 2007 to be about $10 trillion. He estimates the primary supply of collateral to be $3.3 trillion which is derived from two sources. One is securities lending by major custodial agents (e.g., State Street Bank). Based on information from the Risk Management Association he estimates this to stand at $1.7 trillion in 2007. The second primary source of collateral he considers is hedge funds who provide reusable assets to the global banks in two basic ways. One way is as a pledge against a loan provided by the bank. Based on industry expert opinion, he assumes this approach is used by funds pursuing equity long/short and event driven strategies. Using information about hedge fund assets under management in these strategies and using an assumption about degree of leverage typically offered by banks for such facilities he estimates the assets received in this way to be $850 billion in 2007. The second way of receiving assets from hedge funds is through repurchase agreements, a method which Singh argues is used primarily by funds following fixed income arbitrage, convertible arbitrage and global macro strategies. Again, combining estimates of total assets under management in these strategies with an assumption of leverage used in these transactions, he estimates a primary supply of collateral from this source of $750 billion in 2007. Thus he estimates total supply of primary collateral from hedge funds to be $1.6 trillion. Taking the ratio of total collateral received by the global banks to the primary supply of collateral he arrives at an estimated of velocity of collateral of 3 in 2007.

This calculation highlights the crucial role of repurchase agreements and securities lending in the mobilization of collateral. This is an area that has not been extensively studied in the past, in part because data has not been readily available. In the absence of systematically reported data, Singh has been forced to piece together his estimate using periodic industry surveys and informal, experienced-based estimates of crucial ratios. Furthermore, it is difficult to know how much collateral circulates outside the fifteen banks included in the exercise. For example, the December 2012 European Repo Survey conducted by the International Capital Markets Association included responses from 68 institutions and reported total repos outstanding of 6.3 trillion euro ($ 9.12 trillion). The top 10 dealers accounted for 54% of the total, and the top 20 accounted for 79%. It is not clear whether this survey omits some of the repo activity captured in Singh's calculation nor how much of the ICMA survey is missing from Singh's calculation. These types of concerns have given rise to calls for better data collection on repo trading and securities lending (Adrian *et al*, 2013) and has been adopted by the Financial Stability Board as a priority in its agenda for improving the oversight of the shadow banking sector (FSB 2013).

However, it is clear from Singh's analysis that ability of the financial system to respond to a need for collateral will depend upon two broad types of determinants– the willingness of primary owners of long-term safe assets to make them available as collateral for short-term transactions purposes and the contractual arrangements that constrain the reuse of collateral received. The first issue depends in large part on the way investors trade-off risk and return. By freeing up assets for reuse they can obtain some yield enhancement, but they run the risk of encountering some delay of recalling these assets when required or, worse, finding that the receiver of the assets defaults. In low-interest environments that appear benign, investors may be tempted to "reach for yield" and the primary supply of collateral will be relatively large. But if investors (or their regulators) are very cautious, the assets will be made unavailable and will be immobilized or "siloed," to use the terminology employed by Singh.

The contractual provisions fixing the scope of possible reuse of collateral will depend upon the body of law governing the contract and the provisions agreed by the parties to the contract. Depending upon the jurisdiction, the receiver of collateral may be authorized to reuse the collateral by re-pledging, by sale, or by repo (ISDA 2010, p.48). All three forms of reuse of collateral are sometimes referred to as "rehypothecation"; however, strictly the term refers to re-pledging only. The distinction is significant, in the case of sale and repo, there is a transfer of ownership of the security. In the case of security which has been pledged with the right of rehypothecation granted, the ownership of the security remains with the original holder until such time that the security is rehypothecated. At that point ownership is transferred to the party receiving the collateral. In its place the original collateral giver now holds a general interest claim for the return of collateral once the obligation supported by the collateral has been fulfilled. (See, ICMA "Frequently Asked Questions on Repo").

Over time the OTC derivatives market has converged on documentation standards with the most important being those agreed by members of the International Swaps and Derivatives Association.[1] Consequently, a large fraction of OTC trades will have collateral terms set out in ISDA Credit Support Annexes which have been adapted to one jurisdiction or another. The standard English law CSA which is used for many transactions makes the reuse right the default choice, and counterparties need to opt out of this if they wish. This fine point underlying most derivatives trades was not recognized until the Lehman Brothers collapse in 2008 resulted in many investors finding that collateral they had posted in support of their trade was no longer held by their counterparty who was himself at risk of insolvency. Since then some investors have taken steps to restrict reuse of collateral. However, the ISDA Collateral Survey of 2011 (ISDA 2011) reports that for large reporting dealers 88.6% of collateral posted to support OTC derivatives trades were eligible for reuse and that 73.6% was actually reused.

What are the implications of these factors for estimates of collateral scarcity? As in Levels and Capel, most macro estimates of total collateral supply take collateral to be a constant proportion of acceptable assets. However, changes in the investors' willingness to seek short-term yield enhancements of their long-term assets and in the rate of rehypothecation mean that collateral supply need not change in step with changes in the stock of underlying suitable assets. One would expect that in response to the crisis collateral supply may have dropped. Indeed, using the same methodology as above for 2007 but with data updated to 2010, Singh finds that the total primary supply of collateral from securities lending and from hedge funds dropped to $2.4 trillion and that velocity dropped to 2.5 resulting in a total amount of collateral received by the global dealer banks he considers of only $5.8 trillion (Singh 2011). That is, he estimates collateral in the market dropped by 42% between 2007 and 2010. If we accept this line of reasoning, it suggests that the problem of collateral scarcity could become very severe, much more so than suggested, for example, by Levels and Capel.

However, there are reasons to think that this conclusion may be alarmist. First, as already noted, the willingness of long-term investors to make their assets available for yield-enhancing techniques such as securities lending depends on their assessment of risk and reward. In a continuing low-rate environment but with growing confidence in economic recovery, there may be a renewed tendency for real money investors to reach for yield, as suggested recently by Jeremy Stein (2013). Similarly, the velocity of collateral as calculated above is a direct reflection of the willingness of global banks to offer leverage to their clients. Again this tends to be cyclical so that velocity could rise quickly once economic recovery is perceived.

Perhaps of greater importance than cyclical concerns are the structural changes to the financial sector that are changing the practices of many participants and will likely change financial flows in major ways. The calculation of collateral velocity as described above is rather backward looking. It is based on a style of finance and a set of participants that dominated wholesale finance in New York and London in the run-up to the crisis. These are likely to change under the influence of regulatory pressure but also through investor awareness (see for example, Morgan Stanley-Oliver Wyman

[1] There are other masters agreements that are actively used for swaps. An example is the German master agreement for derivatives transactions.

2012, 2013). This does not mean that the techniques of securitized finance that were employed in the pre-crisis shadow banking sector will disappear. In all likelihood they will be adapted to the changing structures and circumstances. Thus, to understand the future collateral supply and demand we need to better understand those structural changes and the ways they affect collateral usage.

In response to the G-20 mandated OTC derivatives reform initiative, several academic papers have tried to provide an insight into the implications of the reform for collateral demand. Duffie and Zhu (2011) made an early contribution and introduced a flexible model that has been borrowed and adapted in a number of subsequent studies. They study how the introduction of CCPs into a formerly bilateral OTC world will affect netting efficiency and counterparty risk. They emphasize the trade-off between multi-product netting possibilities exploited by bilateral relations between intermediaries and their clients versus the multi-agent netting possibilities within a product class offered by CCPs. They show that in plausible cases if the CCP is established only in one derivative class while all other products remain bilaterally traded then netting efficiency is reduced, collateral demand goes up and average counterparty default exposure goes up. The exception is when the number of clearing participants is large in comparison to exposure from bilaterally netted products. In addition they prove that a single CCP is more efficient than several CCPs. For example, a situation where each product class has its own CCP is less efficient than the situation where there is one single CCP handling all product classes. This suggests, in the real world where achieving a single CCP might be unrealistic a move from bilateral to CCPs could involve a loss of netting efficiency. In principle, this could be mitigated by effective interoperability of CCPs. However, the after-trade infrastructure of securities markets is still largely segmented on national lines. In Europe interoperability has been on the policy agenda since the 2001 report of the Giovannini Group (Giovannini, 2001). Despite important regulatory reforms since then progress has been very slow with interoperability being available for equities but not yet for fixed income or derivatives trades.[2]

In their illustrative example Duffie and Zhu (2011) use data from the six US derivatives dealers with the largest notional position sizes separately in different product classes according to data from Office of the Comptroller of the Currency. In addition they assume that there are additional six dealers with similar notional amounts. This is meant to capture the contribution of non-US banks for which they do not have data. We will discuss the Duffie-Zhu model in greater detail below.

Cont and Kokholm (2014) expand on the Duffie and Zhu framework by allowing for heterogeneity in riskiness and correlation of positions across asset classes. They calibrate the model using information on the top ten US OTC derivatives dealers based on information from the Comptroller of the Currency. They consider the introduction of product-specialized CCPs for interest rate swaps alone, CDS alone and both. Expected exposure, Value at Risk and Expected Shortfall are calculated under alternative assumptions about the joint probability of distribution of exposures. As in Duffie and Zhu they calculate the number of clearing members required to compensate for the loss of netting across asset classes available in bilateral OTC trading. They find

[2]See Norman (2012) for a summary of regulatory initiatives in Europe.

that if exposure volatility of the cleared asset class is relatively high and/or positively correlated with other asset classes, the introduction of clearing for that asset class is beneficial even if the number of clearing members is relatively small. They interpret the findings as showing that in view of the high degree of clearing already observed in interest rate swap markets imposing clearing for CDS is likely to produce significant benefits in the reduction of counterparty risk. Similarly to Duffie and Zhu they show that a single CCP would reduce the exposures most.

After noting that netting efficiency arguments seem to point toward a high degree of consolidation of CCPs across product classes, both Duffie and Zhu (2011) and Cont and Kokholm (2014) argue that this would result in a high degree of systemic risk concentrated in these institutions. In effect, CCPs are mandated to become "too-big-to-fail" by design. Subsequently, a number of authors, Singh (2013b), have echoed these concerns. As discussed in Tucker (2014) this was clearly not in the minds of policy makers when the G-20 program OTC derivatives reform was formulated in 2009. He identifies three major, unresolved policy challenges—resolution of a failing, systemically important CCP; reconciling a public responsibility for financial stability with the governance of these private sector institutions; and determining the appropriate scope for the central clearing mandate. The dilemma in reconciling responsibilities to public and private stakeholders is manifested concretely in deciding what is the appropriate approach to margining within a CCP. As discussed in Tambucci (2014) normal prudent approach to margining would call for margin increases in the face of market stress. However, this procyclical margin policy would tend to induce risk spill overs and would exacerbate system wide risk. A similar policy dilemma arises with respect to the question of whether bank exposures to CCPs should be subject to large exposure credit limits. In its consultation document of March 2013 (BCBS 246) the Basel Committee notes the advantages and disadvantages of either applying exposure limits to CCPs or not applying them. In particular they note that application of exposure limits may conflict with the G20 goal of reducing systemic risk because it may impede consolidation of multilateral exposures through centralized clearing. It notes that in many jurisdictions CCPs are already excluded from these exposure limits. However, a very important exception is the United States where the Office of the Comptroller of the Currency has affirmed its intent to apply new large exposure rules to bank exposures to CCPs (see, Davis and Polk, 2013, p.10).

Heller and Vause (2012) develop a model that again is in line with Duffie and Zhu (2011). They focus on estimating how much collateral would be needed to clear all interest rate swaps and all CDS contracts of the largest 14 dealers (referred to as G14 dealers) in those product classes. Based on summary accounts of those dealers they calibrate the hypothetical positions of G14 dealers to be in line with those aggregate characteristics. Their data sources are BIS, company financial reports, DTCC, Thompson Datastream, US Securities and Exchange Commission. They calculate initial margin requirements under three volatility regimes and under three different structures of clearing. With a single CCP for interest rate swaps the total initial margins required for the G14 dealers as a whole are \$15 bn, \$29 bn, and \$43 bn under the low, medium and high volatility scenarios respectively. Assuming all CDS contracts clear through a single CCP they estimate initial margins for CDS to be \$10 bn, \$51 bn, and \$107 bn under the three volatility scenarios. This illustrates the fact that CDS trading is particularly affected by jumps in volatility. When CDS clearing is channelled through three CCPs for the US, Europe and Japan the required initial margins increase substantially. If all interest rate swaps and CDS clear through a single CCP initial margins are significantly reduced. They argue that dealers' initial margin requirements under central clearing would be a small proportion of their unencumbered assets and therefore should be feasible. They show that variation margin calls for G14 major dealers under central clearing could be substantial and could exceed their normal liquidity holdings. The Heller and Vause initial margin estimates appear relatively small when compared to previous estimates of the increased collateral demand induced by central clearing of derivatives (e.g., Levels and Capel). However, it should be recognized that Heller and Vause focus only on estimating margins of G14 dealers and do not take into account the margin requirements of these dealers' other counterparties (clients and smaller dealers).

This last observation raises the issue of the scope of application of the OTC reforms aimed at moving transactions toward centralized clearing. The original proposals called for mandatory clearing of all derivatives transactions would have required posting of initial margins by all counterparties, both financial and non-financial. These proposals met with strong resistance from the banking sector arguing that such a broad scope would increase the costs of legitimate hedging transactions for many highly rated non-financial users which are demonstrably not of systemic importance. Furthermore, it would cover product classes such as foreign exchange where OTC derivatives has long been traded with little evidence of posing a systemic risk. The strength of the official requirement for mandatory central clearing depends in large degree on the consequences of continuing to trade bilaterally without centralized clearing. This issue has been taken up in the joint consultation by the Basel Committee and the International Organization of Securities Commissions which has given rise to recently published official standards for margin requirements for non-centrally cleared trades (BCBS261, 2013). These standards call for two-way initial margins to be applied to all non-centrally cleared OTC derivatives trades with the exception of (a) foreign exchange derivatives, (b) non-financial firms that are not deemed to be systemically important, and (c) sovereigns and multilateral organizations. It is quite likely that many of the "other" counterparties to G14 dealer trades considered by Heller and Vause include many financial firms. And since these other counterparties account for well more than half of notional amounts derivatives trades, it is likely that the Heller and Vause estimate may substantially underestimate the total increased demand for collateral resulting from the combined effect of the move toward centralized clearing and the mandatory initial margins for non-centrally cleared OTC derivatives.

Sidanius and Zikes (2012) also study collateral demand in the CDS and interest rate swap markets. Based on BIS data approximately 50% of interest rate swaps market and 10% CDS deals were centrally cleared at the end 2011. In their simulation they consider raising the centrally cleared transactions proportion to 80% (keeping the current notional values fixed). The market-wide data source for interest rates swaps is TriOptima and for CDS is DTCC. They find that the increased central clearing would increase the collateral demand by $200-800 billion depending upon netting efficiency.

