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PROCYCLICALITY AND RISK-BASED ACCESS: VALUING THE EMBEDDED CREDIT DEFAULT SWAP OF EMPLOYING BILATERAL CREDIT LIMITS IN FINANCIAL MARKET INFRASTRUCTURES

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Procyclicality and Risk-Based Access: Valuing the Embedded Credit Default Swap of Employing Bilateral Credit Limits in Financial Market Infrastructures*

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Abstract

Given institutional knowledge, this paper presents similarities between the survivor pay component (Tranche 2) of the Canadian Larger Value Transfer System (LVTS) and credit default swap (CDS) contracts. Accordingly, the default leg of the financial market infrastructure (FMI) or central counterparties (CCPs) is similar to that of a CDS, whereas liquidity efficiencies are mapped to the premium leg. The paper consequently conducts a simple numerical approximation of the empirical risk neutral daily valuation of Tranche 2 from January 2005 to December 2016. In so doing, the paper identifies conditions under which LVTS participants might withdraw from the loss sharing framework. The results highlights a potential specification of "risk-based access" to clearing and settlement in FMIs. A further policy implication of valuations of the credit risk liquidity risk trade-off is to dampen perceptions of procyclicality in loss sharing arrangements.

Keywords: Risk-Based Access, Credit Default Swap, High Value Payment System, Collateral Requirements, Intraday Liquidity Management, Procyclicality, Financial System Fragility
JEL: G12, G20, G32

Contents

Executuve Summary

With survivor pay loss sharing schemes, particularly in central counterparty (CCP) arrangements, coming under increasing scrutiny through regulatory push for compliances with the Principles of Financial Market Infrastructures (CCPMI-IOSOC, 2012 and 2014), policy concerns have to the fold pertaining to procyclicality in their collateral requirements. Added to these concerns are questions surrounding the specification of "risk-based access" to clearing and settlement in financial market infrastructures. This paper tackles these issues from the basis of the prevailing loss sharing scheme (i.e. Tranche 2) in the Canadian Large Value Transfer System (LVTS). Based on institutional knowledge of the LVTS this paper identifies two distinct operational cash flow legs of Tranche 2 and the similarities of the survivor pay scheme to a credit default swap (CDS) contract. Accordingly, the paper conducts a simple numerical approximation of the empirical risk neutral daily valuation of Tranche 2 participation from January 2005 to December 2016. In so doing, the paper identifies conditions under which LVTS participants might withdraw from the loss sharing framework.

The key results suggest that contrary to policy concerns, loss sharing schemes such as those of the LVTS are actually countercyclical in nature in that the establishment of bilateral credit limits (BCLs) proves beneficial to participants in times of economic stress when liquidity is at a premium. Indeed, the extent to which the loss sharing structure of the Tranche 2 is profitable to participants can be mapped directly to the trade-off between the expected loss to survivors upon the occurrence of defaults and the expected value of the premium required to obtain the liquidity recycling associated with the BCLs they extend. To this end, the results show that at it was exactly at the height of the global financial crisis when the liquidity premium was at its peak that participation in the Tranche 2 loss sharing arrangement proved most profitable. Moreover, with the valuation of credit risk mapped to the default probability of LVTS participants, the results further indicate that access to clearing and settlement in FMIs employing loss sharing arrangements similar to those of the LVTS should be predicated on participants maintaining credit ratings equivalent to Standard and Poor's A- notch or higher. This model suggested access criteria is based on empirical data with a mean liquidity premium of approximately 1%. To this end the paper corroborates recent Bank of Canada research illustrating that with appropriately designed risk protection measures, loss-sharing arrangements can be used to smooth out margin increases at CCPs that would be considered as procyclical.

It should be noted that a similar cash flow valuation approach can be employed to assess procyclicality and risk-based access in real time gross settlement (RTGS) systems. However, further research will be required to tease out the institutional details of RTGS systems and appropriately identify the cash flows and associated valuation model.

1 Introduction

The Canadian Large Value Transfer System (LVTS) is an electronic wire system that facilitates the transfer of Canadian-dollar payments between Payments Canada member financial institutions. The LVTS began operation in February of 1999 and is essential to the Canadian financial system, processing an average daily volume of approximately 22,000 payments, which is equivalent to CA$171bn under a real-time net settlement model with final exchange of value at the end of day. As of November 2016, sixteen financial institutions (FIs) and the Bank of Canada participate directly in the LVTS. These Participants provide LVTS payment agent services to other FIs, as well as domestic and foreign businesses and individuals, through contractual arrangements established between the Participant and its customer. The LVTS is characterized by two alternative payments streams ("tranches"), and Participants may use either stream to send a payment message through the LVTS. Each payment message is assessed against the applicable risk control tests and associated collateralization scheme model, given the tranche it flows through, as specified in the LVTS rules.[1]

The collateralization scheme model in the LVTS has come up for debate in recent times with policy concerns pertaining to the procyclicality of collateral and liquidity requirements of the System especially in times of macroeconomic and market stress. This newly established focus on procyclical collateral management, and more specifically the establishment of bilateral credit limits (BCLs),[2] has been driven by G-20 regulators and central banks ingraining the objective of stabilizing loss allocation with respect to recovery planning into the Principles of Financial Market Infrastructures PFMIs (CCPMI-IOSOC, 2012 and 2014). This paper employs institutional knowledge of the LVTS collateralization model in a cross field analysis to empirically assess

[1] It should be noted that whilst a single LVTS settlement model underpins both streams, each stream is characterized by its own risk and collateralization model.

[2] It is rather important to note that BCLs are not lines of credit as they are sometimes misinterpreted as being. LVTS participants do not lend to one another in order to make LVTS payments. Rather BCLs are a tool used by participants to facilitate the smooth transfer of payments among themselves. They not only represent the value of partially collateralized exposure, in terms of payments received, one participant is willing to accept from another, but they also reflect the underlying payment value flow between each pair of LVTS clearers. By not establishing BCLs with another participant, a direct clearer may prevent the other participant from sending payments to it under Tranche 2.

these policy concerns. More specifically, does the institutional design of the loss sharing component of the LVTS give rise to the procyclical extension of BCLs and what conditions lend to this procyclicality if it does exist?

The underpinnings of this research question and policy concerns can typically be traced back to Fisher (1933), Bernanke and Gertler (1995) and Kiyotaki and Moore (1997) and to macroeconomic models, which argue that frictions and asymmetric information within the financial market can amplify the business cycle and result in large swings in real economic activity. This line of thinking is also referred to as the *"financial accelerator"*.

Others have conjectured that the debt overhang problem that Myers (1977) identified, which implies that banks prefer to shrink their asset base rather than raising new capital, can have devastating economic impacts when multiple banks subject to regulatory capital requirements with the expectation of compliance and prompt corrective action (PCA) are hit by the same shock (see Allen and Gale, 2005; Brunnermeir and Pedersen, 2009; Diamond and Raja, 2009; Docking et al., 1997; Hanson, et al., 2010; Schoenmaker, 1996; Shleifer and Vishnu, 1992, 1997, 2010; Stein, 2009, 2010).[3] With regards to the LVTS, procyclicality and financial fragility are viewed in terms of Participants withdrawing bilateral credit limits during times of stress; thereby impeding the smooth processing of real economy transactions.

Empirical evidence, nevertheless, has suggested that neither the *"financial accelerator"* nor debt overhang problem are sufficient factors to explain the widespread financial instability that results in the large swings in activity in the real economy (Borio et al., 2001). Milne (2002) noted that, when the impact of minimum capital requirement regulations is viewed from an incentive-based perspective, they will actually have only a modest influence on bank behaviour because banks seek to avoid a future breach of minimum capital requirements. In fact, prior to the 2007-

[3] Regulatory capital compliance with PCA can be understood through the following illustrative example. Assuming that a bank with assets of $100 financed by insured deposits is expected to ensure that the value of these assets do not decline beyond an amount equaling 6% with a 99.5% confidence level, micro-prudential regulations require that this bank hold 6% of its assets in regulatory capital. Should the bank incur losses over any given period—for instance, resulting in capital falling to $4—the bank will be required, through PCA, to raise an additional $2 in capital in the markets or reduce its asset base to $66.67 (i.e. 6% = 4/66.67).

