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Abstract

The Large Value Transfer System (LVTS) loss-sharing mechanism was designed to ensure that, in the event of a one-participant default, the collateral pledged by direct members of the system would be sufficient to cover the largest possible net debit position of a defaulting participant. However, the situation may not hold if the indirect effects of the defaults are taken into consideration, or if two participants default during the same payment cycle. The authors examine surviving participant total losses under both one- and two-participant default conditions, assuming the potential knock-on effects of the default. Their analysis includes the impact of a decline in value of LVTS collateral following an unexpected default.

Simulations of participant defaults indicate that the impact on the LVTS is generally small; surviving participants do incur end-of-day collateral shortfalls, but only rarely and in small amounts. Under the two-participant default scenario, the likelihood of the Bank of Canada having to provide funds to ensure LVTS settlement is reasonably low, as is the average residual-coverage amount. The majority of LVTS participants pledge as collateral securities issued by other system members. However, the impact of an issuer of such collateral defaulting is generally not significant in the LVTS.

JEL classification: E47, G21
Bank classification: Financial stability; Payment, clearing, and settlement systems; Financial institutions

Résumé

Le mécanisme de répartition des pertes que comporte le Système de transfert de paiements de grande valeur (STPGV) a été conçu pour qu'en cas de défaillance d'un participant, les garanties données par les participants directs suffisent à couvrir la position débitrice nette la plus élevée possible du défaillant. Toutefois, si l'on prend en compte les répercussions indirectes des défaillances, ou si deux participants font défaut pendant un même cycle de paiement, il se peut que ce garde-fou ne tienne plus. En choisissant de tenir compte des effets en chaîne potentiels, les auteurs analysent le montant total des pertes subies par les participants solvables dans l'éventualité d'une défaillance aussi bien de la part d'un participant que de deux participants. L'analyse porte également sur l'incidence que pourrait avoir, après une défaillance imprévue, une diminution de la valeur des nantissements offerts dans le cadre du STPGV.

Des simulations de défaillances indiquent que les conséquences sont généralement modestes pour le STPGV; les participants solvables se trouvent certes à court de garanties en fin de journée, mais seulement en de rares occasions et pour des montants peu élevés. Dans le cas où deux participants connaîtraient une défaillance, la probabilité que la Banque du Canada se voie dans l'obligation de fournir des fonds pour garantir le règlement est raisonnablement faible, tout comme le montant moyen des garanties

résiduelles. Même si la majorité des participants au STPGV donnent en nantissement des titres émis par d'autres participants, la défaillance de l'un de ces émetteurs n'a dans l'ensemble pas d'impact important à l'intérieur du STPGV.

Classification JEL : E47, G21
Classification de la Banque : Stabilité financière; Systèmes de paiement, de compensation et de règlement; Institutions financières

1 Introduction

Under the collateralized risk-sharing arrangements in the Large Value Transfer System (LVTS), participants may incur losses in the case of a participant default. However, the system was designed to ensure that collateral pledged by participants would be sufficient to cover the largest LVTS net debit position resulting from the default of a single participant. Recent work at the Bank of Canada studied the impact of a participant default in the LVTS, and concluded that participants could manage their potential losses under such circumstances (McVanel 2005; Ball and Engert 2007).

The risk controls within the LVTS include a survivor-pay mechanism that could result in losses for system participants in the event of unanticipated defaults. McVanel (2005) studies the robustness of LVTS participants to unanticipated participant defaults. Using data provided by the Canadian Payments Association (CPA), the study generates a series of defaults to examine the impact of allocated losses on surviving participants, and finds that loss allocations are generally small.

Ball and Engert (2007) extend that study by using data over a longer period and a revised version of the Bank of Finland Payment and Settlement Simulator (BoF-PSS) to assess potential losses to LVTS participants. They also conclude that losses from a participant failure are likely to be small relative to capital, and would be readily absorbed by survivors.

In this paper, we extend the previous work in three ways. First, in addition to loss allocations from a defaulter's own collateral shortfall (i.e., surviving participant additional settlement obligations), we study a potential loss in the value of collateral pledged to the LVTS due to the use of defaulter-issued securities as collateral. Second, we further investigate collateral shortfalls that surviving participants can potentially face at the end of the day, which can be considered as spillover effects of a participant default. Third, we conduct quantitative analyses for a scenario where two participants become non-viable on the same day. While the likelihood of such events is remote, recent international developments suggest that multiple-default scenarios are possible and should be evaluated for their impacts on system participants.

We derive three main findings from our study. First, the possible impact of collateral devaluation under default conditions is generally insignificant. Surviving participant total losses are, on average, small compared to their Tier 1 capital. Under extreme circumstances, a couple of participants suffer a large total loss due to the use of defaulter-issued securities as collateral. Second, surviving participants do incur end-of-day collateral shortfalls, in both one-participant and two-participant default scenarios, but only rarely and in small amounts. Third, when two participants default on the same day, the likelihood of the Bank of Canada needing to provide

additional funds to guarantee LVTS settlement is around 3.5 per cent, and the average amount is about $3.3 million.

The paper is organized as follows. Section 2 reviews the use of securities issued by other participants as LVTS collateral. Section 3 describes the data and methodology used in the simulation of default scenarios, and section 4 examines the results of the simulations. Conclusions are presented in the final section.

2 Use of Participant-Issued Securities as LVTS Collateral

Participants cannot pledge securities that they have issued themselves as LVTS collateral. However, they can pledge as collateral, subject to certain conditions, securities issued by other LVTS participants, including the following (subject to minimum issuer credit ratings)[1]: bankers' acceptances and promissory notes (maximum term 364 days), commercial paper (maximum term 364 days), and corporate bonds. Such securities are included in this study because the default of a participant could affect the market value of the collateral pledged by surviving participants.

The conditions applied to the use of these securities as collateral are intended to mitigate financial risk to the payments system. The main conditions are as follows:

i) only Canadian-dollar securities are eligible to be pledged as collateral;
ii) securities used as collateral must be pledged using CDSX of the Canadian Depository for Securities Ltd., or be physically delivered to the Bank of Canada in certificated form;
iii) no more than 20 per cent of the value of the collateral pledged by an institution should be the obligation of a single private sector issuer or related party; this condition does not apply for borrowings of less than $50 million;
iv) securities issued by the pledger of collateral (or any related party) cannot be used as collateral by the pledger;
v) the security must not have an embedded option or carry a right of conversion into equity securities.

Relatively large amounts of securities issued by other participants are pledged for LVTS purposes. As Figure 1 shows, securities issued by other participants generally represented 14 per cent to 18 per cent of total LVTS collateral during the sample period from 2007Q3 to 2008Q2. As Table 1 shows, many participants were issuers of securities used as LVTS collateral by other participants. Four of the big six Canadian banks were the largest issuers, with a daily average amount pledged of $1,028 million each, in total representing roughly 13 per cent of total LVTS

[1] The minimum short-term ratings are R1 (low) by the Dominion Bond Rating Service (DBRS), A-1 (mid) by Standard & Poor's (S&P), and P1 by Moody's Investors Service (Moody's). The minimum long-term ratings are A (low) by DBRS, A- by S&P, and A3 by Moody's.

collateral. Most of the remaining participants were relatively small issuers of securities posted as LVTS collateral.

Figure 1: Collateral Issued by Other Participants as a Percentage of Total Collateral Pledged

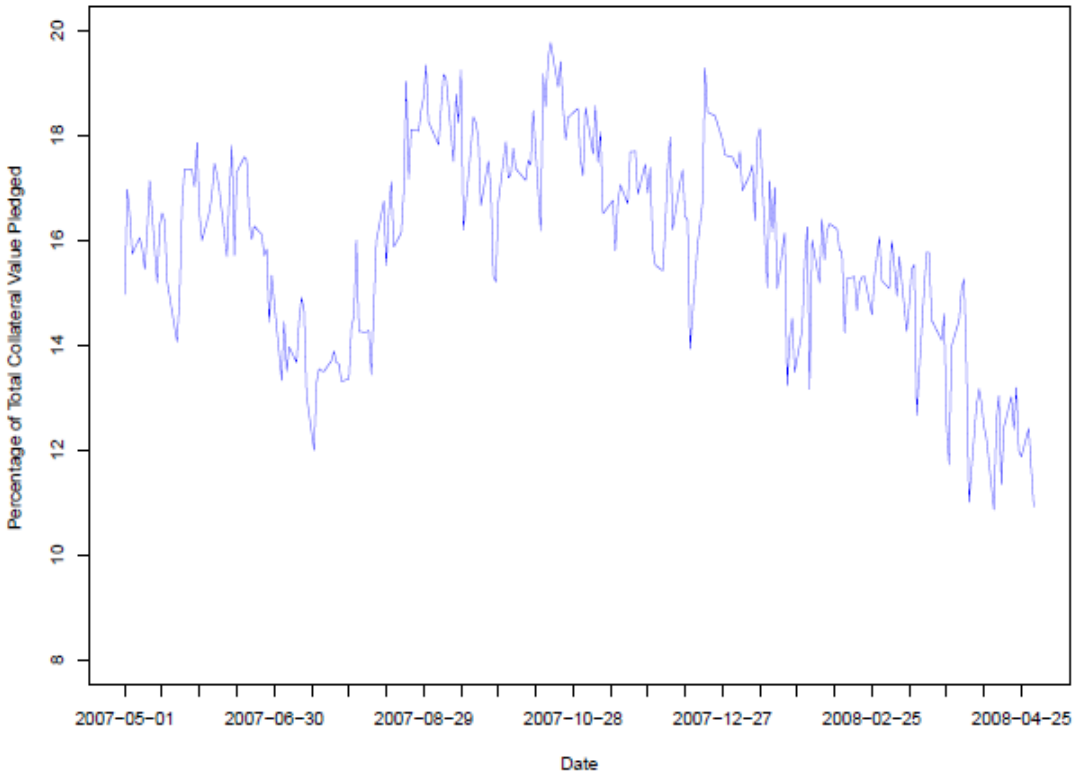


Table 1: Issuers of Securities Used as LVTS Collateral by Other Participants ($ millions)