They stress that the impact of the OTC reform will be gradual since the new rules will apply on the new trades only. They argue that the impact on the interest rate swap market is likely to be quicker since those contracts have shorter maturities.

Expanding on the Duffie-Zhu model, Heath, Kelly and Manning (2013) explore how the different characteristics of agents, OTC derivative products, and clearing arrangements affect collateral needs and exposures. In contrast with the studies above they have two types of agents in the model – banks and investors. Banks constitute the "core"; they trade among themselves and with investors. Investors occupy the "periphery" and trade only with banks. They show that central clearing benefits more the banks with more counterparties compared to institutions in the periphery with a small network of counterparties. Central clearing is found to have smaller exposures and collateral demands compared to bilateral clearing. Also one single CCP is found to have the smallest exposures and collateral demands compared to other clearing arrangements. In addition they find that the increasing collateralization decreases the default risk but increases the contagion due to decreased liquidity of the assets.

Duffie, Scheicher and Vuillemey (2014) also use a network of dealer banks and investors in their analysis. Instead of simulated data as in Heath, Kelly and Manning (2013) they use specific bilateral CDS exposure data from DTCC (data cover 31.5% of global single-named CDS market at the end of 2011) to calibrate their model. By imposing different market clearing structures they are able to simulate the expected collateral demands in different scenarios. In line with Sidanius and Zikes (2010) they argue that OTC derivative reform is likely to have quite a large impact on the CDS market. They cite ISDA's estimate that only 8% of single named CDSs were cleared through CCPs at the end of 2011. They show that in a set up where dealer-to-dealer initial margins are absent the move to CCPs would increase the total collateral demand by 29%. However, under the assumption of dealer-to-dealer initial margins in bilateral trading, the move towards full clearing would decrease the collateral demand by 27% (due to cross-counterparty netting and diversification benefits). In sum, their analysis suggests that the feature of the derivative reform agenda that contributes most to increased collateral demand is the imposition of initial margins for OTC derivatives among financial firms. Given this obligation, the move toward centralized clearing reduces collateral demand. On balance the net effect of the two changes is relatively more modest than suggested by Heller and Vause.

Anderson, Dion and Saiz (2013) impose another level of network structure. They study OTC derivatives reform by looking at a two country set up (domestic and foreign) with one asset class. The foreign market is considered large. They follow Duffie and Zhu (2011) methodology in calculating netting efficiencies but in addition include total system exposures (not only client/dealer exposures but also CCP exposures). By doing this they internalize the issue of CCP becoming the centers of systemic risk. In their simulations they hold the number of foreign clearing members fixed and vary the number of domestic participants. They show that if the number of domestic clearing members is small then unlinked CCPs in each market is preferred to linked CCPs since the additional gains from netting are not covering the additional exposure from the foreign CCP.

To summarize the literature assessing the structural implications of moving derivatives onto centralized clearing, there is a general agreement that the netting benefits of centralized clearing could be substantial if there is a consolidation of trades across geographies and across product classes. This would translate into smaller counterparty exposures among intermediaries and their clients. Moving toward centralized clearing implies a substantial increase in demand for collateral posted as initial margins assuming that prior to the reform most clients in OTC bilateral trades did not post initial margin. The implication for collateral demand if the requirement for initial margins in OTC trades extends only to financial intermediaries is not clear. There is also a broad consensus that consolidating clearing in order to achieve netting efficiency implies that the dominant CCPs would become systemically important. A possible advantage of this is that regulators and supervisors will know that they need to focus their attentions on the risk management practices of these important institutions. The disadvantage is that the framework for supervision and for resolving a systemically important CCP have not been firmly established. The literature we have reviewed leaves open a number of important questions. One is whether on balance an architecture based on tightly regulated systemically important CCPs reduces systemic risk relative to one based on decentralized bilateral trading. Another is whether risks associated with volatile variations margins are managed well in with an architecture based on centralized clearing. We return to this latter question in our analysis in section 4.

3 Collateral management

As has been recognized by several analysts, one of the implications of the growing relative scarcity of collateral assets is that market participants will seek ways to mitigate the adverse consequences of increased collateral needs. In this section we discuss collateral management, that is, the range of techniques that financial intermediaries, financial infrastructures such as CCPs, and other participants in financial markets can use to reduce collateral costs.

It is useful to focus the discussion by formalizing the problem a bit.[3] Collateral is meant to provide a protection against the risk that a counterparty in a transaction may default in the face of an adverse change in the value of his position. This suggests that the amount of collateral required as initial margin should be commensurate with the loss that will occur in the case of default. That is,

$$\textit{Expected loss given default} = \textit{Expected value of collateral} \quad (1)$$

The costs of posting collateral is the opportunity foregone by committing the asset to its use as collateral. This is the difference between the return of the asset that would be held by agent in the absence of posting collateral less the return received on the collateral asset, That is,

$$\textit{Collateral cost} = \textit{Unencumbered asset return - return on posted collateral} \quad (2)$$

[3]See Bauer *et al* (2013) for an extended theoretical development of this framework and an application to the design of optimal bilateral margining.

Different techniques of collateral management act on different parts of this problem. Some seek to reduce the costs in (2) by reducing the spread between the rates of return on unencumbered assets and collateral assets. Others seek to reduce the amount of collateral required (1) by reducing the loss given default that needs to be covered.

This framework can be illustrated by way of an example. Consider a real estate investment firm which holds a portfolio of REIT's (real estate investment trust certificates) as well as other real estate assets and has been funded by equity and floating rate debt. It wants to hedge interest rate risk by entering an interest rate swap, paying fixed and receiving floating. The swap requires the firm to post an initial margin equal to the expected loss assuming the firm were to default following a one-day adverse move at the 99th percentile of the loss distribution of the swap (i.e., the one-day 99% Value at Risk- VaR). Suppose this margin amounts to $1 million and must be posted in cash or in US Treasury bills. To meet this collateral demand the firm can sell $1 million of REIT's and buy $1 million of T-bills. The cost of collateral is $(r_{REIT} - r_{Tbill}) \cdot 1m.$.

There are a number of ways that the firm could attempt to reduce collateral costs. Perhaps the simplest and best would be to *expand the set of acceptable collateral assets*. In this example, if REIT's were accepted as collateral, the cost (2) may be reduced to zero. It may be that the collateral receiver may require more collateral to be posted, that is, it would apply a haircut to REIT's. However, if the firm had sufficient amounts of unencumbered REIT's that it is holding on a long-term basis, this may be quite acceptable to the firm. The main obstacle to this strategy is more likely to be that the collateral receiver may not be willing or able to receive the REIT's as collateral. When that is the case, the firm may try to engage in a number of alternative strategies which broadly can be called "*collateral transformation*". We consider three forms of this strategy: *security lending, asset swaps, and repos*.

One form of collateral transformation would be to borrow the required asset. In the current example, the firm would borrow the required T-bill and retain the REIT's on their balance sheet. The security lender may require security on the loan, in which case the firm may encumber its REIT's. Thus collateral transformation in this case involves finding a security lender willing to accept as collateral an asset that would have been considered unacceptable by the collateral receiver in the interest rate swap. Even if the swap counterparty would accept the same asset as securities lender, the firm may prefer the securities lending strategy if the haircut on the asset posted as collateral on the swap would be greater than the over-collateralisation required for the securities loan.

A second form of collateral transformation could involve an asset swap. An asset swap is a derivative transaction whereby one party pays the return on one asset and receives the return on a different asset. In the example considered, the firm may sell its REIT's to finance the purchase of the T-bills it must post as collateral on the interest rate swap trade. However, it can try to reduce the cost (2) by engaging in a swap whereby it pays T-bill interest and receives REIT interest. In practice there may be significant frictions that mean that using a asset swap in this context may not reduce the cost to zero and in fact may introduce significant risks. First, there may be significant basis risk. For example, the return on the REIT taken from the firm's portfolio may be different than the REIT return referenced in the asset swap. In addition, it may be that an asset swap may be available referencing LIBOR rather than T-bill return. A second problem is that the strategy involves the firm selling its REIT position. This will incur transactions costs and may also have adverse accounting or tax consequences. Finally, the asset swap itself is a derivative transaction which will introduce additional counterparty risk and associated collateral costs and will also have significant accounting and, perhaps, regulatory implications.

A third form of collateral transformation which may avoid some of the negative aspects of the asset swap strategy would be to use repurchase agreements. In the current example this would involve the firm entering into a repo whereby it sells its REIT and simultaneously agrees to repurchase it later. The short-term funds raised in this way can be used either to post as cash collateral or to purchase the T-bill which would be posted as collateral. Using repos to effect collateral transformation involves multiple transactions and this additional complexity may appear unattractive. First, repo transactions are typically short-term whereas the collateral need may be long-term. That would be the case in the example considered where the maturity of the interest rate swap is likely to be much longer than that of a repo transaction. Thus the firm would face rollover risk. Second, the firm may in fact lose some of the benefits of a long-term investment in its preferred asset, here the particular REIT it had purchased. This is because the repo counterparty may require the right to reuse the asset purchased and thus promises only to return an equivalent asset, eg., one of a number of possible REIT's in the example given.

Despite its apparent complexity, repo is probably the most widely used tool for managing collateral because the repo market is often very active and deep. The reason for this is that repo is a useful tool for many purposes with collateral management only being one use and probably not the most important one. Repo involves the exchange of a security for cash over a set term. As such, it is a means for one party to obtain short-term funding and for the other party to obtain the use of a security for a period of time. Many, perhaps most, repo transactions are initiated as a funding operation with the choice of security sold being a secondary consideration. In the "general collateral" repo market the party entering into the reverse repo has surplus cash that it seeks to lend for a short time in return good rate of interest return and adequate counterparty protection in the form of a security taken from a list that is acceptable generally in the market. When the repo market is very liquid, roll-over risk is relatively low. Therefore, by entering into a sequence of very short-term repos a party needing cash can be quite confident of obtaining funding over longer period of time while still retaining considerable flexibility in the type of collateral he supplies. If he has an alternative, higher use for the security currently out on repo he can retain that security at maturity of the repo and supply a different security as collateral for the next repo he enters. In this way, he can support a continuing funding operation while managing a portfolio of securities used as collateral. At the same time at each renewal date the terms and conditions of the repo such as the interest rate and the haircut can be adjusted to changing market conditions as appropriate.

Not all agents are comfortable with bearing rollover risk in all market conditions, and they may try to reduce this risk by more closely matching the maturity of the repo to the period of their funding needs. A longer-term repo also may be appropriate when the counterparty receiving collateral seeks to have use of a specific security for a set period of time. A complication with longer-term repos is that evolving market conditions mean that over time one of the counterparties will be "in the money" and the other will be "out of the money". When this occurs the counterparty protection originally agreed will no longer be adequate. This can be significant when the repo term is set at several weeks or more and become very important in so-called "term-repos" with a maturity of one year or more. In these circumstances the value of the position can be adjusted through the posting of variation margin on the contract. Also, even if funding was the main motive for entering a term repo, it may be that the collateral giver develops a particular need for the collateral initially given and will then wish to substitute an alternative security to back the repo. For these reasons collateral systems required to support a longer-term repo market are more elaborate than in the case of overnight or very short-term repos.

The other way that an agent may attempt to reduce collateral cost would focus on the size of the loss that the collateral is required to cover, that is, to reduce (1). The most direct way this could be done is to simply reduce the risk tolerance used in setting initial margins. For example, initial margin might be set as the 95% Value at Risk rather than at 99%. In most bankruptcy regimes in the case of a default any amount owed on a derivative transaction that is not covered by the posted collateral is joined with other obligations to unsecured creditors. As a consequence, reducing reliance on initial margins amounts to increasing the amount of residual counterparty risk borne as a general interest creditor. This may be an acceptable risk to the collateral taker if the collateral giver is a good credit risk. However, the collateral taker may not be in position to judge this credit risk or may be constrained either legally or by regulation from taking on such risk.

An alternative way that the expected loss given default in relation (1) could be reduced is by altering the loss distribution that effectively reduces the risk to be covered. This is the approach that is taken in strategies that involve "*portfolio margining*". This could take the form of expanding the range of derivatives transactions to be covered by the same collateral assets. If the risks underlying these transactions are not highly correlated there may be substantial diversification benefits in pooling and this could greatly reduce the total amount of collateral required on a pooled basis as compared to posting initial margins for each derivatives position separately. And it may be that the separate derivatives positions are natural hedges, i.e., are highly negatively correlated with one another.

In the example given there might be scope for portfolio margining if the real estate firm had a second derivatives transaction that could be pooled with the interest rate swap transaction. For example, suppose that it attempts to reduce the specific credit risk it incurs in some of its real estate holdings that are leased to a single large client. It may do this by buying credit protection in the form of a single name CDS contract. The distribution of losses on the CDS contract may be uncorrelated with losses on the interest rate swap. Therefore, the 99% VaR on the joint loss may be substantially less than the sum of the 99% VaR's of the two losses considered separately.

In order for portfolio margining to be viable it is necessary for the collateral receiver to be able to join the two transactions. In the case of variation margins, portfolio margining can be implemented by an agent who centralizes the receipt of cash on the account of all the instruments treated by the system. However, for initial margins, portfolio margining will require that the contracts will be joined in the case of a default. In the example given, this would mean that in the case of the failure to pay a variation margin both the interest rate swap and the CDS could be liquidated or terminated. Simplest way this could be accomplished would be for the same agent to be the counterparty for both the CDS and the interest rate swap transactions. Furthermore, in order to assess appropriate initial margin the collateral taker would need good estimates of the joint probability of underlying risk drivers involved in the transactions. This can be technically challenging.

Different types of financial institutions have different types of comparative advantage and disadvantage in providing collateral management services. Banks, especially large global banks, have a number of clear advantages in this area, and this is likely a major reason why their OTC derivatives desks have been able to attract such a large fraction of world-wide derivatives trading. First, at the core of their business banks are specialized in the credit assessment of their clients. This comes not only from having an established relationship as a lender to the client for working capital and project finance. They also often deal with a client on multiple payments-related products which give the bank information about the whole range of the client's activities. Second, the bank is in a position to be the counterparty to a client on a number of transactions which can be pooled for the purposes of collateral management. For derivatives related transactions these will typically be set out in the credit support annex (CSA) to a swap master agreement. There is considerable scope to tailor a CSA to a client's particular circumstances. Bank and client can negotiate the list of acceptable collateral assets, the formula setting initial margins, the terms for marking positions to market and the payment and receipt of variation margin.[4]. Furthermore, the CSA will determine the bank's ability to reuse posted collateral. While information on the precise terms and conditions in existing outstanding CSAs is proprietary, it is generally accepted that many OTC derivatives trades for credit worthy bank clients do not involve any initial margins and those that do will often grant a right of reuse (by rehypothecation or otherwise) to the bank (ISDA 2011).