2009 crisis, banks maintained capital ratios above the target regulatory thresholds of 4% and 8% for Tier 1 and total capital ratios, respectively (Chami and Cosimano, 2010; Demirguc-Kunt et al., 2010; Milne 2002). Moreover, whilst Gai et al. (2006) find that the risk-sharing capacity of the financial system varies with the business cycle and results in procyclical fragility, they also illustrate the amplification of procyclicality in the financial cycle to be driven by the liquidity of collateral assets. Baranova et al., (2016) argue that despite the flight to safety creating an imbalance between the supply and demand for high quality liquid assets (HQLA) as collateral, it is the inability to realize the liquidity of such assets because of a reduction in the willingness and/or ability of market participants to act as intermediaries in collateral markets that is likely to have more serious consequences for the unhindered functioning of markets. Indeed to this end, authorities in both the US and European Union expanded the class of assets they accepted as collateral to include less liquid and of lower quality (Cassola et al., 2011). Moreover, as observed by Allen et al, (2011), Canadian banks did not use short-term liquidity facilities offered by the Bank of Canada aggressively for a sustained period of time.

Notwithstanding, in terms of an application to financial market infrastructures (FMIs), as a fairly recent development, the literature from which policy makers can draw upon is limited. Moreover, much of this literature is centred around central counterparties (CCPs) and not payment systems. That said, the literature does provide insights that may help shape understanding of collateral management and loss sharing by Participants in the LVTS. Indeed unlike other high value payment systems such as the US FedWire, the EU's TARGET, and Japan's BoJNet, which tend to be fully defaulter pay real time gross settlement systems (RTGS), the LVTS is unique in its loss sharing arrangement; thus making it by design similar to CCPs.[4] Murphy et al. (2014) and Park and Abruzzo (2016) argue that the historical basis of margin calculations at CCPs gives rise to large and abrupt increases in collateral demands on Participants in times of stress. Duffie (2014) posits that incentives for loss sharing in times of stress can be strongly influenced

[4]For a comprehensive review of payment systems across the various international jurisdictions, the reader is referred to Tompkins and Olivares (2016).

by exposures outside of the FMI. CCP participants with highly directional positions relative to the CCP would be greatly impacted by loss sharing or allocation schemes unlike Participants with more balanced positions. Therefore, any resolution process that is not well contained within the FMI will result in a divergence of private and social incentives.

Singh (2015) argues that CCPs by "regulatory fiat" have become "too important to fail" but do not warrant government support, therefore greater use of loss sharing is required and desirable. The effectiveness of this loss sharing is argued to be directly linked to the robustness of the CCP's waterfall structures. Manning et al., (2015) similarly address risks arising from the non-conventional banking activities of banks in their over-the-counter (OTC) interactions with other financial institutions that have moved into CCPs in light of post crisis regulations. The authors, using 2012 BIS Macroeconomic Assessment Group on Derivatives (MAGD) data (which includes 41 of the bank participants in the OTC market) show that loss sharing was sufficient to contain default events even during times of stress. Raykov (2016) shows that, both privately and socially, the empirical evidence overwhelmingly points towards the optimality of maximum loss sharing. Indeed, only in the special case where incentives to fully share losses through variation margin gain haircuts (VMGHs) are weakened by procyclicality in the risk-based equity holdings of CCPs, is the ability of participants to trade in an uninterrupted way impeded. To this end Chande and St-Pierre (2016), illustrate that with an appropriate design of risk protection measures, loss-sharing arrangements can be used to smooth out margin increases at CCPs that would be considered as procyclical.

What the literature does show, is the extent to which there is an exacerbation of stress during economic downturns is correlated to the ability of markets to translate HQLA into immediately available liquidity, the containment of exposures within the FMI, and the acyclicality and robustness of FMI waterfall structures.

This paper, contributes to the body of research on the topic of procyclicality in FMIs, and the LVTS more specifically, by addressing the issue from an asset valuation standpoint. Based on an operational understanding of the LVTS presented in **Section 2**, the paper specifies a basic theoretical framework with which to price the trade-off between credit risk and liquidity recycling (i.e. liquidity efficiency) associated with bilateral credit limits. In particular, by noting the existence of two distinct forms of cashflow embedded in the design of Tranche 2 and operational implementation of BCLs. The section then continues by reviewing the data used to model both legs of cash flows. **Section 3** relates the survivor pay component of the LVTS to a vanilla credit default swap (CDS). Under this construct, the survivor pay collateral pool is treated as the contingent leg of the CDS and the premium leg is the liquidity recycling the System offers Participants. **Section 4** describes the resulting CDS valuation model of Tranche 2. **Section 5** discusses the results, highlighting the impact of the credit risk and liquidity risk trade-off on the setting of access requirements and procyclicality of BCL extension. Concluding remarks and potential future research are given in **Section** 6.

2 Review of the LVTS Credit Risk and Collateralization Model and the Data

2.1 Credit Risk and Collateralization Model

Each of the two LVTS tranches has its own set of risk controls which combined guarantee, mathematically, that there is sufficient collateral value apportioned to the LVTS by Participants to ensure that settlement will take place in the event of a single Participant default ("Cover 1"). Counterparty credit risk within the LVTS arises from both the inability of the defaulting Participant to cover its end of day LVTS multilateral net position and the different collateralization models. Under Tranche 1 (T1) payments are fully collateralized by the sending Participant such that, T1 payments will only be accepted by the LVTS, given the applicable risk control test, if the value of the payment being sent does not exceed the sum of the FI's T1 apportionment of collateral and its multilateral T1 position vis-à-vis the LVTS. Conversely, Tranche 2 (T2) collateral requirements are dependent on the bilateral credit limits the FI has established that day.

According to Payments Canada Rules a Participant's apportioned T2 collateral (known as a Participant's Maximum Additional Settlement Obligation or Max ASO) is specified to be the product of the largest BCL it extended during the payment exchange cycle and system wide percentage (SWP). Since the collateral pledged under T2 is with respect to the largest bilateral net negative position the pledging FI is willing to accept vis-à-vis another institution, thus contributing to the reference Participant's T2 Net Debit Cap (T2NDC)[5], it is the institution that extends the BCL that introduces the credit risk. In this regard, the T2 collateral pledged by a Participant is a measure of its confidence that its largest credit risk exposure, as defined by the BCLs it extends, will not default during the LVTS cycle. In the event of a default, such that the referenced Participant did not apportion sufficient collateral to the LVTS to meet its time of default multilateral net debit position (that is the defaulting FI has an Own Collateral Shortfall, OCS at default), the surviving Participants are called upon to cover the shortfall. The allocation of the OSC across surviving Participants is in proportion to their relative share of the total value of BCLs extended to the defaulting FI during the cycle; capped at their respective Max ASOs.