Issuer	Mean	Std. dev.	Per cent
Four largest issuers (total)	4,112	603	13.3
Next four largest issuers (total)	812	125	2.6
Other issuers (total)	49	42	0.2

Most LVTS participants pledge securities issued by other participants as collateral. A majority of participants pledged some amount of such collateral on each day of the sample period studied; however, some participants, including two of the big six banks, did not use any securities issued by other participants as collateral. Of the participants that use such collateral, Table 2 shows the average amount pledged for LVTS purposes, as well as the percentage of each participant's total pledge that was this type of collateral. The largest users pledged over $1 billion of such securities, on average; in one case, the amount exceeded $2 billion. For some participants, securities issued by other participants represented about 30 per cent or more of that participant's

collateral. In one case, such collateral represented over 50 per cent of a participant's collateral, on average.

Table 2: Amounts of Securities Issued by Other Participants Pledged as LVTS Collateral ($ millions)

Participant	Mean	Std. dev.	Percentage
L	2,117	555	32.6
G	1,239	261	39.0
K	453	79	35.4
J	340	101	13.5
I	297	126	52.1
D	249	61	38.7
A	120	50	39.8
B	60	63	26.1
F	29	97	1.4
C	9	6	0.4

The approaches in pledging securities issued by other participants as LVTS collateral vary by participant, but have a few basic patterns. The typical approach (e.g., Participant L in Figure 2) involves pledging securities issued by four to six other participants for extended periods of time. Some participants (e.g., Participant I in Figure 3) use a broader list of eight to ten issuers, while others use a narrower list (charts for other LVTS participants are shown in Appendix A). Some participants pledge individual issues for extended periods of time (a month or longer), while others change their pledges much more frequently. As noted above, some participants do not use this type of collateral for the LVTS. These approaches are typically driven by the securities that are held on the participant's balance sheet and available for collateral purposes.

Figure 2: Securities by Issuer (Other Participants) Pledged by Participant L

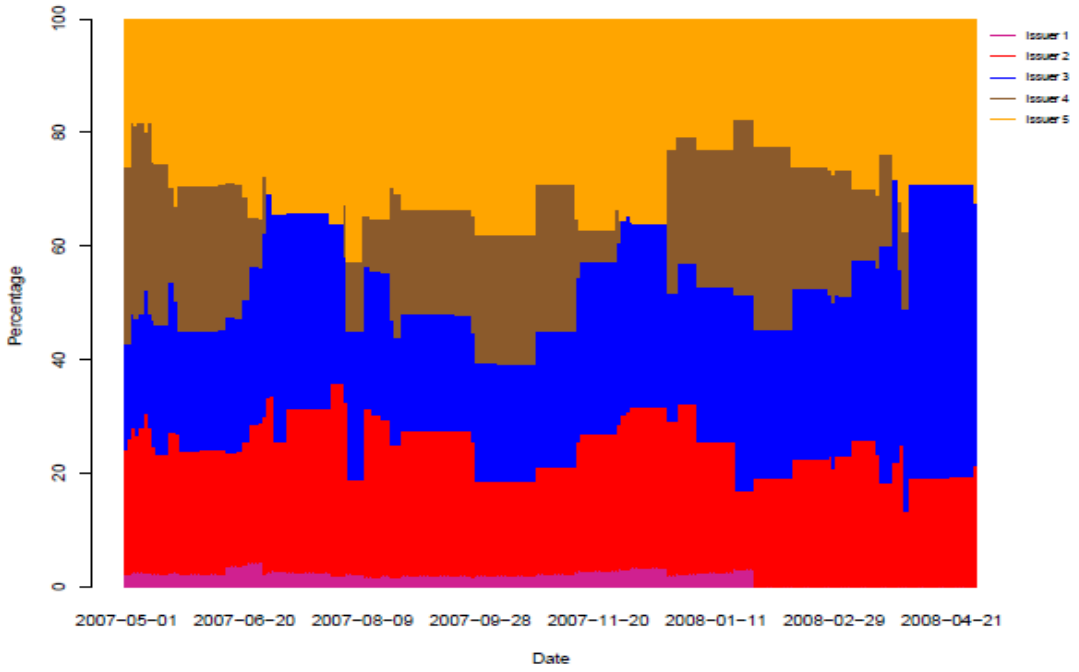
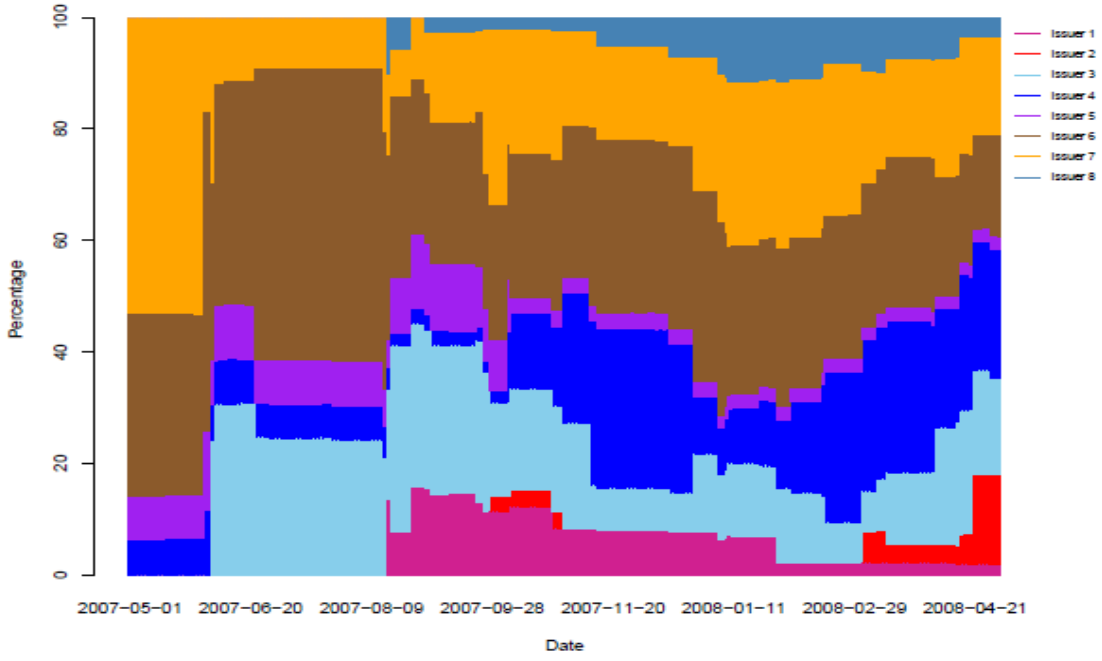


Figure 3: Securities by Issuer (Other Participants) Pledged by Participant I



3 Default Simulations

The unexpected participant defaults studied in this paper fall under the category of non-viability of LVTS participants. This means that a participant is unexpectedly declared non-viable during an LVTS payment cycle by its financial regulator, and thus suspended from further participation in the payment exchange.[2] In the simulations, it is assumed that other surviving participants continue LVTS transactions amongst themselves until the end of the day, and the payments to and from the non-viable participant after the announcement are disregarded.

In this paper, we extend the previous default studies in three ways. First, in addition to the overall loss allocations to the surviving participants (i.e., the additional settlement obligation) as examined in past studies, we examine the potential loss in the value of collateral pledged to the LVTS, namely an unexpected decrease in the value of the securities issued by the defaulting participant. Hence, in this study, a surviving participant's total loss is defined as the sum of its additional settlement obligations (ASO) and the value of its defaulter-issued securities posted as LVTS collateral.