A third advantage enjoyed by large global banks is that the large range of businesses and counterparties they deal with creates natural economies of scope in collateral transformation. If they have a large number of derivatives counterparties they are likely to see a wide range of asset types posted as collateral, and if they have right of reuse they will be able to mobilize these diverse assets using any of the collateral transformation techniques we have considered. Even if they do not have an inventory of an asset required by a client they may be able to effect the collateral transformation through a repo transaction. This is a typical configuration of investment banks which often report large amounts of repo assets and repo liabilities held simultaneously on their balance sheets. Similarly, the large banks will typically have established securities lending programs with large custodial agents.

In addition to these advantages, the largest banks may have an operational advan-

[4]See Bauer *et al* (2013) for a theoretical analysis of optimal CSAs

tage in that they may develop integrated systems for clearing, settlement, risk assessment and other functions needed for securities trading which can also be deployed for the purposes of collateral management. The banks that create such systems on a global scale have a considerable commercial edge in that they can mobilize collateral across a very wide range of businesses.[5] However, the complexity and cost involved in achieving such integrated systems should not be underestimated. It is generally accepted among operations professionals that even some of the largest, most sophisticated global banks operate a patch-work of heritage systems accumulated through their history of mergers and acquisitions. Thus the large banks have an interest in developing market-based solutions for collateral management when possible.

The *tri-party repo market* is an example of a market-based solution that has proved popular with a wide range of banks and other money market participants. In a bilateral repo transaction there is an exchange of securities for cash between the collateral giver and the collateral receiver at the outset of the transaction and an opposite exchange of cash for securities at the maturity of the transaction. Both legs potentially involve the risk of settlement failure which should it arise could have bad commercial consequences and ultimately could result in a declaration of default. In order to minimize this operational risk the two counterparties will need to assure that each side has equipped itself to carry out the steps necessary to achieve settlement. This could mean for example that both counterparties are members of the national central bank's cash payments system and that each also holds an account at the central securities depository (CSD) for the security to be exchanged. These are heavy operating requirements which typically only relatively large institutions with a large transaction flow will be able to meet. In the case of international transactions involving securities issued by multiple countries and multiple currencies as settlement assets, the operational requirements are even more daunting.

The tri-party repo market serves to reduce these requirements by delegating many of the functions involved in managing a repo trade to a tri-party repo agent. Upon the agreement of a trade between two counterparties, the tri-party agent then takes responsibility for selecting collateral on behalf of the collateral giver and in managing clearing, settlement, variation margining, and custodial arrangements. In these roles, it enters solely as an agent and, in principle, it does not take on any counterparty risk. The tri-party repo agent can facilitate settlement risk minimization by creating cash and securities accounts on behalf of the participating counterparties. Then upon receiving a confirmation of a repo trade by both counterparties it can effect settlement on a "delivery versus payment" basis as a debit of the securities account and a credit of the cash account of the collateral giver and a simultaneous credit of the securities account and debit of the cash account of the collateral receiver.

The tri-party repo market has proved very popular in the US where according to data from the Federal Reserve Bank of New York it has accounted for about $1.6 trillion of securities funding in recent times.[6] It is operated by two tri-party repo

[5] For a fascinating description of the "spoke and hub" structure and associated IT system used by Lehman Brothers by the presiding judge in the UK's Lehmann liquidation proceeding see Briggs (2012).

[6] There is also repo trading in the FICC-General Collateral Repo market and in an inter-dealer bilateral repo market. The behavior of this latter market during the crisis of 2007-2008 was studied by Gorton and

agents: JP Morgan Chase and Bank of New York Mellon. It is almost entirely an overnight market. As such it facilitates collateral management and eliminates the need for variation margin as described above. Thus one of the attractions of the US tri-party repo market is to contribute to a free and wide circulation of collateral assets. A very large fraction of the trades are rolled over daily, and operational frictions mean that there is a gap between the time of the return of collateral in the morning in satisfaction of the maturing repo to the receipt of collateral in the afternoon with the opening of the new repo. During this intra-day period the clearing banks involved go beyond the pure role as tri-party agents and enter the transactions as principal whereby the provider of funds is an unsecured creditor of the repo agent. This massive intra-day exposure to two large banks represents a very significant systemic risk for the Federal Reserve System. There are on-going efforts by regulators to reform the system so as to mitigate these risks. For a discussion see Adrian *et al* (2013) and also periodic reform progress updates posted on the web site of the Federal Bank of New York.

There is a very significant tri-party repo market in Europe which operates rather differently than its American counterpart. The principal tri-party agents are Clearstream Luxembourg, Euroclear, Bank of New York Mellon, JP Morgan and SIS. A measure of the size of the market is given by the semi-annual European Repo Survey which is organized by the European Repo Council, an industry association which polls banks, CCPs and other financial institutions participating in European money markets. The June 2013 survey reports 6 trillion euros of contracts outstanding about evenly split between repos and reverse repos. About 10% of this total are tri-party contracts. So the European tri-party repo market is somewhat smaller than the US tri-party market and probably accounts for a smaller fraction of total repo trading in its region. In contrast with the US, a substantial fraction of the repo market is in longer term contracts in Europe and as a consequence, variation margining and managing collateral substitution is an important part of the operational support provided by the tri-party agents. Also in contrast with the US, the tri-party agents do not enter as principals in the transactions even intra-day. If a tri-party repo transaction is to be rolled-over the tri-party agent may extend intra-day credit to the client but this is done on a collateralized basis, which will often mean that the security recovered at the maturity of the repo is not immediately available to the client.

An important service provided by European tri-party repo agents is the collateral management and settlement system for securities issued in different national jurisdictions. The operating complexity of the agents and thus the cost of service reflect the somewhat incomplete integration of European money markets which contribute to impeding the free circulation of collateral assets within Europe. Historically custody of

Metrick (2012). There is no regular reporting of the size of bilateral repo market in the US as available data services to not allow bilateral repo transactions to be distinguished from other true sales of securities. Gorton and Metrick report survey data suggesting that in 2008 the total size of the US repo market was a much as \$4.5 trillion of which about \$2.8 trillion was in the tri-party market. Gorton and Metrick document the very unstable nature of haircuts in the bilateral repo market in the crisis and interpret this as evidence of a run on the market. The analysis of Copeland *et al* (2010) of the haircuts in the tri-party market suggest that this market was more stable during the crisis. See also Krishnamurty *et al* (2013) who study the tri-party market.

European securities reside in national CSDs. Typically these provide accounts only to institutions registered in that national jurisdiction and require payment in central bank money, i.e., through transfer of reserves on deposit at the national central banks or through the European Target 2 system. To exchange collateral from say German Bonds held by a UK bank to French bonds involves a cumbersome process of "repatriation" by way of German and French correspondent banks (see, CPSS, 2003). Tri-party agents manage this process on behalf of clients who maintain cash and security accounts with the agent. Settlement is made on a delivery versus payment (DVP) basis in commercial bank money (i.e., in the funds on deposit at the clearing agent). The clearing agent then manages the portfolio of Euro denominated securities using the Euro area's Correspondent Central Bank Model (see ECB 2010). This cumbersome process could be stream-lined through the "inter-operability" of CSDs as proposed by the Giovanni report (2001). As has been already noted progress in achieving inter-operability has been slow. An important part of the current official efforts in this program are directed toward a revised Correspondent Central Bank Model (CCBM2) which would remove the need for repatriation of securities through the proposed Target2 Securities system (T2S). The aim is to commence operation of T2S in 2015 and as of March 2014 some 24 CSDs had signed T2S framework agreements. However, it remains doubtful that many of these CSDs will be able to participate in T2S from its 2015 start date. This illustrates the collective action problem involved in trying to overcome the apparently conflicting interests in adapting existing infrastructures. (See, Lee, 2011, and Norman, 2012).[7]

The fact that the European tri-party repo market is still work-in-progress despite more than thirty years of effort to develop an integrated European market in financial services and more than ten years of existence of the euro illustrates some of the serious obstacles to developing the international circulation of collateral assets through market based solutions. Outside of the US and Europe the obstacles to achieving free circulation of different categories of collateral are typically even more severe. For example, in Asia the repo market is reasonably highly developed only in Japan. According to the Hong Kong Monetary Authority (HKMA), the amount of assets funded by the repo market in Asia outside of Japan represents 1.8% of regional GDP in contrast with the US and Europe where the comparable figure is 40-50%. However, there are active efforts underway to improve the integration of Asian monetary market using linkages through international CSDs (ICSDs) and global custodians.[8] These involve two-way links between ICSDs and local CSDs and central bank real time gross set-

[7]Inertia is not the only obstacle to promoting freer circulation of collateral in Europe. Proposed regulatory changes have aimed at limiting the right of collateral reuse. The Financial Stability Board (FSB 2013) proposals for enhanced supervision of shadow banking raises the prospect of restricting the scope of asset rehypothecation. In Europe the application of the proposed financial transaction tax represents a direct challenge to the functioning of the repo market unless such transactions would be exempted.

[8]See, HKMA, 2012. The two original ICSDs were created in Europe to facilitate the Euro bond market. Euroclear Bank (Belgium) is part of Euroclear group which also includes six national CSDs in France, Belgium, Netherlands, the UK & Ireland, Finland and Sweden. Clearstream Bank (Luxembourg) is part of the a group that includes national CSDs in Germany and Luxembourg. The original pilot program to integrate international bond settlement across HK and Malaysia initially involved Euroclear. Since then Clearstream and JP Morgan have joined in the process. The latter's entry gives an example of an established

tlement (RTGS) systems, including, in the case of Hong Kong, the HKMA's reminbi RTGS. The growth of this market has been very rapid since 2012. On the one hand, this growth has been driven in part by foreign interest in holding Asian bonds as an alternative to European sovereigns. On the other, this market is actively being used for off-shore reminbi funding collateralized by international (e.g., US dollar) debt.

As discussed in Section 2 central counterparties have become the main focus of the regulatory agenda to promote more transparent market-based alternatives to OTC trading by banks and non-bank credit intermediaries. As is widely recognized an important advantage of CCPs is that they can increase the scope for multilateral netting of positions. More controversially it is argued that CCPs bring a higher standard of counterparty risk management than has often been applied in bilateral trading. As already discussed the concern is that the risk management methods employed by CCPs will create excessive demands for high quality collateral assets.

CCPs have long operated on the basis of a system of initial and variation margins with daily (or more frequent) marking-to-market. As has been widely recognized clearing is most appropriate for standardized products. In many markets standardization has succeeded in creating deep, liquid markets. This feature combined with multilateral netting contribute the ability of CCPs to reduce costs associated with margining. Specifically if a derivatives position must be closed out because of a failure to meet a variation margin call, in a liquid market it can be done so without large price impact. This will result in a smaller expected loss given default for a given position size. Furthermore, netting of off-setting trades can reduce the size of positions that require margining. Both of these effects help to reduce the counterparty exposure in equation (1) and therefore the amount of collateral required as initial margin.

A number of analysts have pointed out other, less desirable, aspects of CCPs risk management which imply significant costs associated with requiring centralized clearing. As discussed above, requiring centralized clearing may imply a loss of the benefits of bilateral clearing of diverse products, a point emphasized by Duffie and Zhu (2011). Pirrong (2013) has pointed out that while strict marking to market may help to reduce the size of initial margin requirements this implies that the users will have in place an adequate liquidity facility to support the associated variation margin fluctuations. While variation margin is payable in cash, the short-term funds needed often will be obtained through secured lending (e.g., through the repo market). Thus the total collateral required to support trading in cleared market will exceed the required initial margins. Furthermore, the required variation margin payments create significant operational risks especially in highly volatile markets when intra-day margin movements may be required. We explore this issue analytically in Section 4 where we show under plausible circumstances enforcing centralized clearing through product specialized CCPs could result in a ten-fold increase in margin movements as compared to bilaterally cleared trading with full multi-product netting.

In contrast with banks, CCPs have had little scope to tailor collateral taking to the needs of clients of clearing members. Traditionally, they have not developed an expertise in credit assessment nor have they accumulated specific information on coun-

securities custodian that is straying into the operations of CSDs as a means of providing smoother settlement.

terparties that could be used in monitoring. As emphasized by Bauer *et al* (2013) given a knowledge of the distribution of client's risk profiles optimal margining arrangements will typically involve smaller initial margins than under a CCP's margin systems. Furthermore, historically CCPs have accepted a fairly narrow range of high quality liquid assets as collateral. Consequently, a move from bilateral clearing to centralized clearing may imply that collateral be managed outside of the CCPs on a bilateral basis (e.g., where collateral management and liquidity provision are provided by banking partners and may rely on repo trading). Thus what may look like a movement toward simpler more transparent market based methods actually involve a new range of less well understood bilateral trading connections.

CCPs have been made aware of these concerns, and there are on-going efforts to develop more flexible and client-friendly risk management techniques within CCPs. Historically CCPs have been product specialized and therefore have had little opportunity of pooling across product classes through portfolio margining. The consolidation of derivatives exchanges across products classes increased the potential netting benefits of portfolio margining. In the late 1980's the Chicago Mercantile Exchange (CME), one of the leaders in the process of derivatives consolidation, developed the Standard Portfolio Analysis of Risk (SPAN) model. Subsequently this has been adopted as a standard tool for margining by large number of CCPs. While this tool allows for netting based on statistical correlation analysis the scope for netting benefits still tends to be limited if applied in a single CCP covering a single product class. The Options Clearing Corporation which provides services to ten US stock, futures and options exchanges has developed a portfolio margin tool that allows netting benefits across all the CCPs participating in the group. In Europe both LCH Clearnet and Eurex Clearing have provided clearing services for both exchange traded and OTC products. They have been expanding their tools for portfolio margining across the two types of products especially in the area of interest rate products. Prior to the emergence of centralized clearing for OTC derivative products it has been possible to achieve netting benefits across exchange traded and cleared products and OTC bilateral products by means of Master Netting Agreements (Jones Day, 2012). It remains to be seen whether this integration of cleared and bilateral products will remain feasible in the future or whether it will be restricted by regulators.