Moreover, by construction a T2 payment will only be accepted by the LVTS if the applicable risk control tests, the Bilateral Risk Control (BRC) and Multilateral Risk Control (MRC), are both satisfied. More specifically, the payment must be (i) less than or equal to the sum of the BCL granted by the receiving Participant and the sending Participant's net bilateral T2 position vis-à-vis the receiving Participant,

$$P_{i,j}^{T} \leq \beta_{j,i} + \sum_{t=0}^{T-1} \left(P_{i,j}^{t} - P_{j,i}^{t}\right) \tag{1}$$

and (ii) less than or equal to the sum of the sending Participant's T2NDC and its net multilateral

[5] The T2NDC is the maximum net debit position that a Participant is able to incur during the payments exchange cycle

T2 position vis-à-vis the System

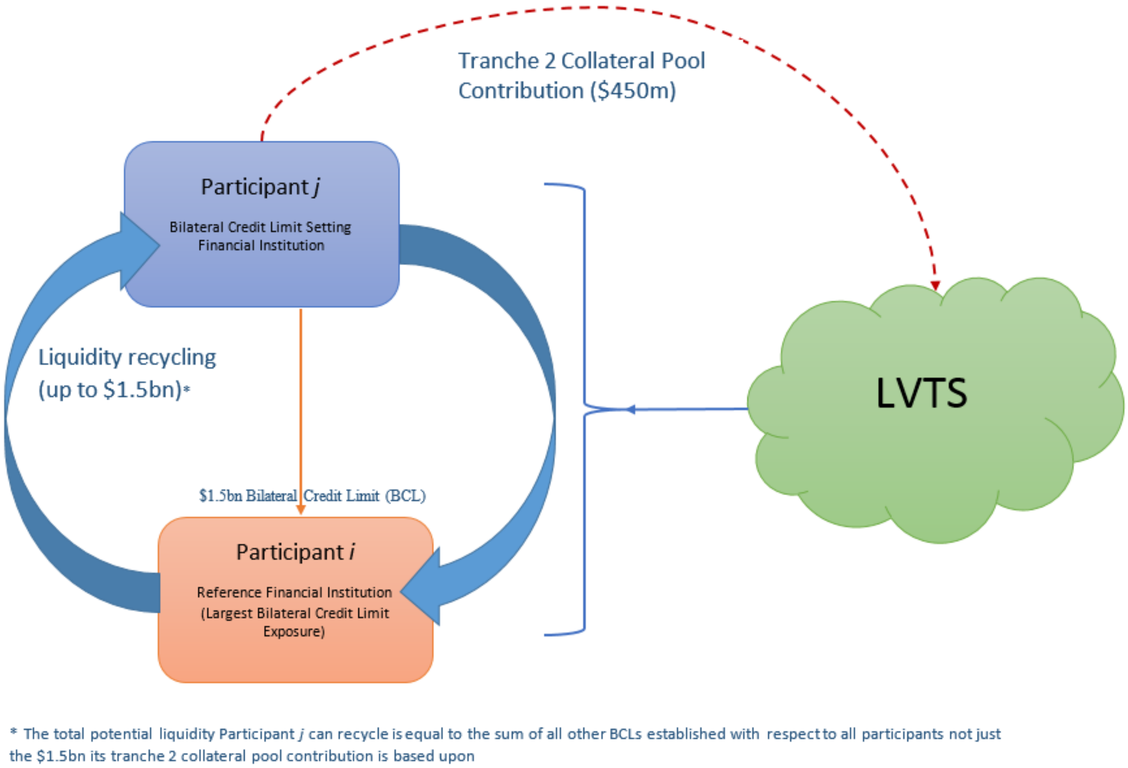
$$P_{i,j}^{T} \leq \sum_{i \neq k \in N} \alpha \beta_{k,i} + \left[\sum_{i \neq k \in N} \sum_{t=0}^{T-1} \left(P_{i,k}^{t} - P_{k,i}^{t} \right) \right] \tag{2}$$

where N represents the set of all System Participants, $P_{i,j}^{T}$ is payment flow from Participant i to Participant j at time T, $\beta_{j,i}$ is the bilateral credit limit j extends to i, and α is the system wide percentage.

It is noteworthy that, given the tranche 2 risk controls, the BCLs act as cap on the value of liquidity that can be recycled on a bilateral and multilateral basis at any point during the day. To see this, imagine Participant j in *Figure 1*, extends CA$1.5bn in BCLs to Participant i at the start of the cycle and Participant i represents j's largest BCL exposure. Further assume at a System-wide level that, Participant i has a T2NDC of CA$3bn. Then at time $t = 0$ when BCLs are established, Participant i can send payments with a total face value of CA$1.5bn to Participant j.

This in turn implies that, regardless of the BCL extended to Participant j by Participant i, Participant j can at time $t = 1$ send payments of value at least $1.5bn to Participant i. Therefore, assuming the SWP of 30%, by pledging CA$450m in T2 collateral, Participant j is able to recycle CA$1.5bn in liquidity throughout the LVTS cycle for that bilateral exchange of payments. Likewise the System as a whole is able to recycle CA$3bn in liquidity with respect to the credit exposure to Participant i for the CA$450m in T2 collateral pledged by Participant j.

Figure 1: LVTS Tranche 2: An Embedded Two Leg Derivatives Instrument



This same process of recycling the face value of individual BCLs extended holds for all other Participants k that j has established BCLs in relation to even though it only pledges collateral against its largest BCL. That is, as par the Rules, Participant j is only required to pledge CA$450m in T2 collateral with respect to Participant i its largest BCL exposure, yet it is able to recycle the total face value of all BCLs it has extended during the LVTS cycle.[6]

From this decomposition of there are two distinct cash flows, one contingent upon a default and the other the availability for liquidity recycling. Moreover, given securities are pledged in other to acquire this liquidity recycling, such liquidity must be valued under prevailing market conditions according to the premium demanded by investors when any given security cannot be easily con-

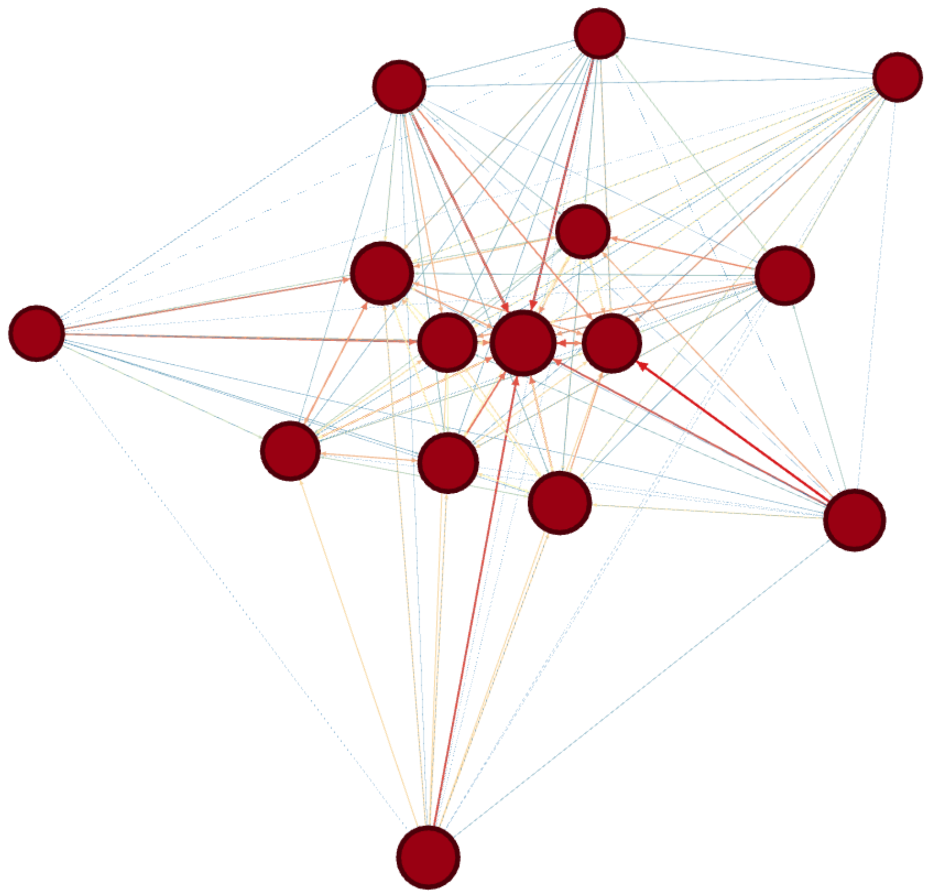
[6]This component of the T2 loss sharing arrangement is the source of the System's liquidity efficiency.

verted into cash for its fair market value. When this liquidity premium is high, and as such the asset is illiquid, investors demand additional compensation for the added risk of investing their assets over a longer period of time since valuations can fluctuate with market effects. Consequently, it is possible to quantify the utility of participating in the Tranche 2 loss sharing schemes using a simple credit default swap (CDS) valuation approach where the breakeven valuation of participating in Tranche 2 is dependent on the trade-off between the default contingent cash flow and the premium associated with the cash flow from liquidity recycling.