Currently, LVTS collateral requirements allow each direct participant to pledge another financial institution's securities as collateral up to a limit of 20 per cent of the total value pledged.[3] A sensitivity analysis is carried out to examine the effect of a hypothetical increase of this limit to 50 per cent of the total pledge on the outcome of simulated participant defaults.

We assume in this paper that the market value of the securities issued by a defaulting participant declines to zero following a non-viability announcement. This assumption is conservative, since recovery rates for some asset classes can exceed 50 per cent. However, there can be considerable delays in the recovery of funds in the event of a default.[4]

For the second way in which we extend the previous default studies, we assume that LVTS transactions continue among surviving participants until the end of each payment cycle, and investigate the potential collateral shortfall that each survivor can face at the end of the day. These shortfalls can be considered as the spillover effect of a failure on the surviving participants.

Third, we expand the qualitative discussions in previous studies about the impact of multiple-participant defaults in the LVTS into quantitative analyses. Simulations are conducted for a

[2] More details about LVTS settlement in the case of non-viability of participants are provided in Arjani and McVanel (2006) and Canadian Payments Association (2010).
[3] This constraint is relaxed for overnight advances of less than $50 million.
[4] In reality, it is likely that the financial shock resulting from a default of a large institution could cause a devaluation of the securities issued by other surviving participants. However, such contagion in the financial markets is not taken into account in this study, because it is reasonable to argue that the possible domino effect would be minor compared to the consequences of the initial default.

scenario where two participants become non-viable on the same day, and the analyses include the Bank of Canada's total exposure to two participant failures. The Bank's exposure consists of the Bank's own ASO (i.e., due to granting bilateral credit limits (BCL) to the defaulting participants) and its ultimate responsibility for settling the LVTS.

3.1 Data

This study makes use of historical LVTS payment flows (both Tranche 1 and Tranche 2), using bilateral and multilateral credit limit (BCL and MCL) data provided by the Canadian Payments Association. The sample period spans from 1 May 2007 to 30 April 2008, consisting of 253 LVTS operating days. The end of the sample was chosen because of the possibility that the change in the LVTS system-wide percentage in May 2008 might have affected participant behaviour. The 1-year sample period provides a sufficiently large sample size for the simulations. Over this sample period, about 21,615 payments worth $185.3 billion were settled in the LVTS, on average, each day.

Collateral data for the same sample period are also used in this analysis. For each day in the sample, the data contain information about every collateral item pledged by LVTS participants, including the International Securities Identifying Number,[5] the security type, security issuer name, par value, discount value, pledge purpose, coupon rate, maturity date, etc. Three distinct types of pledge purposes are indicated in the collateral data: LVTS, advances, and bank note withdrawal. Only the collateral pledged for LVTS purposes is used in this analysis.

As in previous studies, LVTS participant regulatory Tier 1 capital is used as a frame of reference to determine the relative magnitude of losses to surviving participants. For most participants, Tier 1 capital is obtained from the capital-adequacy reports of the Office of the Superintendent of Financial Institutions (OSFI). For some participants, the capital data are collected from their annual reports for 2008, and the amount used is the average Tier 1 capital of 2007 and 2008.[6]

3.2 LVTS settlement under non-viability of LVTS participants

When a financial regulator declares that a participant has become non-viable and that participant is in a net debit position, the Bank will first liquidate that participant's apportioned collateral to cover their debit position. If the participant remains in a net debit position after this procedure, the Bank will collect each surviving participant's ASO in order to satisfy the remaining debit position. In this simulation study, it is assumed that the loss allocation occurs at the end of each payment cycle.

[5] The International Securities Identifying Number is a number that uniquely identifies a security.
[6] These participants are BNP Paribas, Bank of America, La Caisse Centrale Desjardins du Quebec, State Street Bank and Trust Company, and Credit Union Central of Canada (CUCC). The Tier 1 capital of CUCC is represented by the sum of the capital (or equity, if capital is unavailable) of all provincial credit union centrals.

According to the LVTS rule on devaluation of collateral, under unusual circumstances where an intraday revaluation of collateral is conducted, the participants whose reassessed LVTS collateral is lower in value than the requirement must pledge additional collateral to meet the system requirement.

3.3 Simulation methodology

The basic methodology adopted in this study is similar to the approach used by McVanel (2005) and Ball and Engert (2007), but with certain refinements. The methodology is as follows.

In addition to fully replicating the LVTS environment, the simulation program used in this study also assumes that each individual participant has an internal queuing mechanism to help optimize its liquidity usage. All these internal queues are simulated based on a simple first-in-first-out (no-bypass) algorithm.[7,8] It is crucial to include some type of participant internal queuing arrangements in a default simulation study because surviving participants would respond to the cancellation of defaulter-associated transactions from their original payment schedules. The internal-queuing functionality allows the participants in the simulation to react to an unexpected default in the system at run time, retiming and submitting their outgoing payments accordingly whenever liquidity is available. This assumption is intended to make the simulation results more accurate.

The simulation begins with a base-case execution (i.e., running the historical data through the process without modifications), in order to obtain a simulated settlement time for every transaction.[9] This process is necessary to accurately handle queued Jumbo payments in the computation of participant funds positions.

Based on the output of the base-case simulation, the participant's own collateral shortfalls (OCS) are calculated at the transactional level and an intraday maximum is picked for every participant each day. OCS has the same definition as in previous studies: $OCS = (NDP_{T1} + NDP_{T2}) – (C_{T1} + C_{T2})$. NDP_{T1} and NDP_{T2} are an LVTS participant's multilateral net debit position in Tranche 1 (T1) and Tranche 2 (T2) payment streams, respectively. C_{T1} and C_{T2} are the participant's collateral required for T1 and T2, respectively. In previous studies, a defaulter's OCS was obtained by comparing the participant's maximum daily net debit position against the end-of-day value of its collateral holdings. The daily maximum OCS in this analysis is computed based on all intraday values.

[7] For detailed information on queuing arrangements and release methods, please see BIS (2005).
[8] See Appendix B for a more detailed description of the simulation program.
[9] The transactions data provided by the Canadian Payments Association (CPA) currently do not contain the settlement time stamp.

For each day in the sample period, every LVTS participant except the Bank of Canada is assumed to default, independently from one another, at the moment during the general payment exchange period when its largest own collateral shortfall occurs. More specifically, in the one-participant default scenario, 3,542 (253 days * 14 participants) default cases are simulated and examined; for the same-day two-participant default, a total of 46,046 (253 days * 182 pairs of participants) simulations are carried out.

For cases where the defaulter's intraday maximum OCS <= 0, there is no loss allocation to other surviving participants. However, other impacts still exist. First, after one participant is suspended from the LVTS, all the transactions as well as potential changes in credit limits vis-a-vis the defaulter disappear from the system, and that would affect every survivor's end-of-day funds position. Second, the potential devaluation of defaulter-issued securities can have an effect on the values of surviving participant collateral holdings. In such cases, the choice of default time does not matter in terms of creating a worst-case scenario from the defaulting participant's perspective, and it is hard to determine a default time that is the worst in aggregate for all survivors. A fair and easy approach used in this paper is to randomly pick as the default time, with equal probability, a time during the general payment exchange period.[10]

A second simulation uses three types of additional parameters (besides the transaction and credit limit data): a date, defaulting participant names, and the time at which each defaulter is announced to be non-viable. Several events that occur after the default time are excluded from the simulation: (i) all the payment flows to and from the defaulter(s); (ii) any changes in the BCLs of surviving participants vis-a-vis the defaulting participant(s); and (iii) any changes in the defaulter's T2 net debit cap (T2NDC) and T1NDC values. However, the post-default BCLs between the defaulter(s) and all other surviving participants are not immediately adjusted to zero: according to LVTS Rule 13 (Canadian Payments Association 2010), these BCLs will not be reset to zero until the beginning of the next LVTS cycle. Based on this rule, in this analysis, it is assumed that surviving participants' T2NDC and the BCLs from the Bank of Canada are not recalculated (and hence not reduced) due to the suspension of the defaulting participant(s).

The simulation program generates three outputs: every settled payment with a settlement time stamp, every rejected payment that cannot settle at any time before the end of the payment cycle, and every BCL change among the participants.[11] The BCL output provides more accurate post-default BCL values for the calculation of loss allocations. For example, in the computation of loss allocations to the surviving participants, the BCLs granted to the defaulters are the largest values during the payment cycle, up to the default time.

[10] Precisely, a random second is picked from a total number of 17*60*60+30*60 seconds in one payment cycle.
[11] The BCL output would have been the same as the BCL data provided by the CPA, had the process been a base-case simulation. In a default simulation, it deviates from the historical data due to the removal of any changes after the default time between the defaulters and surviving participants.