As this discussion suggests there are important structural changes underway in the market that are being driven by the post-crisis regulatory agenda. This is having an effect on the comparative strengths and weaknesses of banks, CCPs and other institutions providing services as part of the financial market infrastructure. First, heightened capital charges applied to banks (Basel 3) have affected the risk/return trade-offs for many lines of business so that certain low-margin, flow transactions including some OTC derivatives are less attractive than previously. Furthermore, restrictions on proprietary trading and the practical difficulty of proving that a given trade is for hedging or market making purposes exclusively also reduces the attractiveness of many OTC trades. Finally, as will be discussed in Section 4 major banks are likely to feel most strongly the increased collateral demands associated with centralized clearing. At the same time, the increasing scale of operations of some CCPs, in part driven by the regulatory push toward centralized clearing, means that they can develop new products that were uneconomic at a smaller scale. Market participants are experimenting with a wide variety of joint ventures which may combine different parts of the financial market infrastructure in new ways. Morgan Stanley and Oliver Wyman (2013) argue that OTC derivatives reform will provide new opportunities that could produce revenues in a range of $5-9 billion from collateral management activities. In their view the lion's share of this business will be captured by three to five CCPs and two to three ICSDs. Ultimately this prediction may prove correct, but this stage it is hard to point to direct evidence of such a consolidation of activities. In our view it is still hard to predict what will be the dominant business model for collateral management or even if a single model will prove dominant for long.

4 Demand for collateral with market segmentation

In this section we explore a theoretical model of a derivatives market where different regions or segments of the market are specialized in the range of assets that are deemed acceptable for collateral. Our benchmark model is meant to be a stylized version of the dominant mode of trading OTC derivatives through 2007 and is depicted in the top of Figure 2 for the special case of two regions. Investors trade OTC derivatives with regional banks, and investors must post regionally acceptable collateral. Banks off-set their net positions against clients if possible by making hedging trades with other banks in its region, and both sides post regional collateral. The remaining net positions are hedged with banks in other regions if possible, and both sides post global collateral, that is, a higher quality collateral that can be obtained from regional collateral only after a costly transformation.

We then consider modifications of the benchmark model in order to assess the consequences of various structural changes in the market. The first structural change we consider is a move to centralized clearing. This could be imposed at various points within the market. The main alternative we consider is depicted in the bottom of Figure 2. All inter-bank trades, both intra-regional and inter-regional, are required to be centrally cleared and require posting of global collateral as initial margin. There is one CCP or, equivalently, there is full inter-operability among several CCPs. We also discuss other alternative structures including centralized clearing within one or more regions, between some but not all regions, clearing of inter-regional bank trades but not intra-regional trades, and, complete disintermediation through mandatory centralized clearing of all trades. In subsection 4.3 explore a mixed system where large global banks which are active in all regions can net trades using internal systems before hedging their net exposures first in regional markets and then through inter-regional trades. In subsection 4.4 we adapt the model to examine the implications of alternative structures for variation margin movements and associated operational risks and required liquidity management capacity.

4.1 The model

There are B banks and I investors in each of R regions. Investors trade one type of OTC derivative with all the banks in their region but have no trades with other investors or with banks in other regions. An alternative interpretation is that each bank has I investors who trade only with that bank. In region r investor i has a long position of W_{ib}^r with bank b. So the bank's position is $W_{bi}^r = -W_{ib}^r$, and $W_{ib}^r < 0$ represents a short position. Investor positions are independent draws from a normal $N(0, \sigma_W^2)$. It follows that the aggregate notional value of all investor positions is $\sum_{r=1}^R \sum_{i=1}^I \sum_{b=1}^B |W_{ib}^r|$. The notional value $|W_{ib}^r|$ is a draw from the half normal distribution and has a mean $\mathcal{E}|W_{ib}^r| = \sigma_W \sqrt{2/\pi}$. We set $\sigma_W = 1/(R \cdot B \cdot I \cdot \sqrt{2/\pi})$ so that the aggregate expected notional value of all investor trades is normalized to be unity for all choices of R, B and I.

4.1.1 Investors

Investors' positions are marked to market periodically, and investors pay (or receive) variation margin reflecting the change in value of their position over the period between marks. Failure to pay variation margin results in the liquidation of an investor's position. Let z be the return on the derivative over this period. We assume $z \sim N(0, \sigma_z^2)$. By symmetry of the normal distribution then the exposure of bank b against counterparty i is $X_{ib}^r \equiv \mathcal{E}Max(W_{ib}^r z, 0)$. The total client exposure of bank b is $X_b^r = \sum_i^I X_{ib}^r$.

Counterparty risk is mitigated by posting collateral as initial margin. In our benchmark set-up we assume investors post initial margin using 'regional' collateral. Regional collateral is taken from a list of bonds, stocks or other instruments that are acceptable to all banks within a region. We assume initial margins are set to cover 99 per cent of possible losses. The collateral required of investor i by bank b is $C_{ib}^r = 2.33 \cdot |W_{ib}^r| \sigma_z$.

4.1.2 Bank hedging with bilateral OTC contracts

Banks trade OTC derivatives with other banks in order to hedge their positions against investors. We assume that banks do not take proprietary investment positions in OTC derivatives. An alternative interpretation is that a bank's prop trading is reflected as one of the investors in the region. We assume that through their inter-bank derivatives trades banks achieve efficient netting (O'Kane 2013). That is, a bank will search among other banks for one with a client position that is of the opposite sign. These two banks effect a netting trade which reduces the bank with the smaller initial position to zero and reduces the other bank's position commensurately. Banks with non-zero net positions continue searching among other banks until all possible netting trades have been effected. Table 1 gives an example of position compression achieved through bilateral netting within a region consisting of five banks. The net client position of bank b is $Y_b^r \equiv -\sum_i^I W_{ib}^r$. Let $y_{bb'}^r$ be the netting trade between bank b and b'. Then the net position of bank b after netting is $Y_b^{r*} \equiv Y_b^r + \sum_{b'} y_{bb'}^r$. Banks post initial margin with other banks within the region using regional collateral. The total collateral posted by bank b against regional bank netting trades is $C_b^r = 2.33\sigma_z \sum_{b'} |y_{bb'}^r|$

Table 1: Bilateral netting of bank trades

bank	1	2	3	4	5
position before netting	10	-3	-7	2	-5
position after netting	0	0	0	0	-3

Once banks have exhausted netting possibilities within their region they search for netting trades with banks outside their region. Again we assume that efficient netting is achieved through these inter-regional trades. Let $y_{bb'}^{rr'}$ be the netting trade between bank b in region r and bank b' in region r'. The net position of bank b in region r after inter-regional netting is $Y_b^{r**} \equiv Y_b^{r*} + \sum_{r'} \sum_{b'} y_{bb'}^{rr'}$. The reason for netting first within a region and only later inter-regionally is to reduce collateral required to support the netting trades. This is because inter-regional trades require global collateral in satisfaction of initial margin requirements. For these inter-regional trades regional collateral is accepted only after application of a 'haircut'. Alternatively, agents can engage in collateral transformation through an asset swap or the equivalent. The difference between the value of regional collateral and global collateral is the 'basis risk' u. We assume $u \sim N(0, \sigma_u^2)$. Expressed in regional units, the amount of collateral required as initial margin on an inter-regional trade is $2.33 \cdot (\sigma_z + \sigma_u)|y_{bb'}^{rr'}|$. Thus the hair-cut or the price of the asset swap is set at $2.33 \cdot \sigma_u$. Bank b's total demand for collateral to support its inter-regional trades is $C_b^{r*} = 2.33(\sigma_z + \sigma_u) \sum_{r'} \sum_{b'} |y_{bb'}^{rr'}|$.

4.1.3 Centralized clearing

We now consider the model modified to reflect centralized clearing of all inter-bank trades as depicted in Figure 2. We consider the impact effect or first-order effect of this change under the assumption that the distribution of investor trades is unaffected by the move to centralized clearing. We later discuss how trading may be affected by changes in costs from centralized clearing that may be passed on to investors. Since we have assumed that there is only one type of OTC derivative traded and that bilateral trading among banks achieves efficient netting, the move to centralized clearing will have no impact on the expected net exposures in equilibrium. If we had assumed that there were several OTC derivatives traded bilaterally, a move toward centralized clearing only in a subset of these derivatives would typically affect netting efficiency as discussed in detail by Duffie and Zhu (2011).

The imposition of centralized clearing of all inter-bank trades will have implications for the demand for collateral required as initial margins. In the bilateral version of the model we already assumed two-sided initial margins on all inter-bank trades. Therefore, the demand for collateral will be affected only through the amount of collateral required as initial margin for each trade. With centralized clearing, all inter-bank trades will now require posting global collateral independently of whether the banks on the two sides of a trade come from the same region or not. Since in the bilateral version of the model we assumed that all banks sought to off-set their exposures with intra-regional trades before turning to the inter-regional market, the move to centralized clearing will constitute an increase in collateral required to support all intra-regional trades. Specifically, under centralized clearing the total collateral posted by bank b against regional bank netting trades is $2.33(\sigma_z + \sigma_u) \sum_{b'} |y^r_{bb'}|$. Thus the increase in the amount of collateral posted by banks within all regions is $2.33\sigma_u \sum_r \sum_b \sum_{b'} |y^r_{bb'}|$. The amount of collateral required for inter-regional netting trades, $y^{rr'}_{bb'}$, is unaffected by the move to centralized clearing. Thus the increase in demand for collateral implied by the imposition of centralized clearing of all inter-bank OTC derivatives trades will depend upon the relative cost of global collateral, $(\sigma_z + \sigma_u)/\sigma_z$, and the fraction of inter-bank trades that take place intra-regionally under bilateral trading. The first factor is a function of the degree of specialization in collateral taking. The second factor is a function of the depth of the regional inter-bank markets.

Turning to the possible alternative versions of centralized clearing, if centralized clearing were imposed only across a subset of regions, the increase in collateral demand would apply only to the intra-regional netting trades within the regions covered. If central clearing were imposed within each region, the effect on collateral demand would depend upon the collateral requirements of regional CCPs. If they continued to accept regional collateral there would be no impact upon collateral demand. Again, this follows from our assumption that all inter-bank trades required two-sided initial margins in the bilateral version of the model.

Finally we consider a complete centralization of derivatives trading applying to investors and banks alike. Under our assumption of no proprietary trading by banks, this would effectively result in complete disintermediation whereby investors trade among themselves in a single market supported by a single CCP. Under our normalization of the size of the market and assuming no effect on investor demands the amount of investor collateral would increase from $2.33\sigma_z$ to $2.33(\sigma_z + \sigma_u)$. However, since banks have been made redundant in derivatives trading, their collateral demand drops to zero, implying a decrease in bank collateral demand of $2.33(\sigma_z \sum_r \sum_b \sum_{b'} |y^r_{bb'}| + (\sigma_z + \sigma_u) \sum_r \sum_b \sum_{r'} \sum_{b'} |y^{rr'}_{bb'}|)$. Thus the increase in collateral demand implied by a universal imposition of centralized clearing at a global level depends upon the degree to which banks are able to enjoy diversification benefits of meeting the needs of a large number of investors with independently distributed demands. In the extreme case where each bank faces a large number of such investors, the expected net position of client trades will be zero for each bank so that, $y^r_{bb'} = y^{rr'}_{bb'} = 0$. In that case, centralized clearing will increase total collateral demand by $2.33\sigma_u$.

Until now we have assumed the move to centralized clearing has no effect on the distribution of investor trades. However, the increased collateral demand induced by centralized clearing implies a greater cost of trading which may eliminate the expected profit for some investor trades. Thus the move toward centralized clearing may dampen demand for derivatives trading. We can capture this effect as a drop in the volatility of investor positions to $\sigma^*_W < \sigma_W$.

4.2 Simulation of the model

Our model of OTC derivatives trading shows how the operational efficiency of the market, as indicated by the efficiency of netting and the total demand for collateral, depends upon the structure of the market. The presence or absence of centralized clearing is of course one important aspect of market structure. However, the effect of introducing centralized clearing will depend on other structural features of the market, notably the degree of market segmentation and market depth. Market segmentation is reflected in the specialization of regions in collateral taking as captured by the regional collateral haircut, σ_u/σ_z. The higher the degree of specialization the greater the haircut. Market depth is captured at three levels– bank, region and global– and is reflected in the three parameters–I, B, and R. If I is large, each bank receives a large number of trade orders which are independent draws from a distribution with zero mean and constant variance. Thus if I is large the client orders will tend to net out, leaving the bank with a very small net exposure that it needs to hedge through inter-bank OTC derivatives trades. Note that by setting I small we capture much the same effect as would be achieved by allowing for a positive correlation of positions as in Duffie and Zhu (2011). A relatively deep regional inter-bank market is captured by making B large implying that each bank has a large number of regional counterparties with which it can attempt to lay-off net client exposures. Similarly, with R large there will be many opportunities to hedge with banks from other regions.

We simulate our model in order to gain some appreciation of the quantitative importance of these effects. The parameters for our benchmark simulation are as follows. $\sigma_z = 0.1$ and $\sigma_u = 0.05$ which implies a 50% haircut on regional collateral for global trades. The number of banks per region varies between $B = 3$ and $B = 8$, and the number of investors per bank in each region varies between $I = 4$ and $I = 14$. We consider the model initially for two regions $R = 2$ and then later double the number of regions $R = 4$. For each combination of B, I, and R the model is simulated 100,000 times, a sample size at which simulation results stabilize.

Table 4 reports the expected total bank market exposure after banks' regional and global hedging for the benchmark model of bilateral OTC trade with two regions. For any number of banks per region aggregate exposures decrease with the number of investors per bank. This is a reflection of the greater internal diversification possibilities for banks when they have a larger number of clients with uncorrelated trading strategies. For a given number of investors per bank, the net exposures are decreasing in the number of banks per region. This reflects the greater netting efficiency when there are more banks per region. For the example here, the table is close to being symmetrical around the principal diagonal. That is, adding two investors per bank has about the same effect on residual net exposure as adding one bank per region.

Table 5 reports total collateral demand for the benchmark bilateral model when there are two regions. For any given number of banks the total collateral demand is a decreasing function of the number of investors per bank. This reflects improved internal diversification for banks with larger numbers of uncorrelated clients implying smaller net client positions to be hedged through inter-bank trades. For a given number of investors per bank, collateral demand is increasing in the number of banks per region. This reflects the more active hedging activity when the number of banks increases.

In our regional model when the number of banks per region increases this implies that the number of hedging possibilities increases both at the regional level and globally. However, given the regional specialization in collateral taking, the lion's share of the additional hedging will take place regionally. This can be seen by comparing Table 7 which reports total bank collateral requirements for intra-regional trades with Table 8 which presents collateral demand for inter-regional trades. Regional bank collateral demand is an increasing function of the number of banks per region; whereas, global bank collateral demand is a decreasing function of the number of banks per region. This reflects the fact that when the regional interbank market is deep there is a lesser need to have recourse to a more expensive global market. Both regional collateral demand and global collateral demand decline with an increase in the number of investors per bank. In fact, the ratio of global bank collateral to regional bank collateral is approximately constant as I increases holding B constant.