As a direct consequence of this trade-off between credit risk and liquidity recycling, the survivor pay model employed in Tranche 2 potentially provides, both at a private and social level, strong incentives for loss sharing through the extending of BCLs. Moreover, unlike conventional defaulter pay risk models with no loss sharing, by decoupling collateral from the available liquidity with which to settle transactions, LVTS tranche 2 would appear less susceptible to external market pressures on the valuation and availability of the collateral asset .

An argument that has been made against the use of BCLs is one centred around larger Participants squeezing out the smaller Participants during crises. This line of thought however overlooks the expected loss sharing implications of both the Rules and the core-periphery network structure within the LVTS. As illustrated in Figure 2, based on the average dollar value of bilateral credit limits established by LVTS Participants in 2014, there exists a group of 6 to 7 Participants that form the core of the network of BCL extension. These core Participants represent both the key relationships between Participants and the primary contributors to the loss sharing. In other words, the closer Participants are to the central core, the more systemically important they are in a crisis and the more interconnected they are to other Participants in the central core.

Figure 2: LVTS Network of Bilateral Credit Limit Extension (2014)



The network is based on the average value of bilateral credit limits extended by Participants active in the LVTS during 2014. The graph uses the Force Atlas layout typically employed for robust, unbiased and reliable spatial representations of Small-World /Scale-free networks. The farther out in the periphery a node is, the less connected it is to the all other nodes. Nodes at the core are strongly connected to one another. The thickness of the directed edges represent the relative share of the value of bilateral credit limits extended by the granting Participant to all other Participants. The thicker the edge, the larger the share of the value of BCLs the granting Participant extended to target Participant relative to all other Participants it granted BCLs to.

Therefore, not only do these core players introduce the largest potential loss exposure at default into the System, they also assume the bulk of the loss allocation in the event of default. As the most interconnected Participants in the network, the trade-off between the expected loss and liquidity recycling among the core group will likely play a more important role in the extending of BCLs within this group than the potential socialization of losses from periphery nodes. Likewise, the value to the periphery nodes of extending BCLs will likely be driven by the extent to which they are connected to the central core rather than to other periphery nodes. Understanding the value of these relationships is therefore paramount to developing appropriate policy and selecting system designs moving forward.

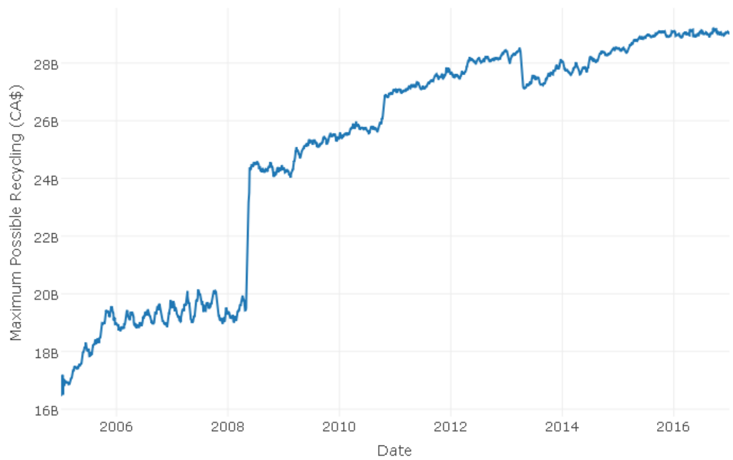
2.2 Data

The data used in the pricing of tranche 2 is based on system level aggregates of the potential liquidity recycling which is assumed to be the sum of the largest Participant level multilateral net debit cap received on each LVTS cycle between January 2005 and December of 2016. Over the same period, the aggregated Max ASO across System Participants is taken as the total collateral value at risk used to capture the maximum potential loss given default. The moving average of both the liquidity recycling and collateral value at risk are plotted in *Figures 3 and 4* respectively. The multilateral net debit cap is taken as the liquidity recycling since it acts as the binding constraint given the construction of the LVTS Tranche 2 risk controls. It represents the largest total value of payments Participants are able to send to others without first having received payments.

The liquidity recycling data suggests there have been multiple structural breaks over the period between 2005 and 2016. The data also indicated multiple regime shifts; the most pronounced of these were in May 2008 and late 2010 spanning to 2013. The first of the structural breaks coincided with the increase in the SWP in May of 2008 and is also present in the collateral value at risk data plotted in *Figure 4*.

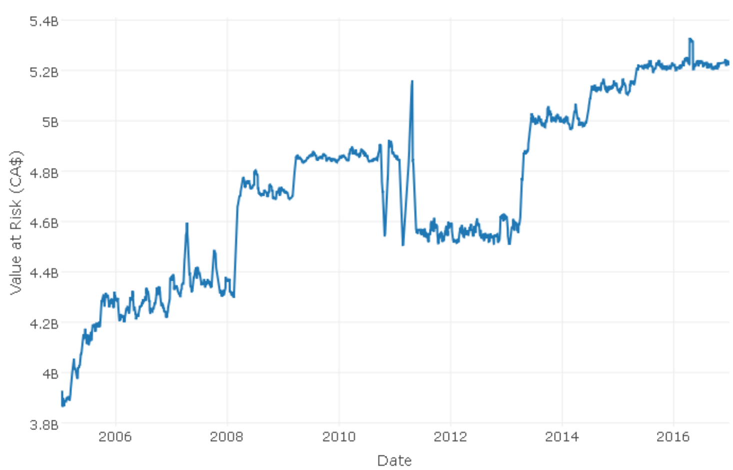
The second structural break, which witnessed an increase in the multilateral net debit caps in conjunction with a drop in Max ASOs, coincided with the entry in October of 2010 and subsequent exist in April 2013 of ING due to the CA$3.1billion acquisition by Scotiabank in August of 2012. January of 2013 also saw the entry of Manulife Bank of Canada into the LVTS as a direct Participant. Despite these regime shifts, the data on the unwinding of exposures on the contingent leg (Max ASO exposure) and premium leg (Tranche 2 liquidity) has continued to increase at a steady pace over time.

Figure 3: System Level Liquidity Recycling (Daily Moving Average 2005-2016)



Maximum potential liquidity recycling is assumed to be the largest multilateral net debit cap accessible to each of the LVTS Participants over the course of a cycle.

Figure 4: Total Collateral Value at Risk (Moving Average 2005-2016)

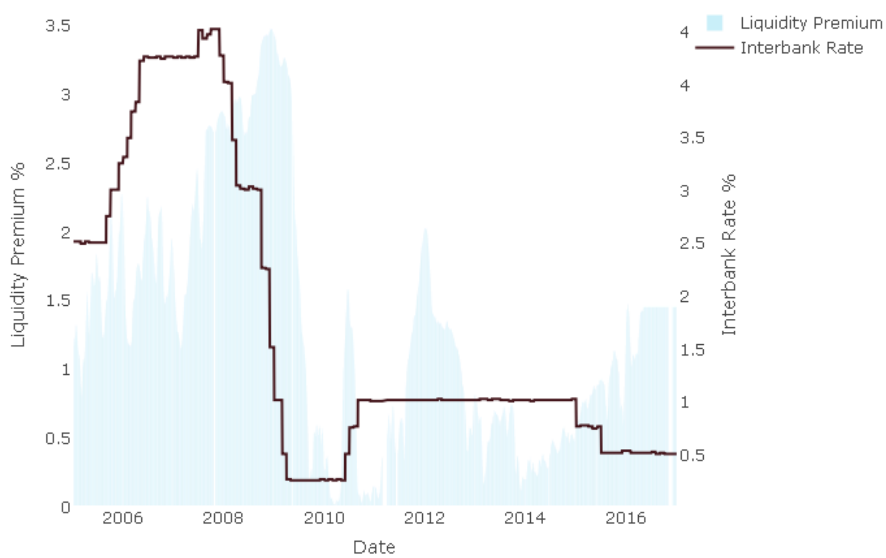


This is based on the maximum settlement obligation of the surviving Participants (i.e. the protection sellers).