The pre-settlement of the LVTS that occurs between 18:00:00 and 18:30:00 is ignored in the simulation, due to the difficulty of making assumptions about participant behaviour in response to their end-of-day funds positions. This omission may exaggerate the collateral requirements for the surviving participants with end-of-day net debit positions, because in reality there is an opportunity for them to flatten their positions without the need to take an advance from the Bank of Canada. On the other hand, it can be regarded as a contributing element in simulating a worst-case scenario.

The first step in the simulation of a two-participant same-day failure is to obtain the largest OCS value for each of the thirteen surviving participants from the results of the one-participant default simulation, as well as the times at which these maximum OCSs occur. For every default case in the one-participant default simulation, there are thirteen surviving financial institutions. In this third simulation process, each of the thirteen survivors, in turn, becomes non-viable at the time when it incurs its largest intraday OCS, given one other defaulter already in the system. This approach results in a total of 46,046 two-participant default cases.

3.4 Variables and assumptions

3.4.1 Loss allocations

In the LVTS, settlement under default conditions includes a loss-sharing mechanism among the surviving participants. If the collateral apportioned by a defaulter is not sufficient to cover its net debit position at the time of default, then the shortfall will be allocated to every surviving participant who has granted bilateral credit to the defaulter on that day. Each survivor's proportion of the defaulter's collateral shortfall, also known as its additional settlement obligation, is equal to the ratio of its maximum BCL granted to the defaulter to the sum of the largest BCLs that the defaulter received from every system member on that day.[12]

In this study, we assume that, despite the unexpected suspension of some participants, the transactions among all surviving participants continue through the payment cycle. Hence, each survivor needs not only to meet its ASO, but also has its own end-of-day funds position to settle. If a surviving participant incurs a final net credit position at the end of day, the funds surplus will be ignored in the analysis. If a participant has incurred a final net debit position, then it is required to have enough collateral to be eligible for an advance from the Bank of Canada in an amount equal to the value of its position. In sum, under default conditions, the total settlement obligation (TSO) of a surviving participant is equal to:

TSO = Own final funds position + ASO.

[12] See Arjani and McVanel (2006) for more details on loss allocations in LVTS settlement under default situations.

It is assumed that, under default conditions, the Bank of Canada would grant an advance to each survivor equal to its ASO, regardless of its final funds position. Therefore, in all simulation cases, surviving participants are required to have sufficient collateral pledged to the system, dollar for dollar, for their ASOs. The total settlement obligation of a surviving participant with an end-of-day credit position is simply the ASO.

In this paper, we allow for the possibility of a defaulting participant being the issuer of the securities pledged as LVTS collateral by other participants. Based on the assumed devaluation of such securities to zero, each surviving participant's total collateral pledged to the LVTS is revalued at the end of the day, or more specifically, discounted by the value of its defaulter-issued securities used as collateral, if there are any.

We also investigate the potential knock-on effects of a failure on the surviving participants.[13] In each default case, every survivor's total settlement obligation is compared against the end-of-day value of its collateral pledged to the LVTS (i.e., discounted by the value of its defaulter-issued securities used as collateral). The difference is the survivor's collateral shortfall (SCS), more specifically given by:

$$\text{SCS} = \text{TSO} - (\text{Collateral pledged to LVTS} - \text{defaulter-issued securities used as collateral}). \quad (1)$$

If SCS > 0, the surviving participant will need to pledge additional collateral to fulfill the requirement; failing to do so will force the participant into a position of a secondary technical default.

Rearranging the terms in the equation above, one can rewrite the SCS in a different way:

$$\text{SCS} = (\text{Own final funds position} - \text{collateral pledged to LVTS}) + (\text{ASO} + \text{defaulter-issued securities used as collateral}). \quad (2)$$

The first grouped term approximates the survivor's end-of-day own collateral shortfall anticipated prior to a default. It is an approximation because every survivor's payment flows, including payment timing, are adjusted after the default has occurred, which might lead to a different final funds position than originally anticipated. The second grouped term – the sum of a survivor's ASO and its re-evaluated collateral holdings at the end of day – is the total loss (TL) of a survivor under default conditions. The total loss is the part of a surviving participant's settlement obligation that is explicitly triggered by the default event:

[13] This paper examines the knock-on effects of the first-round participant default. It is certainly possible to extend such analysis to multiple rounds in future work.

TL = ASO + defaulter-issued securities used as collateral.

According to LVTS rules, a defaulting participant is considered to have a collateral shortfall if its final net debit position is greater in value than its collateral apportioned to the system, which is the sum of its T1NDC and maximum ASO (Max ASO). In this study, defaulter OCSs are computed using the exact definition, though historical data show that, in reality, most participants habitually pledge more collateral than the minimum requirement. One advantage of using this definition of collateral data is that it contributes to constructing a worst-case scenario, because the conservative measure of collateral renders a larger value of defaulter OCS.

However, the total amount of collateral pledged to the LVTS is used in gauging surviving participant financial well-being at the end of the day. It simply makes more sense to compare each surviving participant's total loss in a default event against the value of its total collateral pledged to the LVTS.

This study also includes a sensitivity analysis on a hypothetical increase of the upper limit on securities issued by other participants as collateral in the LVTS. Recall that there is currently a cap equal to 20 per cent of a participant's total collateral pledge of securities issued by a single private sector issuer. A simple linear approach is used to scale the historical data; i.e., multiplying each participant's amount of securities issued by other participants by a factor of 5/2, to simulate a 50 per cent upper limit.

3.4.2 Two-participant default

There are several additional cases to handle in the analysis of a two-participant default. First, defaulting participant A's OCS is adjusted to reflect the depreciation in market value of defaulting participant B's securities, if A uses B's securities in its collateral pledge to the LVTS, and vice versa. Second, every surviving participant's combined loss allocation (i.e., the sum of ASOs) from the two defaults is compared against its cyclical Max ASO value, and the lesser of the two is counted as its actual ASO in this two-participant default case.[14] Third, it follows that, in every case of a two-participant failure, the Bank of Canada faces a possibility of providing funds to meet its guarantee of settlement. Calculations are conducted in this regard to reveal the frequency and the level of exposure to the Bank in terms of the amount of funds required.

Recall that defaulter OCSs are calculated based on apportioned collateral, rather than the total amount pledged to the system. Thus, it is non-trivial to apply the upper limit on securities issued by other participants, because a participant's actual use of any other participant's securities can be greater in value than its apportioned collateral. Hence, a revaluation method is specifically

[14] LVTS rules stipulate that a participant's Max ASO is also the legal upper limit of loss-sharing obligation in the case of a multiple-participant default.

needed in the analysis of two-participant failures to incorporate collateral limits into the calculations of two defaulter OCS values. It works as follows: defaulting participant A's apportioned collateral is discounted by an amount equal to the lesser of two values: (i) 20 per cent (or, hypothetically, 50 per cent) of A's apportioned collateral; and (ii) defaulter A's actual use of defaulter B's securities.

4 Simulation Results

Two types of financial losses are examined in this simulation: the additional settlement obligations of each surviving participant who grants a BCL to the defaulting participant, and a potential loss in value of defaulter-issued securities held in a survivor's collateral pledge. Further investigation is conducted on surviving participant post-default financial conditions; i.e., whether they incur an end-of-day collateral shortfall as a consequence of all settlement obligations. The simulation results also include statistics on the Bank of Canada's provision of residual funds to guarantee LVTS settlement under a two-participant default scenario.

4.1 One-participant default

4.1.1 Losses to participants

As outlined in section 3, every LVTS participant except the Bank of Canada is assumed to default, independently from one another, on each of the 253 days in the sample period. There are a total number of 3,542 simulated defaults, of which 1,846 are the cases where the defaulter's OCS > 0 (52.12 per cent).

Figure 4 shows the distribution of all defaulting participant OCSs, which are, on average, larger in value than the results found by McVanel (2005). This can be attributed to a longer sample period, and one more potential defaulter.[15] Another major contributing factor might be that each participant's OCS is calculated at the transactional level based on all intraday values, rather than comparing the maximum net debit position with end-of-day collateral values.

The average defaulter OCS value over all default cases is $386.1 million, and the largest single instance is around $3.6 billion. The value of 95 per cent of the default OCSs falls under $1.7 billion. The participant-level statistics show that one participant incurs an average OCS of more than $1.8 billion, and seven participants show a maximum OCS value of over $1 billion in their respective default cases. Among the four participants who have an average OCS value of more than $500 million, three are big banks and one is a small participant found by previous

[15] State Street Bank and Trust Company (State Street) is not included in McVanel's study (2005), because the sample period chosen is prior to State Street's entry into the LVTS.

internal Bank studies to have a high efficiency in intraday liquidity recycling. One large bank shows a particularly low average amount of own collateral shortfall, far below the median.