Table 6 reports total collateral demand when all inter-bank trades are cleared through a single central CCP. The effect of introducing mandatory central clearing of all inter-bank trades can be seen by comparing this with total collateral demand in the bilateral benchmark, Table 5. Moving to centralized clearing in this way increases collateral demand in all cases. However, the amount of increase is particularly large when the regional inter-bank market is relatively deep (B large) and internal diversification possibilities are limited (I small). This is depicted in the Figure 10 which plots the increase in total collateral by introducing a CCP for each combination of B and I. As mentioned earlier, under our assumptions of effective netting through inter-bank OTC derivatives trade and no prop trading by banks, the move to centralized clearing has no effect on the residual net market exposure of the banking system, as reported in Table 4.

One might ask how the total demand for collateral with centralized clearing of all bank trades compares to the disintermediated solution where all investors trades are cleared centrally and require initial margins paid in global collateral. Given our normalization of the scale of the expected notional value of investor trades at unity and our assumption on the size of the haircut, the expected total collateral for all combinations of R, B and I is 0.350 ($= 2.33 \cdot 0.15$). Comparing this to Table 6, we see that the total gross collateral in the intermediated structure can exceed total collateral in the disintermediated structure even though in the latter case investors' initial margins are substantially higher (here 50%) under centralized clearing. This may seem puzzling at first, but it should be remembered that Table 6 reports *gross* margins. If investors' agreements with their banks allow banks to rehypothecate collateral, as is widely the case, then total investor collateral will more than exceed the collateral needed to support bank hedging trades, even under mandatory centralized clearing of all bank trades. Thus the total net demand for collateral corresponding to Tables 5 and 6 is 0.233 for all R, B and I. That is, when bilateral OTC trades allow rehypothecation of collateral, a move to centralized clearing for all trades including investor trades will result in an increase in total collateral demand at the rate of the haircut between regional and global collateral.

The effect of an increase in the number of regions can be seen for the case of four regions as reported in Tables 9-11. Increasing the number of regions reduces the residual net market exposure of the banking sector. As can be seen by comparing Table 9 with Table 4 this is true for all numbers of banks in each region and all numbers of investors per bank. Comparing Table 10 with Table 5 we see that total gross collateral demand is greater with more regions, reflecting the increased opportunities to hedge exposures across a larger number of market segments. The same holds true when inter-bank trades are centrally cleared as can be seen by comparing Table 11 with Table 6. Overall, in the symmetrical version of the model considered here, the effect of moving from two market segments to four market segments is not large. However, this is not likely to remain true for some asymmetric versions of the model. For example, adding two isolated regions with shallow inter-bank markets (small B) and limited internal diversification possibilities (small I) into an integrated market consisting of two regions with deep regional markets (large B) but also limited internal diversification (small I), would likely result in a substantial decrease in net exposures and an increase in total collateral demand for the four regions considered as a whole.

4.3 Global banks

We now reconsider our model to take into account the presence of global banks. Banks with global reach have the possibility of netting positions across multiple regions, in effect, gaining the benefits of diversification across a wider market. Furthermore, as discussed in Section 3 global banks may have distinct advantages over smaller banks in collateral management in that collateral of one type may be shifted from one part of the group to another where there is a higher need, if need be, replacing it with another type of collateral.

We first examine the impact of the presence of global banks in a bilateral trading model. The basic idea is captured in Figure 11 for the case of one global bank, two regions and two regional banks per region. Banks trade with local investors as before. The global bank group first calculates its net exposure on a group basis. It may implement this netting with explicit trades between members of the group, but this is done without the need for collateral. Once it determines its global net position against clients it will then attempt to hedge this position with trades taken against regional banks in all the regions where the group operates. For these trades two-sided initial margins are required. However, importantly, all these margins are posted in local collateral. Then, as in the basic bilateral regional model, any remaining net exposures are hedged if possible through trades with banks in other regions. And for these trades, global collateral is used in posting initial margins.

We adapt the basic regional model as follows. In each of R regions, there are B_G global banks present, denoted $b = 1, .., B_G$. In each region there are $B - B_G$ local banks, denoted $b = B_G + 1, .., B$.

As before, investor i has a position of W^r_{ib} with bank b. Investor positions are independent draws from a normal $N(0, \sigma^2_W)$. Investors post one-sided initial margins with banks set as $C^r_{ib} = 2.33 \cdot |W^r_{ib}|\sigma_z$. The net client position of bank b is $Y^r_b \equiv -\sum_i^I W^r_{ib}$.

Global banks ($b \leq B_G$) calculate their net position for the global group, $\sum_r^R Y^r_b$. If this is positive they will seek to hedge their global position with offsetting short position with regional banks. Note this may involve taking short positions in regions where they are already net short. Conversely, if their global client position is net short they will try to offset this with long positions against regional banks. Given the adjusted net

Table 2: Bilateral netting with a global bank

	Bank				
Before netting	1 (GB)	2	3	4	5
Region 1	10	-3	2	2	-5
Region 2	-7	5	-2	4	6
Region 3	3	10	2	-6	-10
After global bank netting					
Region 1	2	-3	2	2	-5
Region 2	2	5	-2	4	6
Region 3	2	10	2	-6	-10
After global bank & regional netting					
Region 1	0	0	0	0	-2
Region 2	0	5	0	4	6
Region 3	0	0	0	0	-2
After regional netting only					
Region 1	2	0	2	2	0
Region 2	0	0	0	0	6
Region 3	0	0	0	0	-1

positions of global banks, all banks attempt to hedge their positions through trades with other banks within the region. Intra-regional netting is done efficiently as before. Any remaining net exposures are then hedged through trades with banks in other regions if possible.

Table 2 illustrates the effect of global bank netting of positions across all its regional subsidiaries for the case of one global bank, three regions and four regional banks in each regions. The top panel show the net positions against clients of all banks. Bank 1, the global bank, has a net exposure across three regions of +6. It attempts to hedge this net long position by offsetting short positions with trades in regional markets in the first instance and then in the global market if need be. How it allocates to trades to its regional subsidiaries will be a function of its knowledge of regional market conditions. Here we assume that it has no particular knowledge that would suggest hedging more in one region than another; so it spreads it net exposure evenly across regions. This is illustrated in the second panel of Table 2 where the adjusted position of the global bank is +2 in each region. As mentioned earlier this may be implemented through explicit trades between its subsidiaries. Here this would imply that the sub of Region 2 buys 8 units against the sub in Region 1 and 1 unit against the sub in Region 3. Given the global bank subsidiaries' adjusted exposures, banks attempt to lay-off their exposures among one another within each region. This is illustrated in the third panel of the table.

This risk management strategy of the global bank could be improved upon if it has better information about local market conditions. For example, if it knows the aggregate net position of other banks in the region, $\sum_{b=2}^{5} Y_b^r$, it can allocate its hedges to the regions that can accommodate its trades most easily. In the case shown, the net positions of the regional banks are -4, 13, and -4 in Regions 1, 2, and 3 respectively. So an improved hedging strategy for the global bank would be to allocate its net exposure of +6 to the three regional subs as 4, 0, 2. In this way it knows it would be able to hedge out its exposures in regional markets without having recourse to the global market.

This example illustrates several implications of having global banks who net their exposures across regions before attempting to lay-off their exposures in external markets, either regional or global. In the fourth panel of Table 2 we present the net positions of banks after regional netting assuming that bank 1 was not a global bank, or equivalently, it was a global bank but it was incapable of effecting global netting of the group positions either because it lacked the internal systems to do so or because it was prohibited from doing so for legal or regulatory reasons. Comparing this with panel 3 we see that the total positions needed to be hedged out globally (the sum of the absolute values of the positions) is 13 in panel 4 versus 19 in panel 3. This illustrates the fact that internal netting by global banks may be beneficial to the global bank because it reduces its need to hedge externally; however, the reduction of its presence in regional markets can reduce the depth of those regional markets and can force the remaining regional players to have recourse to more costly risk management methods (in this case, the use of global markets requiring more expensive global collateral). Specifically in the example given, bank 1's large short position against clients in Region 2 would have been able to off-set much of the +13 net long exposure of the remaining banks in that region. Instead, after internal netting by the global bank, its position was converted to a net long position exacerbating the imbalance of trading in Region 2. Second, by comparing panels 3 and 4 we see that the net position of all banks after global netting (the sum of all positions in the panel) is independent of the presence or not of global banks. This is because we have assumed efficient netting through bilateral trades, implying that the total imbalance in the market after all netting is unchanged by changing the order of the netting.

The main implication of internal netting of positions by global banks is to reduce the global banks' need for collateral to mitigate counter-party risk. This may come at the cost of requiring other banks to engage in more collateral transformation in order to manage their own risks. The overall effect on the demand for collateral will depend upon the depth of the regional and global markets, in our model captured by the number of regions, the number of banks in each region and the number of investors in each region. Table 12 reports the result of a simulation assuming 4 regions and one global bank, with other parameters chosen as in the simulations previously reported. As before the total demand for collateral is increasing in the number of banks, reflecting the greater opportunities for hedging risks in deeper markets, and decreasing in the number of investors, reflecting reduced demand for hedging with greater diversification in client trades. If we compare this to Table 10 we see that the total demand for collateral is reduced in the presence of global banks, and this reduction is most pronounced when there are relatively few banks and few investors. There is a 7.2% reduction in collateral demand in the case of 3 banks and 4 investors in each region as compared to a 1.5% reduction when there are 8 banks and 14 investors in each region. This is a reflection of the fact that when there are few banks and investors in each region, there is a greater need for spreading risks globally. When this can be done internally through global banks, this represents a substantial reduction in the costs of risk managing counter-party risks.

4.4 Operational risk

As has been emphasized by Pirrong (2013) moving derivatives trading onto standardized platforms with clearing through CCPs creates increased demands for liquidity to support variation margins. For many participants the most effective way to access liquidity is through secured short-term lending, e.g., through the use of repos. Thus increased liquidity demands will imply increased demands for collateral. If a derivatives position is held over an extended term, participants will not want to immobilize collateral for this long term. Instead, they will seek to reduce the amount of collateral used by committing it as and when required. But doing so places a strain on the operational capacity of the participant and his clearing agents. If this system runs smoothly, the amount of collateral committed to support liquidity for marking to market can be relatively low. This perhaps describes the operations in the US tri-party repo market. But in other settings, where settlement delays are longer or when more exotic collateral is to be mobilized, the amount of committed collateral can be much higher. As our discussion in Section 3 suggests this can be the case, for example, in international collateral movements across widely separated time zones. This can significantly increase the operational risks involved.

The trade-off between more committed collateral and greater liquidity coverage is embedded in many margins systems which define thresholds that will trigger a variation margin movement. The lower threshold is the minimum margin below which variation margin must be paid in or else the position will be closed out by the counter-party. The difference between the initial margin and the minimum margin is the amount of initial cushion that the participant has allowed to absorb mark to market fluctuations. By using a larger cushion, the number of margin calls can be reduced and in this way operational risks can also be reduced.

This is illustrated in the first row of Table 3 where we have simulated margin call frequency for varying values of the maintenance margin cushion expressed as multiples of the daily volatility of risk traded in the derivative contract. A margin movement (either a debit or a credit) occurs each time the absolute value of the cumulative change in the position value since the last margin movement reaches the stated multiple of one-day volatility. For example, setting maintenance margins at a one sigma move gives rise to margin movements once every 2.8 days on average.

This table can be used to reinterpret the 'haircut' on local collateral in our regional model of bilateral trading. It is a measure of the operational efficiency in moving collateral from one region to another. For example in our benchmark simulations we assumed that the haircut was $\sigma_u/\sigma_z = 0.5$. Furthermore, we assumed the initial margin on global trades was set at $2.33(\sigma_z + \sigma_u)$. If we interpret $2.33\sigma_u$ as a cushion to allow time to effect collateral transformation, we see that the parameter values of our

Table 3: Maintenance margin and margin calls

Maintenance margin (multiples of σ)	0.50	0.75	1.00	1.25	1.50	1.75	2.00	2.25
Margin call frequency in one market (days)	1.67	2.23	2.79	3.74	4.80	5.37	6.89	8.40
Margin call frequency in 4 segmented markets(days)	0.40	0.53	0.70	0.92	1.16	1.37	1.71	2.00
Margin call frequency in 4 integrated markets (days)	2.61	4.42	6.62	9.17	13.51	15.87	18.51	27.77
Margin call frequency in 8 segmented markets(days)	0.20	0.26	0.34	0.45	0.56	0.71	0.85	1.02
Margin call frequency in 8 integrated markets (days)	4.40	7.29	12.34	16.66	21.27	27.77	38.46	47.61

simulation allowed for three days to convert regional collateral into the form required in global markets. Given settlement delays in many securities settlement systems, suggests that our assumed haircut level was not excessive.

The table can also be used to see the effect of market stress on the frequency of margin movements. For example suppose that the maintenance margin (or cushion) is set at two times normal market volatility. Then the agent can expect a margin movement once in every 6.9 days. Suppose in the stressed situation the market volatility doubles. Then the maintenance margin is set at one times stressed-sigma, in which case margin movements occur once ever 2.8 days, i.e., about 2.5 more frequently.

The implications of market segmentation for numbers of margin calls and associated operational risks are illustrated in rows 2 and 3 of Table 3. Row 2 records the frequency of margin calls for an agent operating in four markets without access to portfolio margining. We suppose that in each market the agent has a liquidity facility of the indicated size (expressed in multiples of volatility of that market). Thus for example if the agent operates with a liquidity cushion of one sigma in each market he can expect a margin call at the rate of once every 0.7 days, i.e., about 2 margin movements every 3 days.

In row 3 of the table we calculate the frequency of margin calls for the same agent operating with the same total liquidity facility but where there is portfolio margining across the four markets. Portfolio margining could be achieved because the trades are cleared through a single CCP or cleared through separate CCP's but with full interoperability. Alternatively, this could represent bilateral trading with the same counterparty in four OTC derivatives markets. The effects of market integration are dramatic. Integrating across four markets reduces margin calls by an order of magnitude, e.g., by a factor 9.4 to 1 with a one sigma cushion.

The impact of market integration on numbers of margin movements, operational risks, and liquidity management will depend upon the numbers of markets and the correlation of underlying risks across the markets. In rows 2 and 3 of Table 3 we have assumed zero correlation across four markets. When we do the same calculation across eight uncorrelated markets operating with a one sigma liquidity facility, margin movements are reduced by a factor of 36 to 1 (rows 4 and 5 of the table). When underlying risks are positively correlated across the markets the effect of integration is smaller but still significant. This is because integration operates in two ways, namely, by reducing the number of counter-parties who will receive or will pay variation margin and also through the diversification effect in the calculation of total change value of the overall portfolio. So for example, market integration across four perfectly correlated markets would reduce the number of margin movement by a factor of 4 to 1.