The risk free rate is taken as the immediate rate on Canadian money market calls or interbank lending with duration of less than 24 hours. This is plotted against on the right hand axis of *Figure 5*. Like most other major interbank rates, the Canadian interbank rates follow the same upward climb in the build up to the subprime crisis and subsequent global financial crisis. These rates started decreasing from their 2008 heights of 4.5%, just shy of their 1995 peak of 3.5%, once quantitative easing policies were introduced by the major central banks. Rates futher increase from June of 2010 and plateaued at approximately 1% till January of 2015, coinciding with the sovereign debt crisis in Europe. It should be noted that the only other time the liquidity premium fell below 1% for a prolonged period of time was during the global recession of the early 2000s, that affected Europe from 2000 and North America from March of 2001 lasting through 2003 coinciding with the pre-2007-09 crises overnight rate historical lows of approximately 2.5%.

The liquidity premium to be applied to the potential recycled liquidity in Tranche 2 is taken as the interbank liquidity spread, which forms part of the contributions to the interbank liquidity spread that was discontinued in May of 2016. The final recorded liquidity spread of 1.44% has therefore been rolled forward to later months. The liquidity premium is plotted against the left hand axis of *Figure 5* and shows that between 2006 and November of 2008 the liquidity premium rose to a peak of 3.4%. The progressive jumps in the liquidity spread can be mapped to events in the global financial markets. These include but are not limited to the mortgage crisis, the collapse of Bear Stearnes, the September 2008 bankruptcy of Lehman Brothers, and the November 2008 acquisition of Merrill Lynch by Bank of America after it suffered from the pulling of lines of credit by lenders and almost year-long sell-off of its shares; particularly following Lehman's implosion. Spike in the liquidity premium in June of 2010 and December of 2011 related to the multi-year European Sovereign Debt Crisis which began at the end of 2009 with the PIGS (Portugal, Ireland, Greece and Spain). From 2014 onward, the rising liquidity premium has been in part due to the sell-off of Italian banking stock and onset of the Italian banking crisis. The extremely low and near 0% liquidity premium observed from 2009 throw 2011 can be traced to quantitative easing

Figure 5: Liquidity Premium and Interbank Rate (2005-2016)



The liquidity premium is assumed to be captured by the Contributions to the Cleveland Financial Stress Index: Interbank Liquidity Spread (DISCONTINUED) (FRED Ticker: IBLSD678FRBCLE)
The interbank rate is taken to as the Immediate Rates: Less than 24 Hours: Call Money/Interbank Rate for Canada (FRED Ticker: IR-STCI01CAM156N)

and the Troubled Asset Relief Program (TARP).

Default probabilities for each of the LVTS Participants are based on the one-year default probability tables published by the Standard and Poor's (S&P) in its Annual Global Corporate Default Study And Rating Transitions. Of the seventeen Participants in the LVTS over the period between January 2005 and December 2016, eight had ratings of between double-A minus and double-A. The lowest observed rating was triple-B minus. As a crown corporation, one of the Participants was assumed to be triple-A rated in accordance with the provincial government under which it was established. Default probabilities associated with these ratings ranged from 0.00% to 0.28% with an average of 0.05%.

PV01 data are derived from the historically recorded daily prices of the iShares Core Canadian Universe and Short-Term Bond Index Funds managed by Blackrock. These funds are constituted by the Government of Canada and Canadian provincial and municipal government debt issuance. The Universe fund also includes debt issuance from various sectors of the Canadian economy including, but not limited to, energy, financial, infrastructure, and securitizations.

3 Credit Default Swaps

A credit default swap (CDS) is a derivatives instrument through which a party buys credit protection from another in relation to exposures against some underlying reference entity or asset. It is thus a form of insurance against credit risk such that, on the occurrence of a credit event–including a default, credit quality downgrade or restructuring of the reference entity or asset–the credit protection buyer makes a claim against the protection seller for part or the entire face value of the underlying credit exposure (the contingent or default leg). Like an insurance policy, the protection seller receives a fixed fee or premium from the protection buyer (the premium leg) up until the credit event or maturity of the CDS. Credit default swaps are used by protection sellers to gain exposure to the underlying credit risk where they do not have access to the underlying asset for a number of reasons. Protection buyers on the other hand utilize CDS trades in order to off-load the credit risk whilst maintaining legal ownership of the underlying exposure.

The literature on the valuation of CDSs has grown over time and covers different aspects of the valuation. The models evaluate the pricing of a CDS in terms of the expected present value of both the premium leg and contingent leg of the swap, the timing of the contingent payment (Jarrow and Yu, 2001 and Jarrow and Yildirim, 2002) the potential default of both the reference entity and the protection seller (Hall and White 2000,2001 and Leung and Kwok 2005). As instruments insuring against default, the CDS valuation models have utilized one of two default risk models. Firstly, CDS valuations derived from structural default models are typically based on Merton (1974), Black and Cox (1976), Longstaff and Schwartz (1995), Zhou (1997, 2001a,b), who model the probability of default within a structural framework by using an option contract (European or American) pay-off process where the firm's asset value is a stochastic process, the strike price is the face value of the firm's debt, and default is assumed to occur on or before some maturity date T. In structural models, the firm is said to be in default when the asset value drops below the strike price. Alternatively, CDS valuation can be derived from reduced form models of default (see Duffie and Singleton 1999, 2003 and Lando 1998) which by contrast to structural models, do not explicitly draw a connection between the asset value of a firm and its default probability. Rather, reduced form models assume default to occur at the first jump of an exogenous stochastic process parameterized with respect to the hazard rate from market data. In these models defaults are not only stochastic but can also be specified to correlate with macroeconomic activity.

Focusing specifically on tranche 2, recalling *Figure 1*, it is clear that the survivor pay or loss sharing risk model is somewhat analogous to a CDS in that, the Participant pledging T2 collateral with respect to its largest BCL exposure is in fact selling credit protection against the default of that FI to the wider System; this collateral represents the contingent leg of the CDS and will only be drawn upon in the event of a default. On the other hand, the LVTS Participant extending the BCLs receives cashflows in terms of its ability to recycle the liquidity associated with the BCL it granted both on a bilateral and multilateral basis. At each point during the settlement and exchange cycle, the BCL extending Participant can recycle either the full face value of the BCL it extended vis-à-vis the reference Participant or, the net outstanding liquidity it has exchanged with that entity relative to the BCLs it extended. The expected value of these recycled intraday positions can be thought of as the CDS premium and represents the cash flow on the premium leg of the CDS. It follows that each of these cashflows can be valued to quantify the risk-reward trade-off assumed by each LVTS Participant in their establishing of bilateral credit limits.

4 Tranche 2 Credit Risk Valuation Model

Given the aforementioned similarity of the LVTS tranche 2 survivor pay model to a vanilla CDS and identification of the associated cash flows, it is possible to quantify the pay-off associated with participating in tranche 2 using conventional valuation techniques. Specifically, it is possible to value the embedded CDS in the LVTS tranche 2 survivor pay model as,

$$V_j^{T2} = E\left[PV\left(premium\, leg\right)\right] - E\left[PV\left(contingent\, leg\right)\right] \tag{3}$$

which is the difference between the expected present value of the premium leg and the expected present value of the contingent (or protection) leg.

Note the value of the tranche 2 embedded credit default swap is expressed from the perspective of the protection seller. Consequently, LVTS Participants will find value in selling credit protection to the wider System if the expected value of the liquidity recycling exceeds the expected loss in the event of the default of the reference Participant. Conversely, if the expected loss at default on the contingent leg exceeds the expected value of liquidity recycling on the premium leg, the Participant will refrain from extending bilateral credit limits and switch, potentially, to making payments under the defaulter pay model of Tranche 1. The Participant breaks even and is indifferent about making payment under Tranche 2 where, the expected value of the premium and contingent legs are identical.