Figure 4: One-Participant Default – Defaulting Participant OCSs

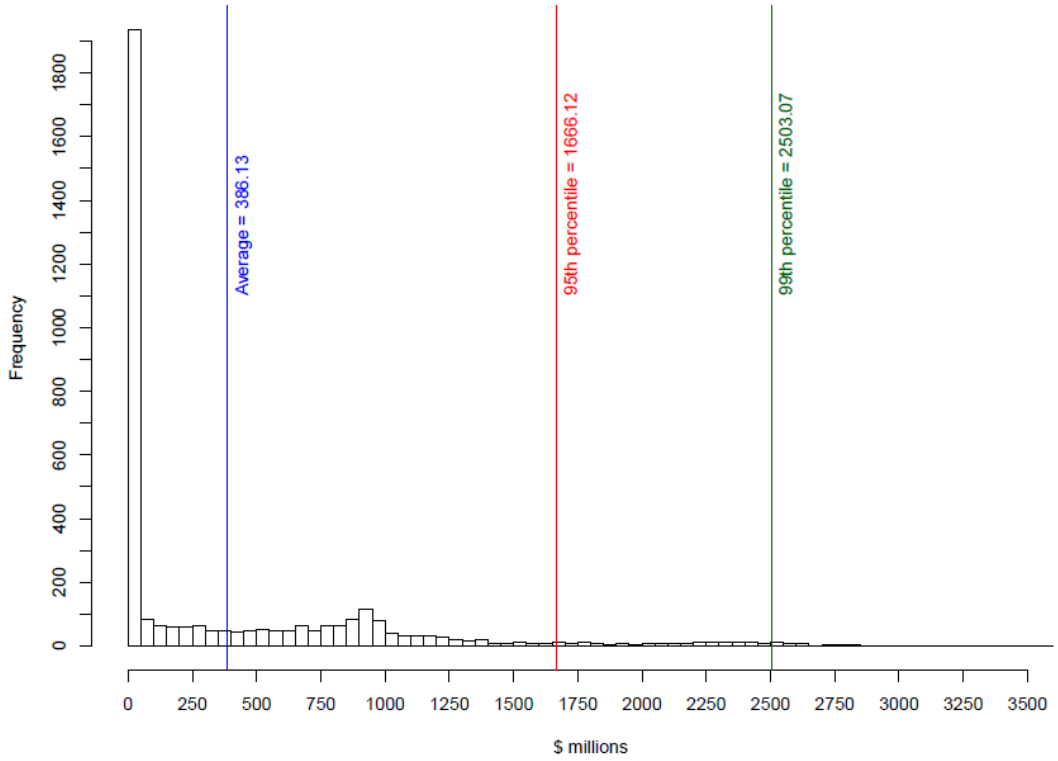
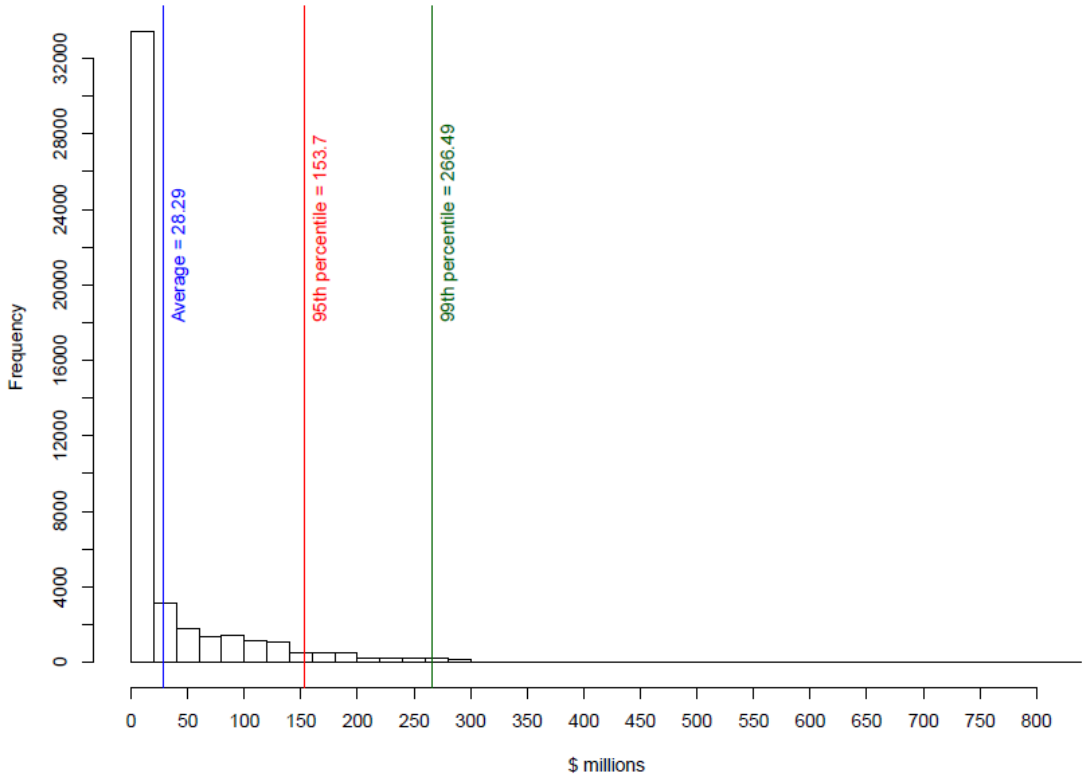


Figure 5: One-Participant Default – Individual Surviving Participant ASOs



The results show that survivor additional settlement obligations are generally small. Figure 5 illustrates the size distribution of the loss allocation to each surviving participant in all 3,542 defaults. The average participant loss allocation is around $28.3 million, and in 95 per cent of the cases survivors experience a total loss below $153.7 million.

The largest loss allocation to any surviving participant in any default is $828.9 million. The big six Canadian banks all show an average ASO value (over all 3,289 defaults) of $30 million or higher, and the largest average loss allocation among the big six is $59.6 million. Three small participants, on average, bear very little of the loss-sharing responsibilities in an event of default: under $5 million each.

Table 3 shows the loss allocations from the single largest defaulter OCS (a shortfall of $3.57 billion), as a percentage of every surviving participant's Tier 1 capital. These ratios suggest that, overall, the ASOs allocated to LVTS participants in this case are relatively small. Only one participant faces an ASO of more than 10 per cent of its Tier 1 capital, and in total only three survivors have ASOs above 5 per cent of their Tier 1 capital. Compared to the results reported in Ball and Engert (2007), these ASO values are, in general, smaller.

Table 3: One-Participant Default – Losses from the Single Largest Defaulter OCS ($3.57 billion)

Surviving participants	ASO relative to capital (%)	Total loss relative to capital (%) (20% limit)	Total loss relative to capital (%) (50% limit)
A	1.1	1.1	1.1
B	2.2	2.2	2.2
C	6.0	6.3	6.7
D	0.2	0.2	0.2
E	0.2	0.2	0.2
F	1.8	1.8	1.8
G	1.2	2.4	4.4
H	6.7	6.7	6.7
I	4.9	15.7	32.0
J	11.4	12.8	14.8
K	1.5	2.0	2.9
M	4.2	4.2	4.2
N	2.0	2.0	2.0

Table 4 provides surviving participant average and maximum loss allocations (for all 3,289 defaults) relative to their Tier 1 capital. On average, every survivor's loss allocation is under 1 per cent of their Tier 1 capital. One participant's maximum ASO amounts to 17 per cent of its

Tier 1 capital, significantly higher than other system members. The average-ASO-to-capital ratios are comparable with the results found in Ball and Engert (2007), but the maximum-ASO-to-capital ratios are generally lower.

Table 4: One-Participant Default – Average and Maximum ASOs Relative to Tier 1 Capital (%)

Participants	Average ASO relative to capital (%)	Maximum ASO relative to capital (%)
A	0.1	2.2
B	0.5	2.4
C	0.7	6.1
D	0.0	0.3
E	0.0	0.4
F	0.3	2.7
G	0.2	2.1
H	0.5	6.7
I	0.4	8.7
J	0.7	17.4
K	0.2	1.8
L	0.2	2.3
M	0.2	4.4
N	0.2	2.9

Recall that, in each default case, the securities issued by the defaulting participant are assumed to be worthless after the default, and every other surviving participant's collateral pledged to the LVTS is discounted accordingly. Hence, in this study, surviving participants not only face loss allocations from defaulter OCSs, but also suffer a potential loss in their collateral pledge. The sum of the two is called a survivor's total loss.

Figure 6 shows the size distribution of the sum of total losses of every surviving participant in all 3,542 defaults. The average total loss of any participant is around $55.3 million, and 95 per cent of the losses fall under $262 million. Evidence suggests that, if the possibility of defaulter-issued securities being devalued to zero is taken into account, participants generally face a much bigger total loss than the loss allocations from defaulter OCSs.

Two large participants incur an average total loss of more than $100 million each, and the highest average total loss to any participant is around $215.2 million. Only one participant has a maximum total loss exceeding $1 billion. The results also show that Participant I was a particularly heavy user of defaulter-issued securities, with 44 per cent of its total loss attributed to its use of such collateral, the highest percentage among all participants.