This discussion points out an additional factor that should be weighed in evaluating the effect of moving trade from bilaterally cleared trades with portfolio margining (i.e., full multi-market netting) to centrally cleared with multiple CCPs that operate in separate markets. As reviewed in Section 2 Duffie and Zhu and others have already emphasized the fact that this involves a trade-off of multi-market and multilateral netting. In addition, our analysis shows that moving toward central clearing with product specialized CCPs can greatly increase the numbers of margin movements which will place greater demands on a participant's operational capacity and liquidity. This can be interpreted as tipping the balance of benefits and costs in favor of retaining bilateral OTC markets for a wider range of products and participants. Alternatively, assuming a full commitment to centralized clearing, it points out the importance of achieving consolidation and effective integration across infrastructures for a wider range of financial products.

5 Conclusions

In this paper we have explored how the use of collateral assets is changing under the influence of regulatory reform and changing market practice. In particular, we have assessed the idea that changing conditions are giving rise to a scarcity of collateral that will impede the flow of credit in supporting real economic activity. Our main finding is that the total supply of collateral is in principle sufficient to meet increasing demands but that weaknesses in infrastructure make it likely that collateral will be immobilized, at least temporarily, in one part of the system and unable to meet the demand in another part of the system. Large global banks with integrated systems have had a comparative advantage in accommodating diverse client needs in managing collateral, but they are being increasingly constrained from doing so by regulatory reform. Securities market infrastructures have been mandated by G20 to fill the gap, but at present they are impeded by incomplete market integration. Efforts to mitigate these problems either through consolidation or through inter-operability across infrastructures struggle to overcome collective action problems. As a result bottle-necks in the system are likely to arise for some time to come.

The move toward centralized clearing and standardized platforms creates increased collateral demand for initial margins. It also poses new demands for more efficient, comprehensive liquidity management. This reform sacrifices benefits of multi-product netting which are significant. A system relying principally on centralized clearing to mitigate counter-party risks creates increased demand for liquidity to service frequent margin calls. This can be met by opening up larger liquidity facilities, but indirectly this requires more collateral. To economize on the use of collateral, agents will try to limit liquidity usage, but this implies increased frequency of margin calls. This increases operational risks faced by CCPs which, given the concentration of risk in CCPs, raises the possibility that an idiosyncratic event could spill over into a system-wide event.

We have emphasized that collateral is only one of the tools used to control and manage credit risk. The notion that greater reliance on collateral will eliminate credit risk is illusory. Changing patterns in the use of collateral may not eliminate risk, but it will have implications for who will bear risks and on the costs of shifting risks. Changing structures can eliminate risks at the cost of not creating the underlying credit and of not seeing the associated investment undertaken. In the hopes that worthwhile risky investment projects will be undertaken, there is a collective interest in seeing that credit risks are borne by the agents that are best placed to acquire and assess information relevant to managing risks intelligently. Historically, banks have benefitted from a variety of advantages in assessing and managing credit risks, and their active role in the taking and managing of collateral is a manifestation of this. However, regulatory reform and financial innovation may change this going forward. The search for new methods of achieving economical collateral transformation is giving opportunities to market infrastructures and others to provide much needed support for credit creation. In the process, the patterns of risk bearing will be changed, and understanding this represents a challenge both to regulators but also to investors.

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Table 4: Total bank exposures after global netting, 2 Regions

Investors	Number of Banks					
0	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000
4.0000	0.0095	0.0082	0.0074	0.0067	0.0062	0.0058
6.0000	0.0077	0.0067	0.0060	0.0055	0.0051	0.0048
8.0000	0.0067	0.0058	0.0052	0.0048	0.0044	0.0041
10.0000	0.0060	0.0052	0.0047	0.0042	0.0039	0.0037
12.0000	0.0055	0.0048	0.0042	0.0039	0.0036	0.0034
14.0000	0.0051	0.0044	0.0039	0.0036	0.0033	0.0031

Table 5: Total collateral demand, 2 Regions

Investors	Number of Banks					
0	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000
4.0000	0.3117	0.3170	0.3202	0.3228	0.3247	0.3262
6.0000	0.2972	0.3015	0.3041	0.3062	0.3079	0.3092
8.0000	0.2886	0.2922	0.2948	0.2965	0.2978	0.2990
10.0000	0.2826	0.2861	0.2883	0.2898	0.2911	0.2921
12.0000	0.2783	0.2814	0.2835	0.2847	0.2858	0.2869
14.0000	0.2750	0.2777	0.2797	0.2809	0.2820	0.2829

Table 6: Total collateral with centralized clearing of all bank trades, 2 Regions

Investors	Number of Banks					
0	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000
4.0000	0.3362	0.3461	0.3524	0.3572	0.3615	0.3638
6.0000	0.3173	0.3253	0.3304	0.3343	0.3449	0.3399
8.0000	0.3060	0.3127	0.3175	0.3208	0.3338	0.3256
10.0000	0.2981	0.3045	0.3087	0.3116	0.3141	0.3158
12.0000	0.2924	0.2982	0.3021	0.3045	0.3068	0.3086
14.0000	0.2881	0.2933	0.2970	0.2993	0.3015	0.3030

Table 7: Total regional bank collateral demand, 2 Regions

Investors	Number of Banks					
0	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000
4.0000	0.0491	0.0581	0.0644	0.0689	0.0723	0.0752
6.0000	0.0401	0.0476	0.0526	0.0563	0.0591	0.0615
8.0000	0.0350	0.0412	0.0457	0.0487	0.0513	0.0532
10.0000	0.0312	0.0369	0.0407	0.0435	0.0458	0.0476
12.0000	0.0284	0.0337	0.0372	0.0399	0.0419	0.0435
14.0000	0.0263	0.0311	0.0344	0.0368	0.0388	0.0403

Table 8: Total global bank collateral demand, 2 Regions

Investors	Number of Banks					
0	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000
4.0000	0.0297	0.0257	0.0228	0.0209	0.0194	0.0181
6.0000	0.0241	0.0209	0.0187	0.0171	0.0159	0.0149
8.0000	0.0209	0.0181	0.0163	0.0149	0.0137	0.0129
10.0000	0.0187	0.0163	0.0145	0.0133	0.0123	0.0115
12.0000	0.0171	0.0149	0.0133	0.0121	0.0111	0.0104
14.0000	0.0159	0.0137	0.0123	0.0111	0.0103	0.0097

Table 9: Total bank exposures after global netting, 4 Regions

Investors	Number of Banks					
0	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000
4.0000	0.0054	0.0047	0.0042	0.0039	0.0036	0.0033
6.0000	0.0045	0.0039	0.0034	0.0032	0.0029	0.0027
8.0000	0.0039	0.0033	0.0030	0.0027	0.0025	0.0023
10.0000	0.0034	0.0030	0.0027	0.0024	0.0022	0.0021
12.0000	0.0032	0.0027	0.0024	0.0022	0.0020	0.0019
14.0000	0.0029	0.0025	0.0022	0.0020	0.0019	0.0018

Table 10: Total collateral demand, 4 regions

Investors	Number of Banks					
0	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000
4.0000	0.3326	0.3348	0.3365	0.3375	0.3384	0.3392
6.0000	0.3142	0.3163	0.3176	0.3183	0.3190	0.3197
8.0000	0.3033	0.3051	0.3062	0.3069	0.3075	0.3081
10.0000	0.2961	0.2975	0.2985	0.2991	0.2997	0.3002
12.0000	0.2904	0.2919	0.2927	0.2934	0.2939	0.2944
14.0000	0.2861	0.2874	0.2883	0.2889	0.2894	0.2898

Table 11: Total collateral with centralized clearing of all bank trades, 4 Regions

Investors	Number of Banks					
0	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000
4.0000	0.3572	0.3639	0.3686	0.3719	0.3745	0.3768
6.0000	0.3343	0.3401	0.3438	0.3464	0.3485	0.3504
8.0000	0.3207	0.3257	0.3290	0.3313	0.3331	0.3347
10.0000	0.3116	0.3160	0.3188	0.3209	0.3226	0.3240
12.0000	0.3046	0.3087	0.3113	0.3132	0.3148	0.3161
14.0000	0.2992	0.3030	0.3055	0.3074	0.3088	0.3100

Table 12: Total collateral demand with one global bank, 4 regions

Investors	Number of Banks					
0	3.0000	4.0000	5.0000	6.0000	7.0000	8.0000
4.0000	0.3086	0.3174	0.3226	0.3263	0.3289	0.3309
6.0000	0.2947	0.3020	0.3064	0.3092	0.3111	0.3129
8.0000	0.2864	0.2927	0.2965	0.2989	0.3009	0.3023
10.0000	0.2809	0.2865	0.2899	0.2919	0.2937	0.2950
12.0000	0.2767	0.2818	0.2848	0.2868	0.2884	0.2896
14.0000	0.2732	0.2782	0.2810	0.2830	0.2844	0.2855

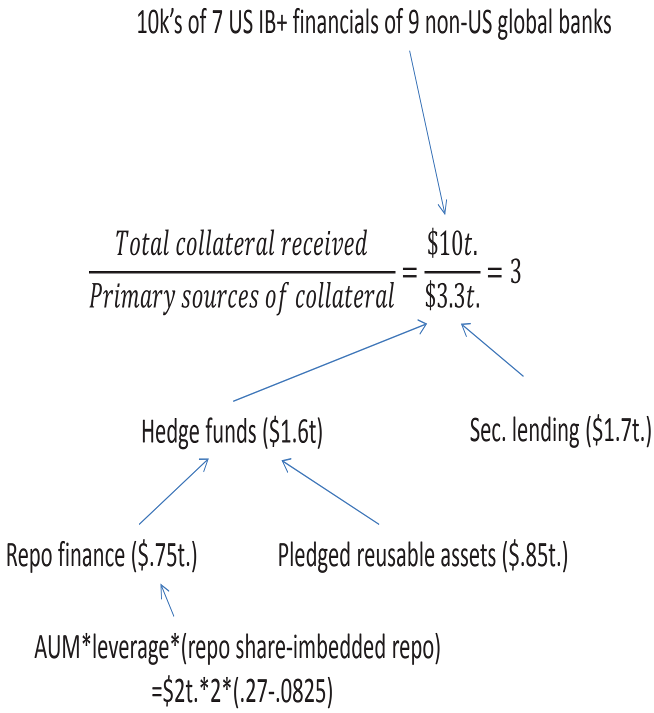

Figure 1: Velocity of Collateral 2007 (Singh 2011)