4.1 CDS Contingent Leg: Survivor Pay Credit Risk

Referring back to *Figure 1*, we note that the survivor pay cashflow in the event of a default, i.e. the Max ASO or collateral pledged under T2, is the dollar value of the expected loss at default of a reference Participant i during the course of the LVTS cycle. This implies the present value of the contingent leg can be specified as:

$$\Psi_j(i) = \gamma_{ji} E\left[e^{-\int_t^{\tau} r(s)ds}\left(1-\phi_i^{\tau}\right)\mathbb{I}_{\tau<T}\right] \tag{4}$$

where

$$\gamma_{ji} = E\left[\sum_{i\neq k\in N}\sum_{t=0}^{T-1}\left(P_{k,i}^t - P_{i,k}^t\right)\right]\left[\frac{\beta_{j,i}}{\sum\limits_{i\neq k\in D\subseteq N}\beta_{k,i}}\right] \tag{5}$$

is the loss given default and represents the expected value of the Participant j's exposure to Participant i's multilateral net debit position in the event Participant i defaults. The term $\left[\frac{\beta_{j,i}}{\sum\limits_{i\neq k\in D\subseteq N}\beta_{k,i}}\right]$ is the survivor pay component of Participant j's exposure to Participant i's default. That is to say, given that Participant i defaults during the course of a payment cycle, the survivor pay component is Participant j's relative share with respect to potential losses for every dollar of system-wide exposure to Participant i at default. The term $E\left[\sum\limits_{i\neq k\in N}\sum_{t=0}^{T-1}\left(P_{k,i}^t - P_{i,k}^t\right)\right]$ is the expected value of Participant i's multilateral net debit position at the time of default. Finally, $\left(1-\phi_i^{\tau}\right)$ is the actual proportion of multilateral net exposure Participant i accumulated that is not recoverable based on the collateral it pledged to the payment system. This reflects the fact that a defaulting financial institution, does not necessarily default on their entire multilateral net debit position at the end of the cycle but only on that portion over and above the value of the total collateral it apportioned to the System.

Where it is assumed that recovery rates, hazard rates (i.e. default probabilities), and default time are independent, the present value of the protection leg can be rewritten as:

$$\Psi_j(i) = \gamma_{ji}\left(1-\phi_i^{\tau}\right) E\left[e^{-\int_t^{\tau} r(s)ds}\mathbb{I}_{\tau<T}\right] \tag{6}$$

and with the further assumption that interest rates are independent of hazard rates Equation 6 becomes:

$$\Psi_j(i) = -\frac{\gamma_{ji}\left(1-\phi_i^{\tau}\right)}{V\left(t,t_m\right)}\int_t^{t_M} V\left(t,s\right) dQ\left(t,s\right) \tag{7}$$

which can be approximated as:

$$\Psi_j(i) = -\frac{\gamma_{ji}(1-\phi_i^{\tau})}{V(t,t_m)}\sum_{m=1}^{M} V(t,t_m)\left(Q(t,t_{m-1}) - Q(t,t_m)\right) \tag{8}$$

Given that the LVTS opens each day with participants individually making the decision as to whether or not to extend BCLs to others, it is possible to assume that the BCL establishment decision is a single period CDS transaction. As such, the non-deterministic components of the valuation of the protection leg (i.e. the discount factor, $V(t,s)$,and the hazard rate, $dQ(t,s)$) can be reduced to single period problem with a constant hazard rate;

$$\Psi_j(i) = -\frac{\gamma_{ji}(1-\phi_i^{\tau})(1-Q(t,s))}{(1+r_f)} \tag{9}$$

4.2 CDS Premium Leg: Liquidity Recycling

The premium leg of the CDS is defined as the liquidity recycling component of the LVTS tranche 2 collateral model. This leg can be specified as the expected value of liquidity available to be recycled in each payment exchange cycle. To the extent that intraday liquidity recycling up until the time of default results in multilateral net debit position offsets and overnight positions, surviving participants are able to accrue premium between instances of payments by selling CDS protection to the System. Therefore, the present value of this leg, assuming the premium leg and independence of interest rates, hazard rates and time of default, is specified in two part as; (1) the value of premiums only

$$\Phi_j^{premium\,only}(i) = \lambda\mu\varpi_\eta\left[\sum_{m=1}^{M}\Delta_m e^{-\int_t^m r(s)ds}\mathbb{I}_{m<\tau}\right] \tag{10}$$

or

$$\Phi_j^{premium\,only}(i) = \frac{\lambda\mu\varpi_\eta}{V(t,t_m)}\sum_{m=1}^{M}\Delta_m V(t,tm)\,Q(t,m) \tag{11}$$

which states that the value of the premium only component of the premium leg is the contractual default spread (i.e. the discounted value of the future payout on default) multiplied by the present value of a defaultable zero coupon bond that survives between times t and m. (2) the accrued premium

$$\Phi_j^{accrued\,interest}(i) = \lambda\mu\varpi_\eta \left[\sum_{m=1}^{M} \psi(o_m, \tau)\, e^{-\int_t^\tau r(s)ds} \mathbb{I}_{o_m<\tau<c_m}\right] \tag{12}$$

or

$$\Phi_j^{accrued\,interest}(i) = -\frac{\lambda\mu\varpi_\eta}{V(t,t_m)} \sum_{m=1}^{M} \left[\pi_m \int_{o_m}^{c_m} (s - o_m)\, V(t,s) \frac{dQ(s)}{ds} ds\right] \tag{13}$$

where, $\psi(o_m, \tau)$, is the date count fraction between the last instance of liquidity recycling, o_m, and the default time, τ; $-\frac{dQ(s)}{ds}$ is the unconditional probability of default between valuation time t and some time s between premium payments or liquidity recycling window $\{o_m, c_m\}$; and $\pi_m = \Delta_m / \psi(o_m, c_m)$ is the ratio date count fraction for premium payments or liquidity recycling measured as the accrual interval.

Lehman Brothers (2003), O'Kane and Turnbull (2003), and O'Kane (2008) have shown that the integral can be approximated by assuming that, if default occurs between two instances of liquidity recycling or premium dates, the average accrued interest is half the full premium due or the amount of liquidity that could have been recycled over the premium window. Consequently, equation 12 can be rewritten as

$$\Phi_j^{accrued\,interest}(i) = -\frac{1}{2}\frac{\lambda\mu\varpi_\eta}{V(t,t_m)} \sum_{m=1}^{M} \left[\pi_m V(t,t_m)\left(Q(t,t_{m-1}) - Q(t,t_m)\right)\right] \tag{14}$$

Combining both the premium only and the accrued interest components, the valuation of the CDS premium leg can be expressed as

$$\Phi_j(i) = \frac{\lambda\mu\varpi_\eta}{V(t,t_m)} \sum_{m=1}^{M} \begin{bmatrix} \Delta_m V(t,t_m)\, Q(t,t_m) \\ -\frac{1}{2}\pi_m V(t,t_m)\left(Q(t,t_{m-1}) - Q(t,t_m)\right) \end{bmatrix} \tag{15}$$

This is essentially stating that the value of the premium leg is the product of the discounted market premium adjusted value of the liquidity recycled and the RPV01 or Price Value of a Basis Point (PVBP) of a defaultable zero coupon bond.[7] Again since the working assumption is that LVTS Participants enter new CDS contracts on a daily basis and value these single period contracts accordingly, the premium leg can be reduced to

$$\Phi_j(i) = \frac{\lambda\mu\varpi_\eta}{(1+r_f)} * RPV01 \tag{16}$$

Together $\lambda\mu\varpi_\eta$ is the LVTS Tranche 2 equivalent to the coupon on the CDS, where ϖ_η is the potential liquidity, given established BCLs, which can be used in recycling payments during the course of the day, or rolling time interval, η. The term $\lambda = \left(1+\frac{1}{\theta}\right)$, for $\theta \geq 1$, is a liquidity premium adjustment, used to capture the marginal benefit of sourcing additional liquidity. The liquidity premium adjustment assumes that as the System's liquidity efficiency ratio, θ, increases beyond some optimal level, there is a diminishing value of each additional unit of liquidity that is available to be recycled. Conversely, as the market liquidity premium increases, typically in times of stress, the value of an additional unit of liquidity increases.