Figure 6: One-Participant Default – Individual Surviving Participant's Total Loss

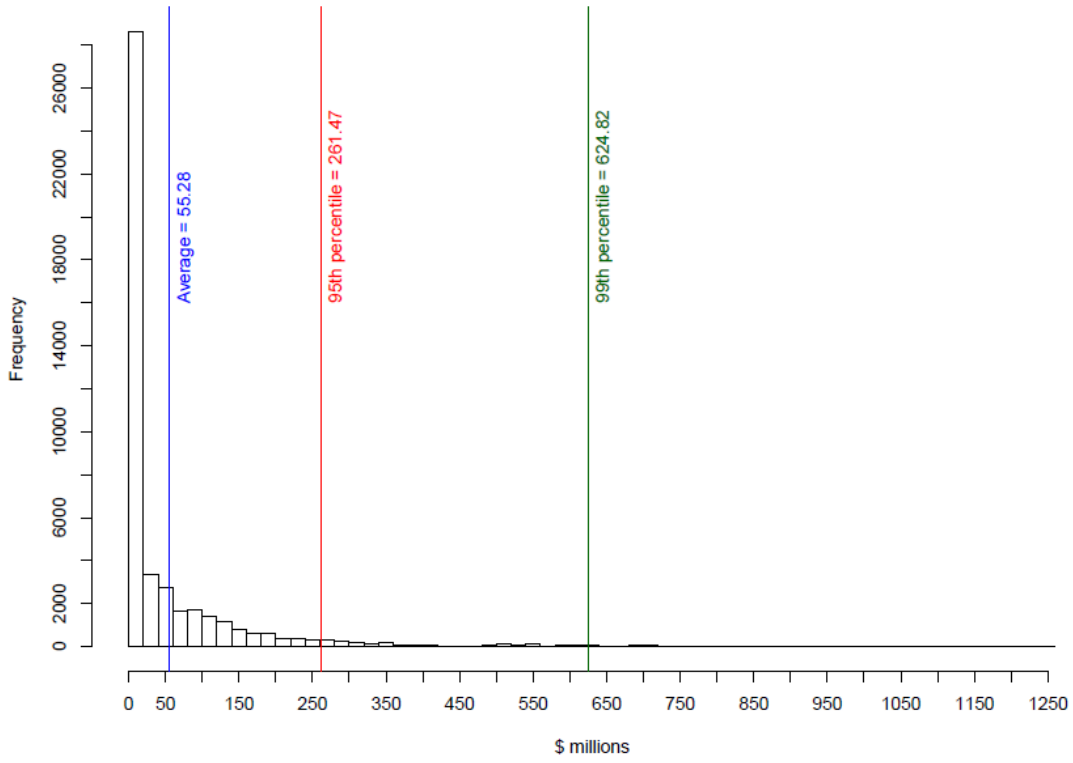


Table 5: One-Participant Default – Average and Maximum Total Losses Relative to Tier 1 Capital

Participants	20% limit		50% limit	
	Average total loss relative to capital (%)	Maximum total loss relative to capital (%)	Average total loss relative to capital (%)	Maximum total loss relative to capital (%)
A	0.6	3.8	1.5	9.3
B	1.0	7.5	1.7	15.5
C	0.7	6.3	0.7	6.7
D	0.1	0.3	0.1	0.5
E	0.0	0.4	0.0	0.4
F	0.3	2.7	0.3	5.0
G	1.2	7.4	2.8	18.5
H	0.5	6.7	0.5	6.7
I	3.1	18.5	7.2	45.2
J	1.4	18.1	2.5	23.5
K	0.4	2.3	0.6	4.0
L	0.9	5.3	2.0	11.7
M	0.2	4.4	0.2	4.4
N	0.2	2.9	0.2	2.9

Table 5 compares every participant's average and maximum total loss against their Tier 1 capital. In general, total losses under one-participant default scenarios are small. In the base case (20 per cent limit of securities issued by other participants), none of the participants has an average total loss of more than 5 per cent of their Tier 1 capital. Two participants, I and J, have a maximum total loss of 18 per cent of their Tier 1 capital.

4.1.2 Survivor end-of-day collateral shortfalls

Further examination of potential knock-on effects of a default on surviving participants is also conducted in this analysis. In all 3,542 default simulations, 10 participants show a total of 208 instances of positive end-of-day SCS, 0.46 per cent of the maximum 46,046 potential cases. Due to the scarcity of these SCSs, the average SCS value of every participant is particularly low, with the highest average being $10.4 million. The statistics also show that three participants incur a maximum SCS of over $1 billion each, and the single largest SCS in all defaults is around $2.1 billion. However, these survivor end-of-day collateral shortfalls do not necessarily mean that these participants would themselves default as a result of the first default. As noted above, the LVTS pre-settlement process is ignored in the simulations. In reality, participants can make use of the overnight interbank market to flatten their end-of-day net debit positions and thus incur much lower total settlement obligations than are shown in the simulations.

We also find that, if each of the 208 SCSs is broken down in light of equation (1), the majority of these shortfalls are not direct consequences of the loss allocations from default and usage of defaulter-issued securities. Instead, in more than 75 per cent of the 208 cases, these SCSs begin with survivors' own net debit positions falling short of their collateral pledge. As specified in the methodology, the survivor's collateral shortfall at the end of the day should not be much different from their original expectation prior to the default, because the net impact of a participant failure on their final funds position is not major. Hence, it is reasonable to argue that participants should be somewhat prepared for the first component of their SCSs shown in equation (2).

Moreover, the results show that the survivor collateral shortfalls at the end of the day are fairly small in value with respect to Tier 1 capital, indicating no significant exposure to these 10 participants. Table 6 shows every surviving participant's SCS value averaged over their total number of positive shortfalls, in relation to Tier 1 capital. The SCS-to-capital ratio is under 6 per cent for every participant, which suggests that these participants should be able to provide additional collateral to fulfill the settlement requirement, even if they chose not to flatten their own funds positions in the overnight interbank market.

Table 6: One-Participant Default – Survivor Collateral Shortfalls Relative to Tier 1 Capital (%)

Participants	SCS relative to capital (20% limit)	SCS relative to capital (50% limit)
B	2.4	3.1
C	5.1	5.1
D	0.2	0.2
E	0.2	0.2
F	3.1	3.1
I	2.5	2.4
K	2.1	2.3
L	1.3	3.0
M	3.1	3.1
N	2.6	2.6

4.1.3 Sensitivity analysis

This analysis also investigates surviving participant losses in the event of a default, under a hypothetical condition where every LVTS participant is permitted to pledge any other system member's securities up to 50 per cent of the total value of its collateral pledge. Note that, in a one-participant default scenario, the defaulter's OCS and the loss allocations to survivors from the OCS are not affected by increased usage of securities issued by other participants.

Tables 3, 5, and 6 show some differences in the simulation results, if each participant had pledged defaulter-issued securities in every default in an amount up to 50 per cent of its total LVTS collateral. In the case of the single largest defaulter's OCS, the vast majority of the participants show minor increases in their total loss, except for Participant I. Based on each participant's maximum total loss in all defaults, Participants I, J, and L each show a large increase in total loss. Specifically, Participant I's largest total loss amounts to 45 per cent of its Tier 1 capital. No major impact from the increased limit is found in participant SCSs.

4.1.4 Losses to the Bank of Canada

In the LVTS, the Bank of Canada also extends a BCL to every direct system member in the amount of 5 per cent of the sum of all BCLs received by other participants. In other words, in the event of a participant default, the Bank also faces an ASO in loss allocation that is no more than 4.762 per cent of the defaulter's collateral shortfall.[16] Over all of the 3,542 simulated defaults, the average loss to the Bank is $18.4 million and the maximum allocation is $169.8 million, both relatively small amounts.

[16] If the sum of all BCLs received by a participant from other financial institutions is normalized to 1, then the Bank's BCL to that participant is 0.05. Hence, 0.05/(1+0.05)=4.762 per cent.

4.1.5 Unsettled payments

In the simulation, transactions that are unable to settle at the end of each payment cycle reflect part of the impact of an unanticipated participant default on the surviving participants. The results show that this impact is negligible. There are a total of 105 unsettled payments in all 3,542 simulations, which account for less than 0.0002 per cent of the total number of actual transactions settled during the sample period.[17] On 76 per cent of the days (192 out of 253), none of the LVTS participants has a single payment that failed to settle at the end of the day. The maximum total value of unsettled payments of any participant on any day in this simulation is relatively small, at $275.9 million.

One conceivable reason for this small maximum total value is that, during the post-default period, surviving participants should have more multilateral liquidity available than had the default not occurred, because their BCLs vis-à-vis the defaulting participant are not adjusted to zero after the event. It is true that surviving participants lose the liquidity of originally expected payment receipts from the defaulter; however, at the same time, they gain liquidity by cancelling their outgoing payments to the defaulter. The net impact, on average, should not be major.