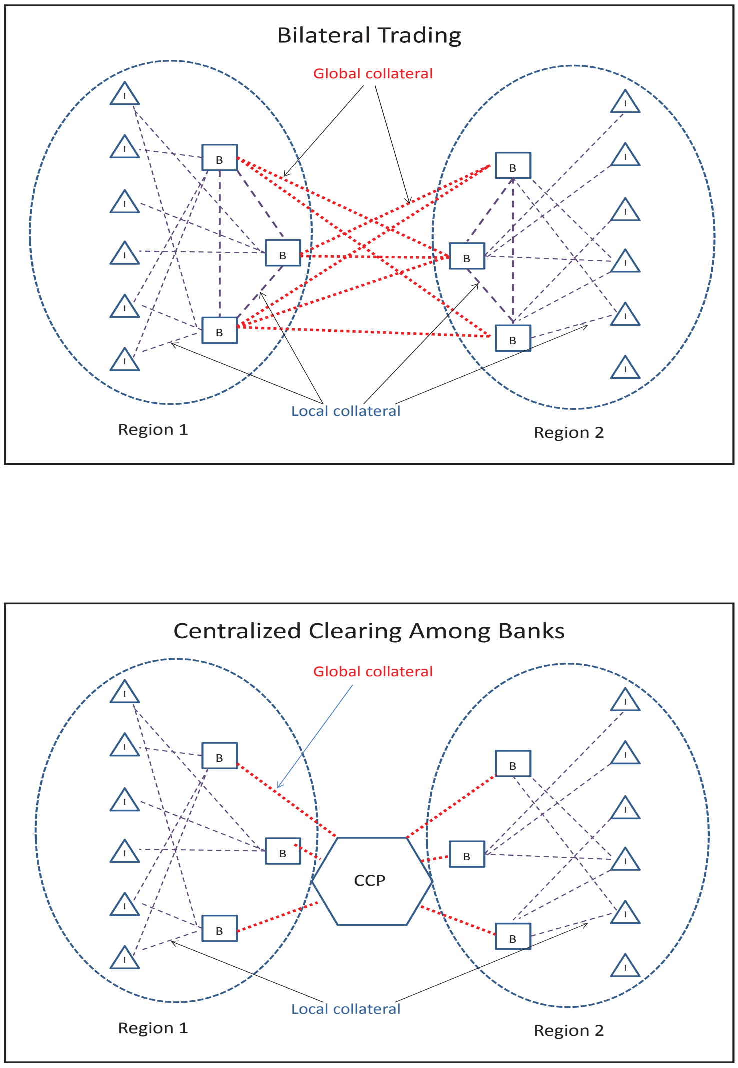

Figure 2: The Regional Model

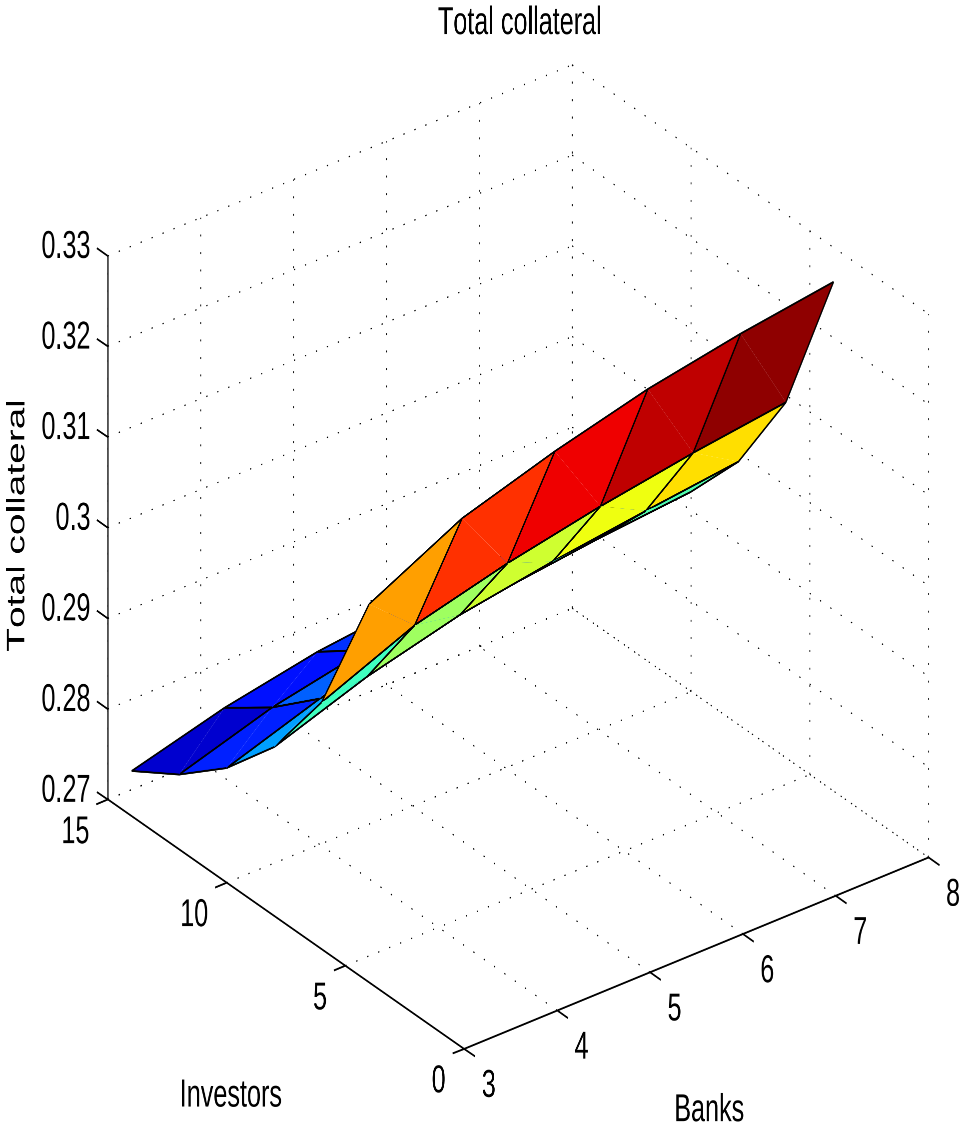

Figure 3: Total collateral demand after regional and global netting

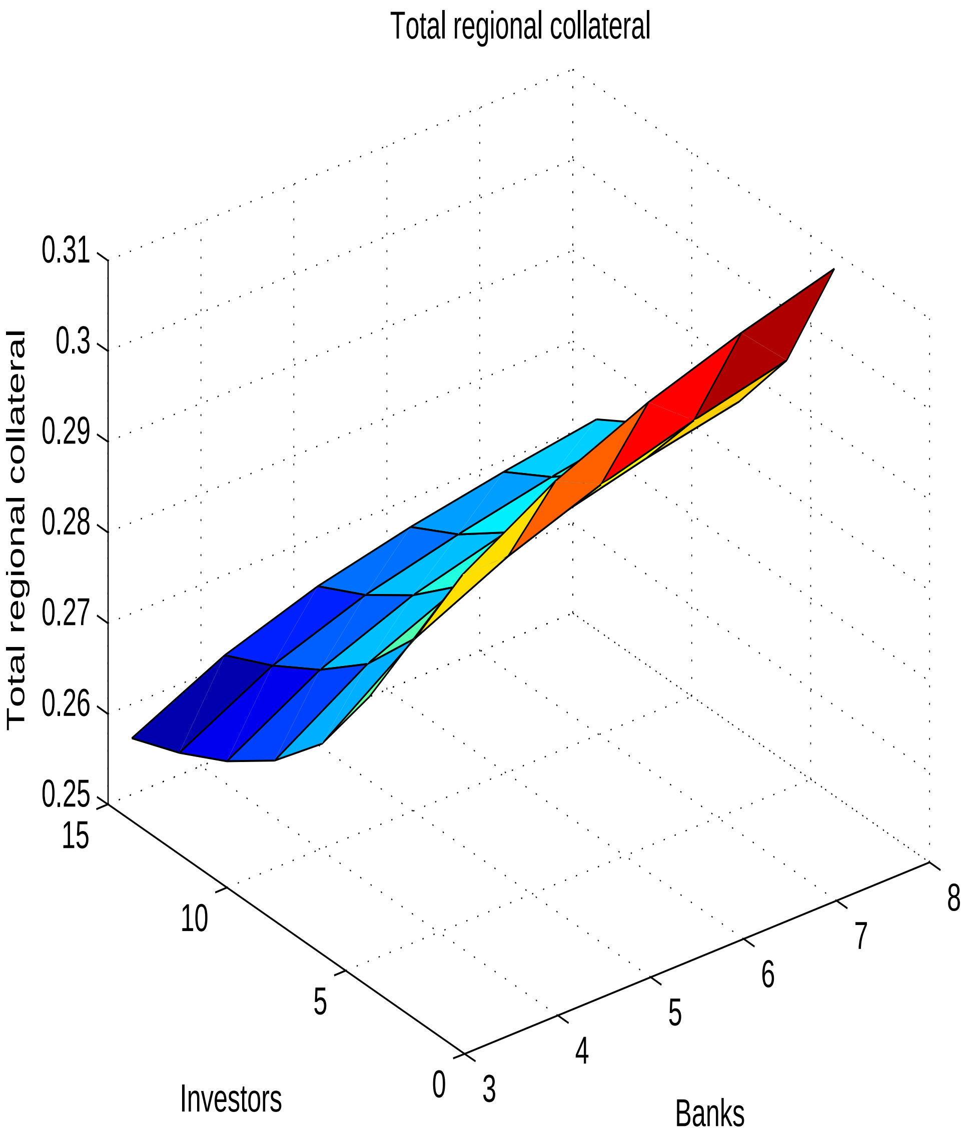

Figure 4: Total regional collateral demand

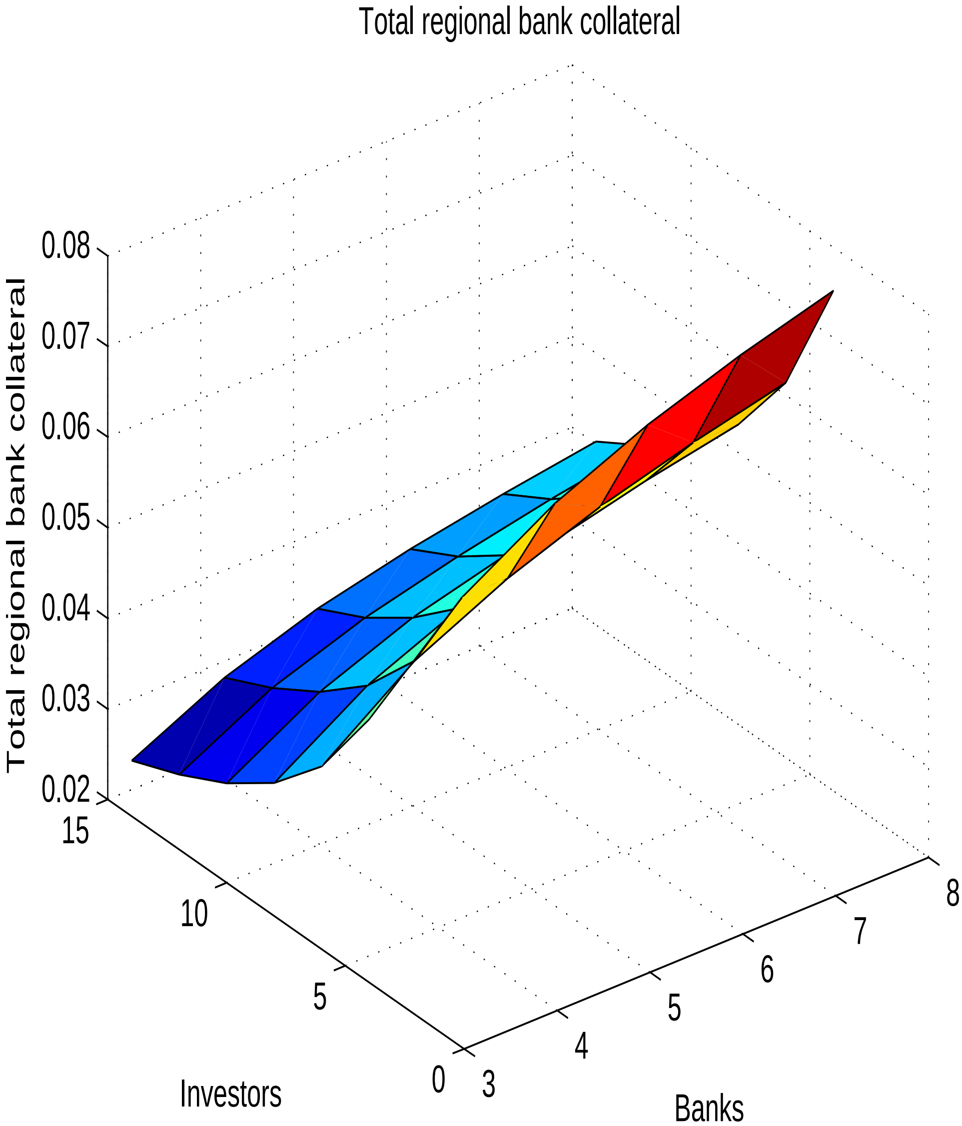

Figure 5: Total regional bank collateral demand

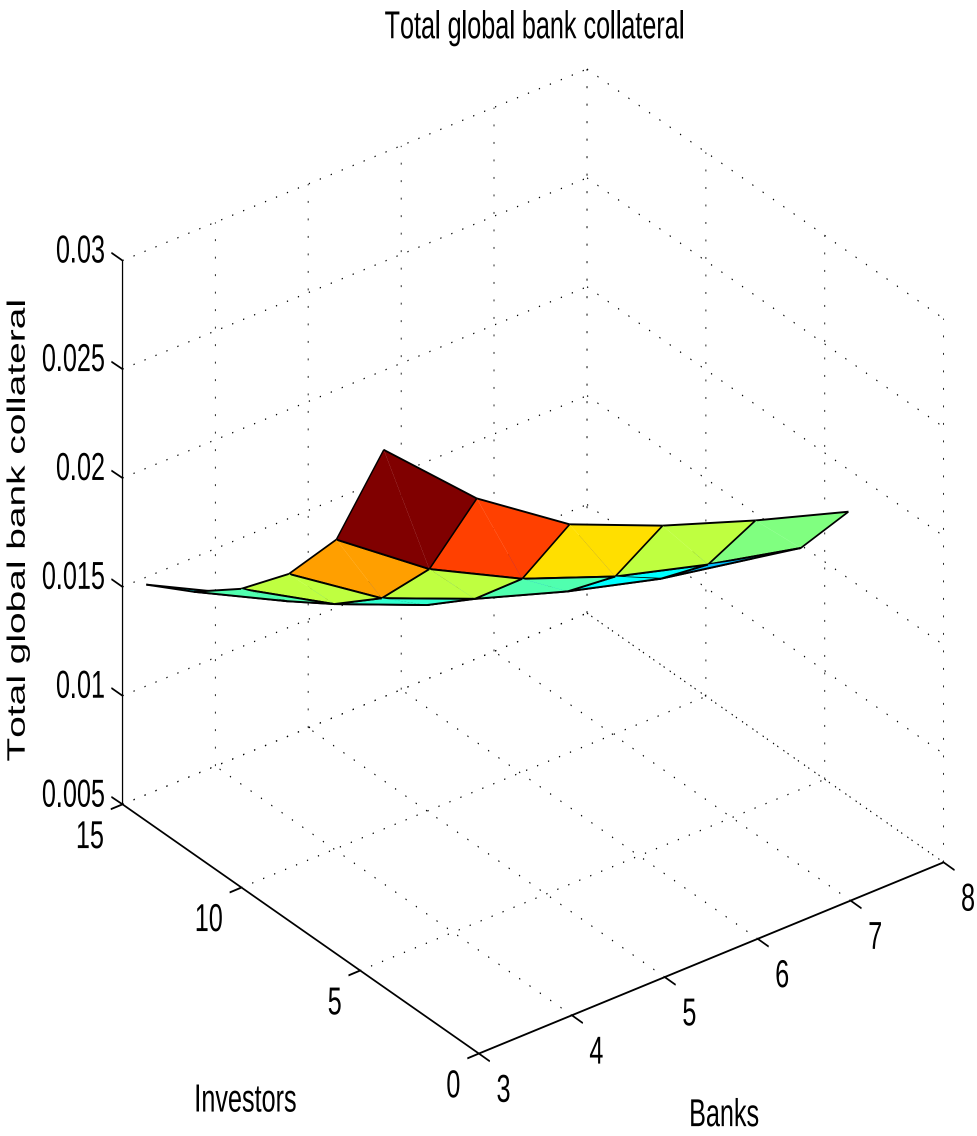

Figure 6: Total global bank collateral demand