4.3 System Level Generalizations

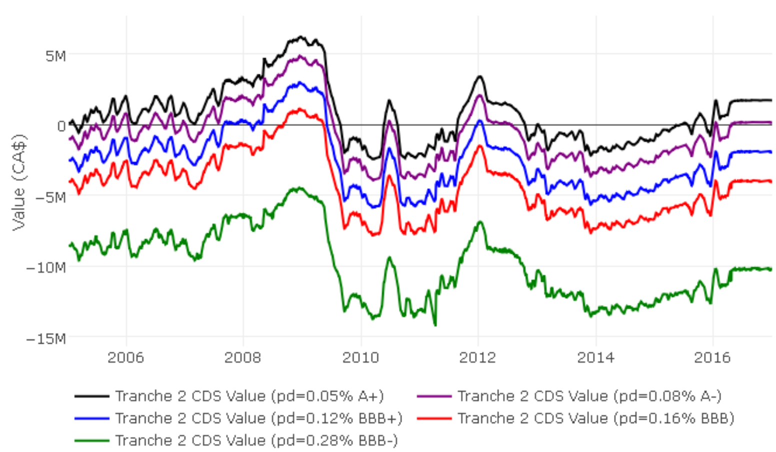
At the system level, given equations 3, 8, and 14, it is possible to not only determine the daily risk-neutral valuation of participation in Tranche 2 of the LVTS, but also the default probability implied by the extension of BCLs. Moreover, we are are able to numerically ascertain the default probabilities that would give rise to LVTS Participants withdrawing BCLs. For simplicity and tractability of this first iteration of the valuation model, whilst the analysis presented thus far is generalized at the participant level, empirical results will be aggregated to the System level.

[7] The PV01 or PVBP is a measure of the absolute value of the change in price of a bond for a one basis point change in yield. It is a further means through which interest-rate risk can be measured. A thorough review of interest rate models and bond and other fixed income instrument valuations can be found in Brigo and Mercurio (2006).

5 Results

Results are based on the simulation of the daily risk neutral pricing of loss sharing in Tranche 2. Presented in *Figure 6* are the five-day moving average valuation of the embedded CDS in Tranche 2 from the protection seller's perspective given the associated default rates. The results suggest that the daily value of the credit insurance sold by Participants in light of their activities within the LVTS is impacted to some extent by the market premium on liquidity. Indeed the results indicate that it is particularly in those moments where the market places a high premium on liquidity that the extension of bilateral credit limits becomes increasingly more valuable to System Participants. The value of extending BCLs are observed to be at their lowest during periods of near 0% liquidity premium. Given that the analysis covers a time where the global economy was under stress and subjected to extensive levels of ongoing government and central bank intervention in bolstering markets through policies geared at increasing the supply of liquidity, the losses in the value of BCL extension post crisis can in part be attributed to these policies.

Figure 6: Simulated Valuation of Loss Sharing Under Tranche 2 (2005-2016)

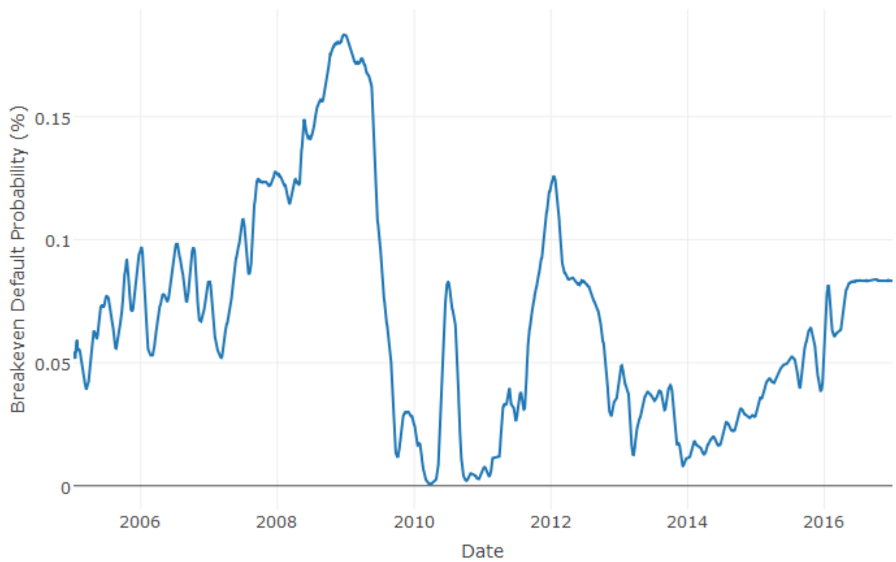


Notes: The simulated valuations represents the five-day moving average and assumes risk neutrality

This liquidity premium effect is nevertheless, tempered by the operating default rates. More specifically, as default rates increase, the daily value of the embedded CDS drops. That is, as the probability of default increases, protection selling is observed to become less in the money; to the point that at default rates aligned with those historically witnessed in BBB+ rated corporates globally, the pay-offs from protection selling become predominantly negative. For both default rates associated with BBB+ and BBB, an approximately 3.5% liquidity premium would be required to make the extension of BCLs worthwhile.

Figure 7 plots the five-day moving average of the simulated path of the empirically implied break-even default probabilities associated with protection selling through the establishment of BCLs. The break-even default probability represents the probability of default at which the Tranche 2 CDS breaks even given all other inputs into the valuation of the contract are known. It may be thought of as the default rate at which LVTS Participants are indifferent between extending bilateral credit limits or not under the risk neutral pricing. That is, it is the level of credit risk Participants price into their BCL decisions and an indication of the credit risk they are willing to absorb given all other factors.

Figure 7: Break-even Default Probabilities of Loss Sharing Under Tranche 2 (2005-2016)



Notes: The simulated break-even probability of default represent the 5-day moving average and assumes risk neutrality

There are a number of striking observations evident from the results in Figure 7. Firstly, aside from the period during the height of the 2007-2009 financial crises and the post crises period of quantitative easing, the break-even default probability has tended to fluctuate between 0.05% and 0.1%.[8] With regards to the Participants' expectations of the credit quality of others within the LVTS, these default rates indicate a belief that, on average, no Participant will maintain credit ratings or default likelihood below that of an A- rated corporate. A second striking observation is that at the height of the 2007-2009 crises, Participants, by continuing to sell protection through the establishment of BCLs, were willing to absorb default probabilities of 0.18%—default rates typically associated with BBB+ to BBB rated corporates. That said, this 0.18% break-even default rate was still short of the 0.41% corporate default rates observed in relation to AA and 0.60% for A- rated corporates in 2008.[9] Therefore, while these default rates returned to their near 0% rates

[8]Due to the analysis centring around moments of financial crises primarily due to limited LVTS data, a longer time horizon would be needed to identify the long-run mean of the break-even default probability.

[9]It should be noted that global corporate ratings modifiers higher than AA (i.e .AA+ and AAA) remained unaffected by

by 2009 and 2010, the results suggest that, purely from a risk neutral perspective, there may have been pressure in 2008 to cut BCLs. This arises from the observation that given such high default rates, protection selling would have been significantly out of the money, even with the peak in liquidity premium.