Another factor is that each participant is simulated as having an internal payment queue. The value and volume of unsettled payments would be significantly higher if, in the simulation, participants were not allowed to respond to the unanticipated default by adjusting payment timing according to real-time liquidity availability.

4.2 Two-participant default

4.2.1 Losses to participants

There are a total of 46,046 simulated defaults in this scenario, of which 19,432 cases show that both defaulters' OCS > 0 (42.2 per cent). The single largest sum of two defaulters' own collateral shortfalls in all cases was $5.04 billion.

Figure 7 shows the size distribution of the sum of the two defaulters' OCSs each day. The average total shortfall of a two-participant failure is around $796.1 million, as expected, twice as large as in the one-participant default scenario. The value of 95 per cent of the OCSs falls under $2.5 billion.

[17] CPA data show a total of 5.468 million transactions during this sample period, during the general payment exchange period.

Figure 7: Two-Participant Default – All Defaulting Participants' OCS

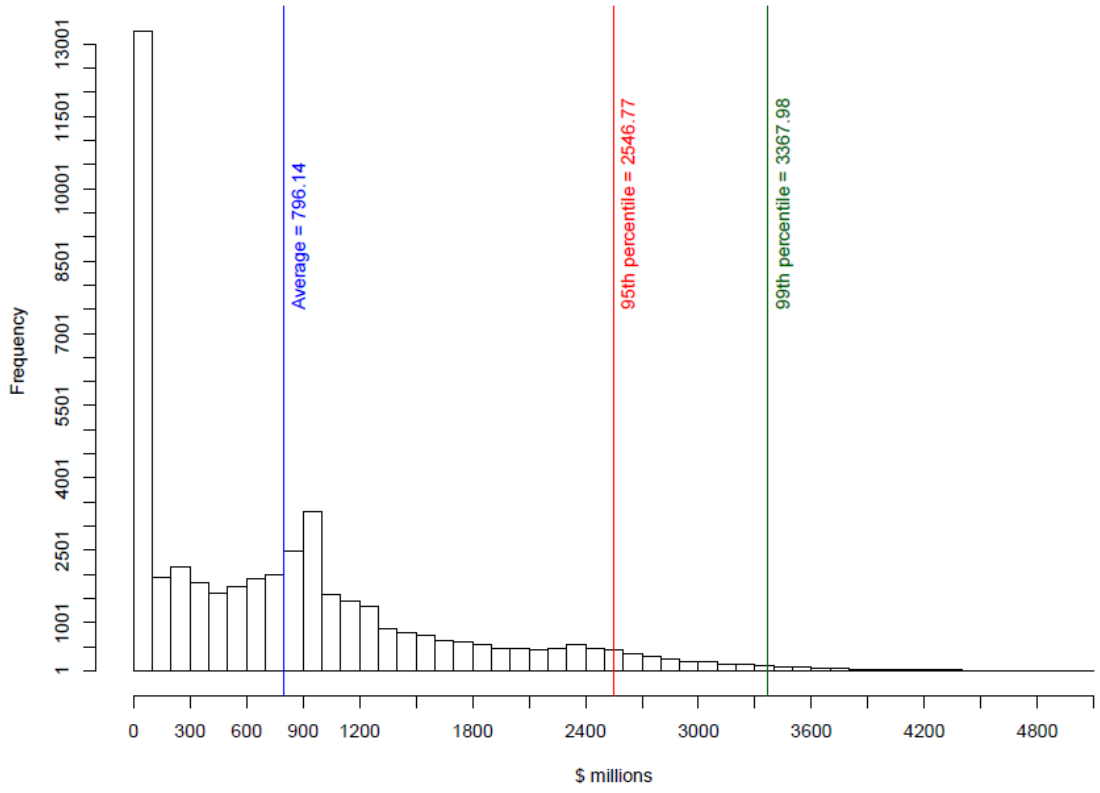
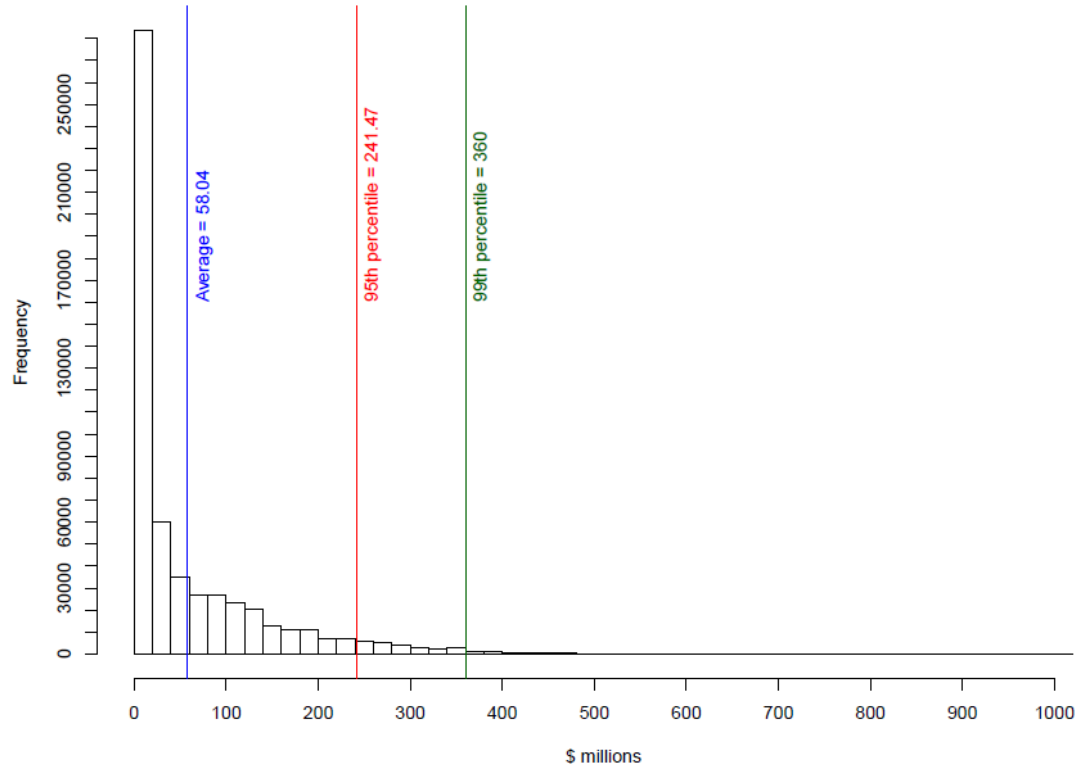


Figure 8: Two-Participant Default – Individual Surviving Participant's ASO

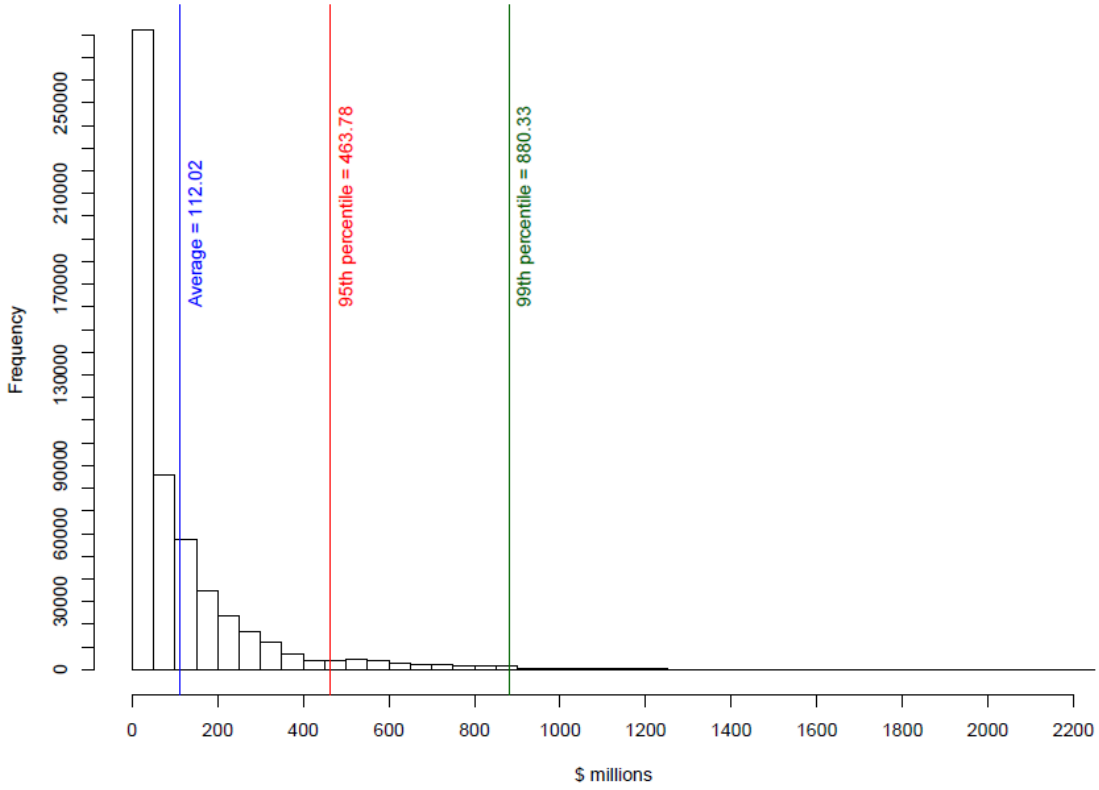


With a second participant suspended from the system, the loss allocations to surviving participants in this simulation are larger in value. Figure 8 illustrates the distribution of loss allocations to surviving participants in all 46,046 simulated defaults. The average loss allocation to any participant is $58 million, and there is a 5 per cent chance of any participant's ASO exceeding $241.5 million.