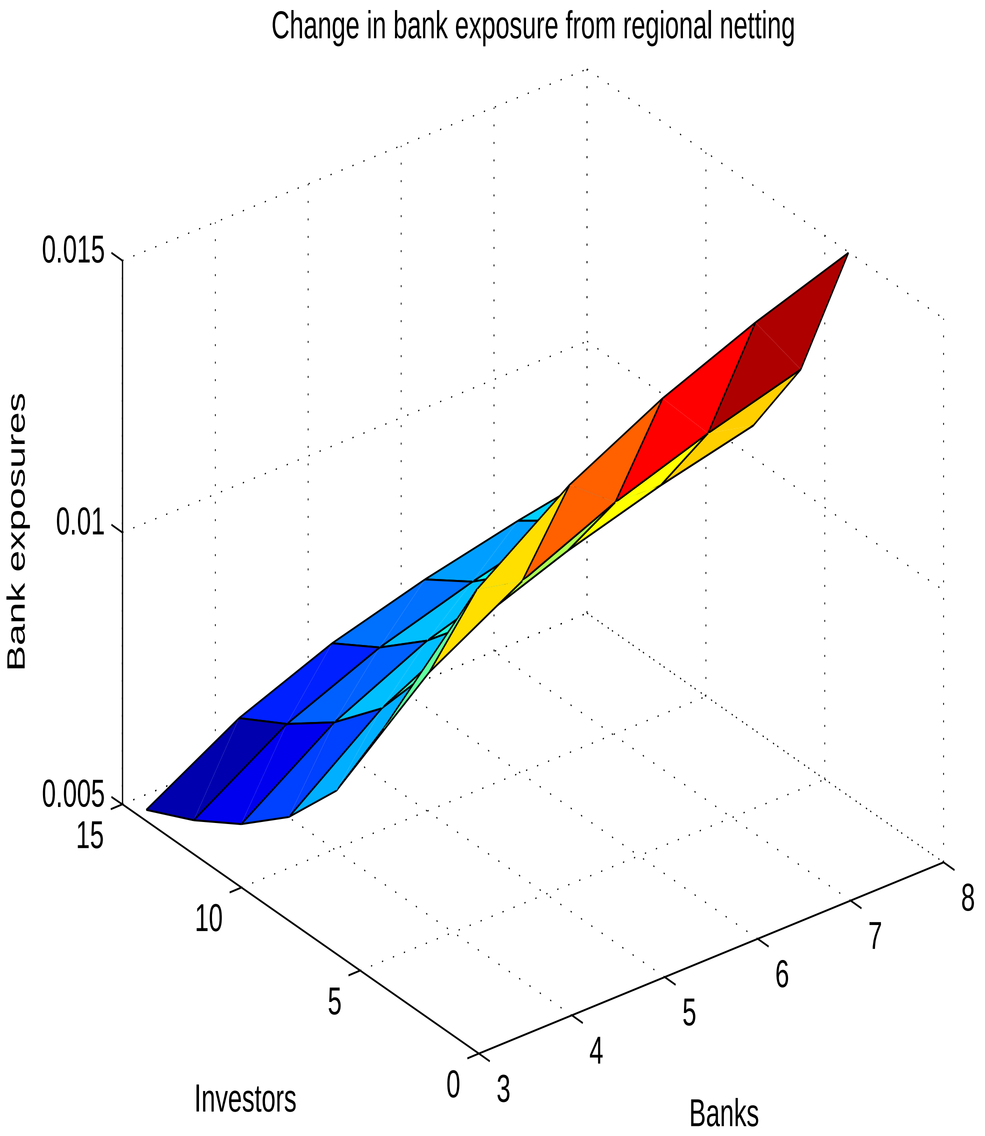

Figure 7: Total reduction in bank exposures from regional netting

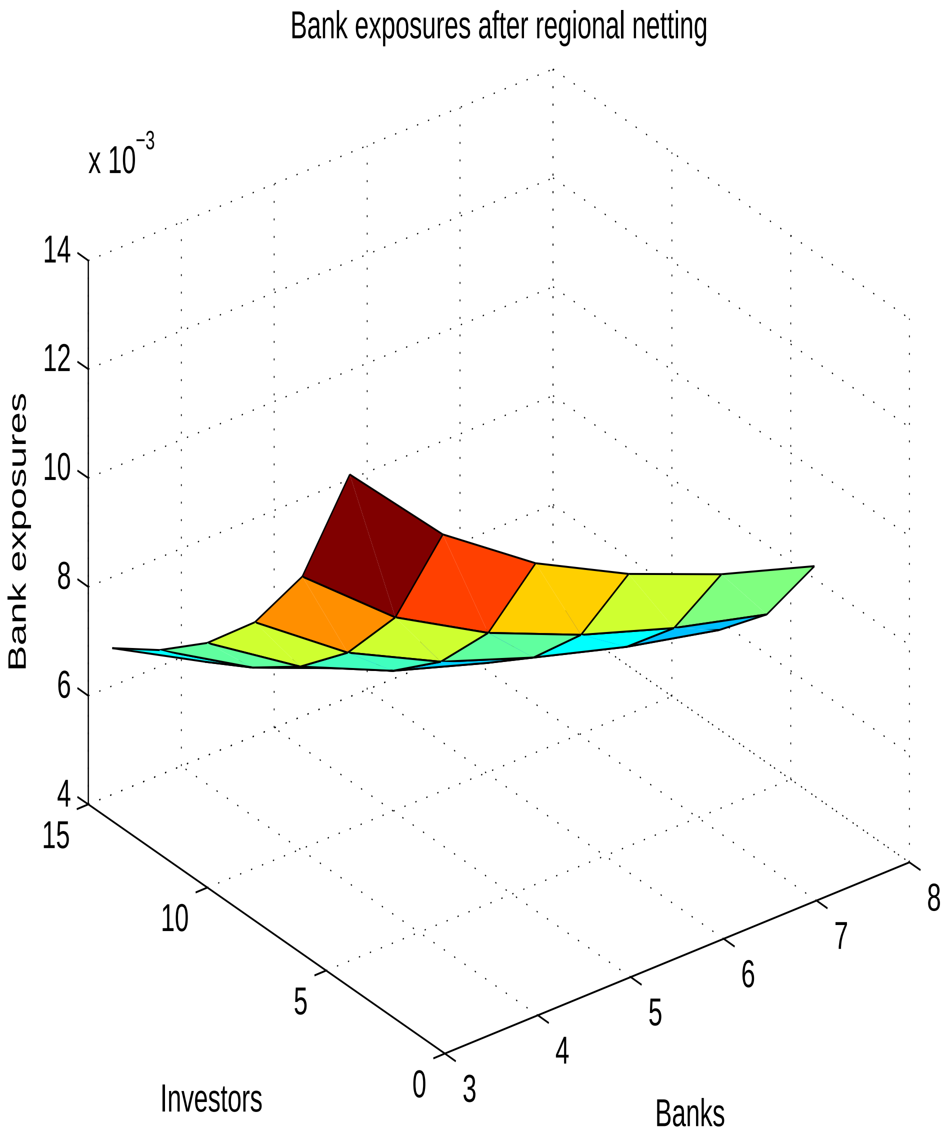

Figure 8: Total bank exposures after regional netting

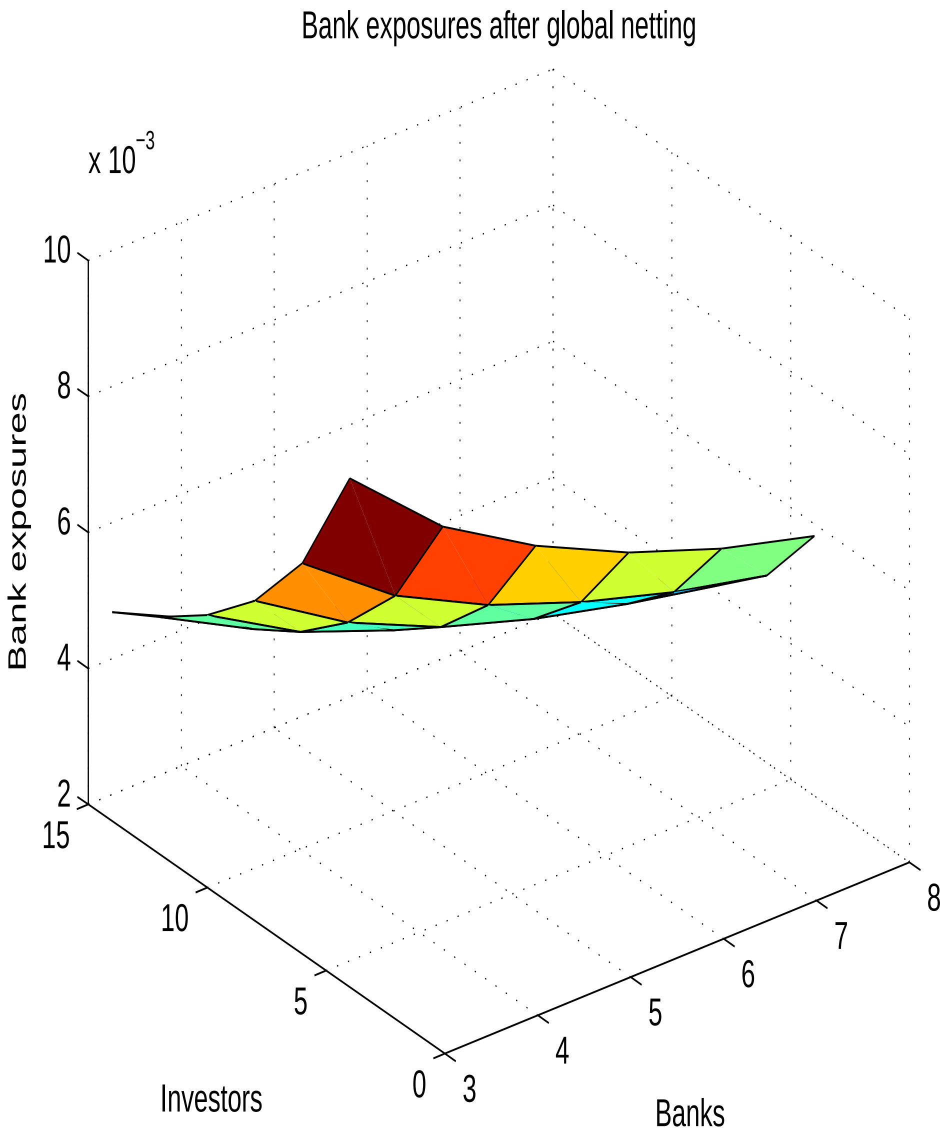

Figure 9: Total bank exposures after global netting

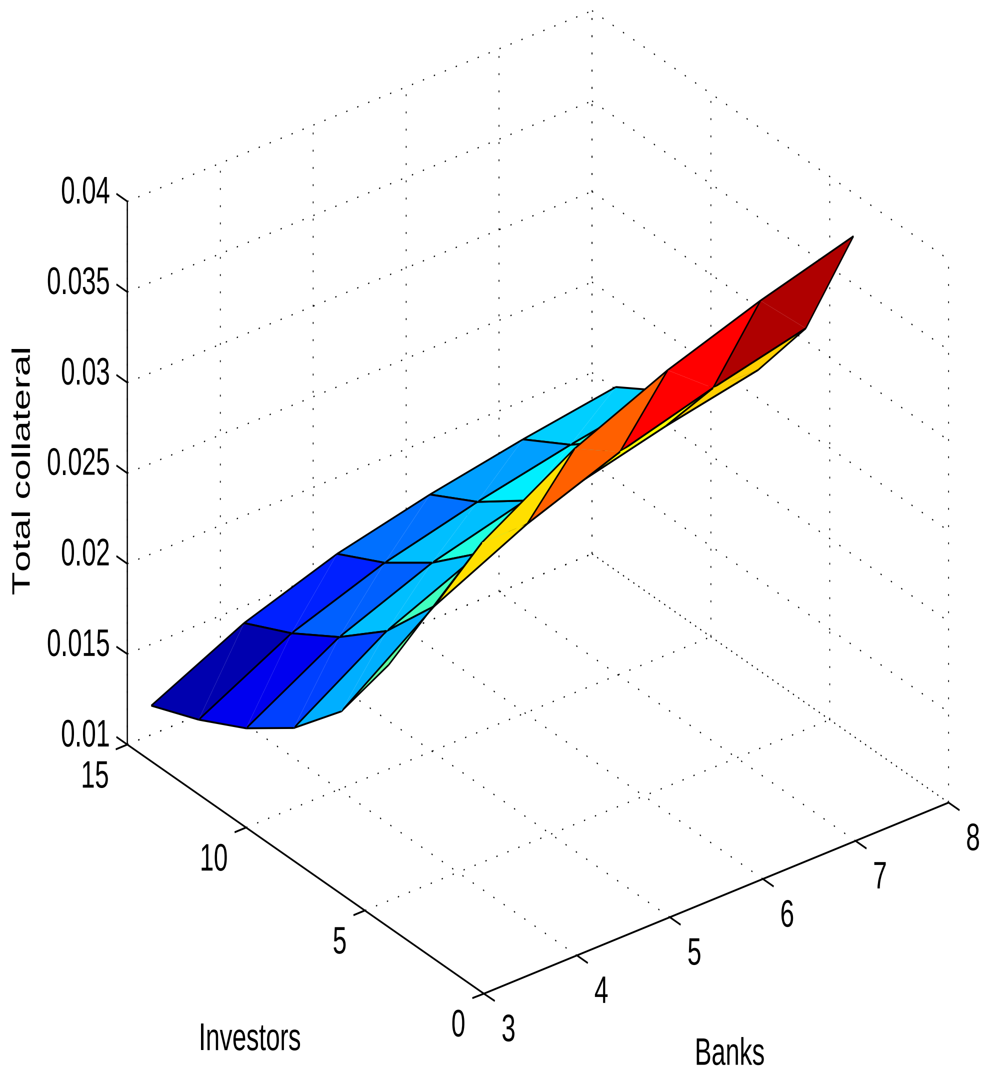

Figure 10: Change in total collateral due to centralized clearing of bank trades

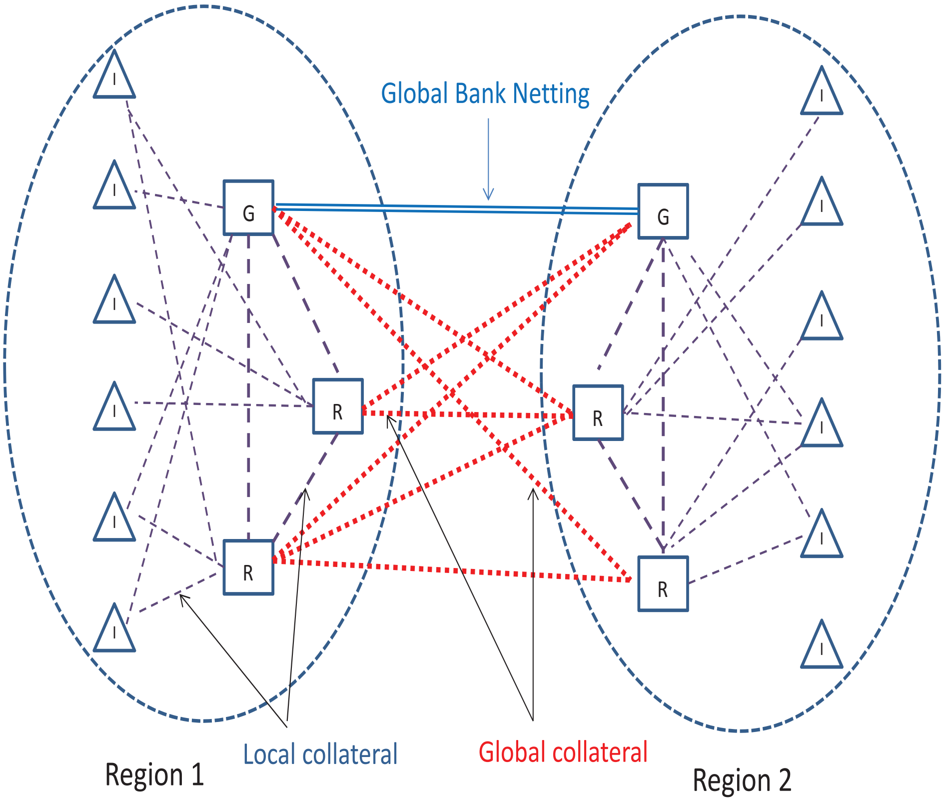

Figure 11: Global Banks