The results further illustrate the importance of the way in which policy makers assess access to clearing and settlement functions within payment systems or CCPs. Whilst the implied break-even default rates do appear responsive to market pressures in terms of credit risk absorption, by Participants, spikes in excess of these break even rates would, all else being equal, have put the LVTS loss sharing arrangement under pressure. This raises the question of what credit risk in loss sharing models really means. In the case of the LVTS and payment systems more broadly, credit risk has been interpreted from the standpoint of intraday multilateral net debit positions used to determine the potential credit losses upon the default of a Participant. Credit risk management in these systems has therefore been focused solely on collateralising all ("cover-all") or some percentage ("cover one") of these exposures. What these results suggest is that the efficacy of loss sharing may be tied to the ability of Participants to withstand economic stresses. Consequently, credit risk management should be linked to risk-based access policies geared towards ensuring Participants maintain economic stress tested ratings or other credit quality measures.

Moreover, even in a world where positions are fully collateralized through intraday liquidity provisions by the central bank in the form of Repos, to what extent is the central bank willing to hold on to collateral pledged by Participants that are highly susceptible to default in times of stress? What would be the wider knock-on implications to the economy if and when the central bank does choose to contract its balance-sheet? It has certainly been noted (see Ferguson et al. 2014) that historically, clusters of large expansions and contractions in the balance sheets of central banks have been associated with periods of geopolitical or financial crisis—the largest

the 2007-2009 financial crises and maintained their 0% default rates.

of these being World War II and the 2007-2009 global financial crises. Thus giving rise to co-movement between the size of central bank balance sheets and public debt levels, as well as, on average, with the larger expansions, a longer period to unwind and very much dependent on the composition of the balance sheet. Indeed, Fergerson et al. 2014 indicate that successful contractions of central bank balance sheets have come from the maturing of short-term lending programs or assets and never from the sale of longer-term government or private sector securities.

6 Conclusions

Based on institutional knowledge of the LVTS, this paper notes that the System's loss sharing mechanism, Tranche 2, bares a sufficient number of similarities with credit default swaps in the sense that not only do LVTS Participants insure the System against defaults, they also, in return for establishing BCLs, are able to continuously recycle liquidity intraday at minimal cost. As such, it is possible to decompose Tranche 2 into a default contingent leg and a liquidity generation or recycling premium leg. Viewed as such Tranche 2 is not merely, for want of a better expression, a liquidity saving mechanism, but also a credit default swap in which the value of participation is dependent on the trade-off between the expected payout upon a default and the premium associated with the level of liquidity recycling. Given this decomposition, the paper numerically priced embedded Tranche 2 CDS using empirical data between January 2005 and December 2016.

The results showed that, given the historical average default probability of corporates with similar credit ratings as the LVTS direct clearers, in times of stress, particularly when the liquidity premium is high, protection selling (i.e. establishing BCLs) under Tranche 2 CDS has empirically tended to be in the money. Indeed only where the liquidity premium was sustained at rates below 1% was the establishment of BCLs not optimal under the risk neutral pricing. This tends to support the importance of liquidity risk and use of BCLs and the Tranche 2 loss sharing and liquidity saving mechanism as a tool to guard against the procyclicality in collateral management in clearing and settlement systems.

The paper further illustrated the extent to which default rates impact the value of selling credit protection under the Tranche 2 CDS. It was shown that as default rates increase, the value of protection selling declines; as represented by the downward shift in the simulated path of the Tranche 2 CDS price between 2005 and 2016. This downward shift would suggest policy makers are correct in their fears as it pertains to procyclicality in BCL extension. However, this concern is only supported in so far as Participants' experience catastrophic colapses of their default probabilities. Moreover, given the empirically observed average default probability of LVTS Participants, the results explain why they have continued to maintain a skin in the game through establishing BCLs with one another and the Tranche 2 CDS has been empirically profitable for the Participants.

Further discussed is the extent to which the implied default probabilities can advise policy on access to clearing and settlement systems. To this end, the risk neutral break-even default rates were computed. These probabilities suggested that any form of risk-based access to clearing and settlement functions should be focused on the ability and active monitoring of Participants to weather economic stresses. Accordingly, it was suggested that entities engaged in clearing and settlement should be monitored in terms of maintaining credit ratings or other ongoing financial health checks that ensure they are more resilient to stresses.

Due to data limitations, this paper was centred on a period of time in which markets were turbulent. Therefore, further research will be required to identify the long-run break-even default rates. The paper also does not address the question of how one would derive the intraday yield and credit curves or default correlation when pricing the Tranche 2 CDS. Notwithstanding, the results have illustrated the manner in which loss sharing through the use of bilateral credit limits can help in abating procyclical collateral management and as a tool to monitor the resilience of direct clearing within clearing and settlement systems.

It should be noted that this paper has not purported to introduce ground breaking research or techniques into the literature on the valuation of CDS contracts. Rather, it introduced a novel approach to assessing the merits of BCLs as utilized in Tranche 2 of the LVTS by using existing practice to empirically evaluate the value of Tranche 2 and similar clearing and settlement mechanisms. The paper also did not consider dimensions of complexity in the valuation of CDS contracts such as correlated defaults or the default of protection sellers or the protection buyer. These have been assumed away at this stage in the research since collateral under Tranche 2, and presumably in a CCP waterfall that relies on BCLs to avoid procyclicality, is pledged in advance of the credit event and claimed back, in part or whole, at the end of the cycle. Also out of scope of this analysis is the modelling of intraday yield or credit curves (see for example Monticini and Ravazzolo, 2011, Kokoszka et al., 2014 and Demertzidis and Jeleskovic, 2016), such an exercise has been left for future research.

Finally, whilst the similarities between the LVTS loss sharing arrangement and those of CCPs mean the CDS valuation approach could be easily transferable, a similar valuation approach can be applied to real time gross settlement (RTGS) systems based on an understanding of their credit risk and liquidity-based cash flows. For instance it may be possible to model an RTGS as a collateralised debt or equity obligation (CDO or CEO). To see this, consider that in an RTGS, institutions pledge collateral in exchange for liquidity with which to conduct the intraday settlement of payments. These collateral pledges, unless held in form of cash reserves at the central bank, have haircuts applied to them as determined by the central bank. These haircuts may or may not be tied to the likelihood of the institutions' default probabilities. Where the institutions' default probabilities are excluded from the haircut calculations, only the quality of the pledged collateral portfolio is considered. Consequently, the haircut may be viewed as the equity or first loss tranche of the CDO maintained by the institutions. This leaves the participants with the opportunity to select a collateral portfolio constitution that is the cheapest to deliver in terms of central bank accepted encumbered liquid assets. The liquidity premium attached to these encumbered assets would define the tranche and waterfall structure of the implied CDO. Depending on the pricing of risk implied by the applicable haircuts and RTGS participants' default risk and liquidity requirements outside the payment system during times of market stress, the central bank may, as a result be at risk of maintaining a large pool of illiquid assets on its balance sheet. Again, further research is required to better understand the valuation and thus systemic dynamics of an RTGS.

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Appendix A

Table 1: List of Symbols

α	system wide percentage
$\beta_{j,i}$	bilateral credit limit Participant j extends to reference Participant i
r_f	risk free rate of return
$P_{j,i}$	payment flow from Participant j to Participant i
μ	liquidity premium
λ	liquidity premium adjustment factor
θ	liquidity efficiency ratio as a percentage
γ_{ji}	Participant j's Max ASO on Participant$i$'s default
ρ	probability of Participant i defaulting
$\mathbb{I}_{\tau<T}$	the binary indicator parameter specifying if default occurred prior to the maturity of the CDS
τ	instance of the default
η	interval between premium payments
ϕ_i^τ	reflects the recovery rate on multilateral net debit positions Participant i accumulates over a cycle
N	the set of all Participants in the system
$\Psi_j(i)$	the expected present value of the contingent leg
$\Phi_j(i)$	the expected present value of the premium leg
M	periods leading up to maturity or default
D	the subset of all N agents in the system that extend BCLs to agent i
$V(t,s)$	the value of a zero coupon bond at valuation time t with time s maturity
$Q(t,s)$	the survival probability of the reference obligation between the valuation time t and the premium payment time s
Δ_m	the day count fraction between premium data m