The big six Canadian banks each show an average ASO value of more than $70 million (over a total of 39,468 defaults). There are two participants with a maximum loss allocation in excess of $1 billion each, and these two participants also have the highest average ASOs in the system, above $100 million. Three small participants contribute, on average, less than $10 million each to loss sharing under two-participant default conditions.

Figure 9 illustrates the distribution of the total loss to every surviving participant in all simulation cases. The results show that the average total loss of any participant in the simulation is $112 million, and, in 99 per cent of the cases, any participant's total loss is under $880 million.

Figure 9: Two-Participant Default – Individual Surviving Participant's Total Loss



Participant-level statistics indicate that five participants each have an average total loss of more than $100 million, and the highest average is $433 million. The five participants are not all big

banks; two are small participants, one of which pledged more than the average amount of securities issued by other participants during the sample period. The single largest total loss to any participant in any default is $2.2 billion, and the highest average percentage of any participant's total loss being collateral devaluation amounts to 65.2 per cent.

Nevertheless, these losses are generally small compared to each participant's Tier 1 capital, and unlikely to generate a significant financial risk exposure to any participant. Table 7 shows surviving participant losses from the single largest sum of two defaulters' OCSs ($5.04 billion), with respect to every participant's capital. The maximum ASO allocation relative to any participant's Tier 1 capital is 14 per cent, and the highest total-loss-to-capital ratio of any participant is around 16.5 per cent. For both measures, the majority of the participants have losses under 5 per cent of their capital. The large difference between Participant I's ASO and total loss indicates that its collateral pledge includes a large amount of defaulter-issued securities.

Table 7: Two-Participant Default – Losses from the Single Largest Sum of OCSs ($5.04 billion)

Participants	ASO relative to capital (%)	Total loss relative to capital (%)
A	1.3	1.3
B	3.8	3.8
C	8.3	8.6
D	0.2	0.2
E	0.3	0.3
F	2.9	2.9
G	1.6	5.5
H	7.7	7.7
I	5.6	16.5
J	14.2	15.5
K	1.7	2.9
M	4.8	4.8

Table 8 provides the average and maximum ASO values of every participant in all defaults relative to their capital, as well as the average and maximum total-loss-to-capital ratios. On average, LVTS participant ASO allocations and total losses are small in value with respect to their Tier 1 capital. None of the participants' average ASO values are above 2 per cent of their capital, and the highest average-total-loss-to-capital ratio of any participant is 6.3 per cent. Three participants' maximum ASO values exceed 10 per cent of their capital, with the highest ratio in the system being 21 per cent. Two participants each show a relatively large maximum total loss of more than 25 per cent of their capital. Participant I has the largest maximum-total-loss-to-capital ratio, 34 per cent, among all LVTS participants.

From an LVTS settlement perspective, the results show that LVTS participants should not have difficulty absorbing the losses resulting from a two-participant default, even under the assumption that defaulter-issued securities are worthless after the event.

Table 8: Two-Participant Default – Average and Maximum Losses Relative to Tier 1 Capital

Participants	Average ASO relative to capital (%)	Maximum ASO relative to capital (%)	Average total loss relative to capital (%)	Maximum total loss relative to capital (%)
A	0.2	2.8	1.3	7.2
B	0.9	5.9	1.9	14.5
C	1.5	10.4	1.5	10.7
D	0.0	0.4	0.1	0.5
E	0.0	0.5	0.0	0.5
F	0.6	4.9	0.6	4.9
G	0.4	2.7	2.5	12.6
H	1.0	8.1	1.0	8.1
I	0.9	13.5	6.3	34.7
J	1.3	21.1	2.8	26.6
K	0.5	3.4	0.8	4.3
L	0.5	4.4	1.9	9.5
M	0.5	5.5	0.5	5.5
N	0.5	3.9	0.5	3.9

4.2.2 Survivor end-of-day collateral shortfalls

A total of 5,728 cases are found in all simulated defaults where surviving participants encounter a collateral shortfall at the end of the day, 1 per cent of the maximum 552,552 potential instances. As discussed in section 4.1.2, these SCSs represent the knock-on effect of a two-participant failure, such that any participant who incurs an SCS needs to pledge additional collateral to the LVTS in order to satisfy the settlement requirement.

Ten participants each incur at least one SCS in this simulation. The infrequency of these shortfalls produces a very low average SCS value for every participant, with the highest average being $22 million. Four participants show a maximum SCS of over $1 billion each, and the single largest instance in all cases is around $1.9 billion. We also find that, in 72 per cent of the 5,728 cases, the surviving participants already incurred positive own collateral shortfalls prior to the loss allocations. This suggests that the direct knock-on effect of a two-participant failure on surviving participants is fairly minor.

A comparison of the SCSs with each LVTS participant's Tier 1 capital confirms that these shortfalls are not worrisome signs of potential secondary defaults. Table 9 shows every participant's SCS value averaged over their total number of shortfall instances, in relation to their capital. For most LVTS participants, when they incur end-of-day collateral shortfalls under two-participant default conditions, the SCS value is, on average, under 4 per cent of their Tier 1 capital. The highest average SCS-to-capital ratio of any participant in this simulation is around 9 per cent.

Table 9: Two-Participant Default – Survivor Collateral Shortfalls Relative to Tier 1 Capital

Participants	SCS relative to capital (%)
B	3.1
C	3.3
D	0.2
E	0.2
F	2.2
I	3.1
J	9.0
K	3.0
M	3.9
N	0.3

4.2.3 Sensitivity analysis

Under two-participant default circumstances, an increase in the use of defaulter-issued securities as collateral affects not only surviving participant total losses but also their ASOs through the initial effect on the two defaulters' OCSs. Table 10 compares the simulation results in two separate scenarios: the current 20 per cent limit, and a hypothetical cap of 50 per cent. The table shows that, even under two-participant default conditions, the impact of this type of collateral on surviving participants is generally not significant. In extreme cases, the losses can be substantial to those participants who pledge large amounts of such collateral.

In this study, under two-participant default circumstances, the amount of defaulter-issued securities used as collateral affects the losses to the Bank for two reasons. First, each defaulter's collateral pledge is also subject to a potential devaluation of the securities issued by the other defaulter. Hence, the base amount for loss sharing among all surviving participants is higher than otherwise. Second, a larger value of defaulter OCSs leads to a higher probability of surviving participants incurring actual ASOs that are greater than their Max ASOs. Therefore, the residual for the Bank to fund will be higher in value.

Table 10: Two-Participant Default – 20% versus 50% Limit
(Monetary values are millions of dollars)

Statistics	20% limit	50% limit
Number of defaults where both OCSs > 0	19,432	19,432
Average sum of two OCSs	$796.1	$853
The single largest sum of OCSs	$5,040.3	$6,444.9
Average ASO	$58	$61.4
Largest ASO of any participant	$1,018.1	$1,018.1
Average total loss	$112	$196.4
Largest total loss to any participant	$2,222.6	$4,731.2
Highest average percentage of total loss being defaulter-issued securities	65.3%	70.2%
Highest maximum-ASO-to-capital ratio of any participant	21.1%	23.3%
Highest maximum-total-loss-to-capital ratio of any participant	34.7%	80.4%
Number of SCS instances	5,728 (1%)	7,238 (1.3%)
Largest SCS of any participant	$1,856.8	$2,188.4
Highest average-SCS-to-capital ratio of any participant	9.0%	9.1%
The Bank of Canada's average residual funds	$3.3	$10.8
The Bank's maximum residual funds	$1,055.7	$1,804.7
The Bank's average total loss	$41.1	$51.4
The Bank's maximum total loss	$1,280.4	$2,078.6

4.2.4 Losses to the Bank of Canada

Recall that the Bank grants a BCL to every LVTS participant in the amount of 5 per cent of the total value of bilateral credit the participant receives from all other system members. Hence, in the two-participant default scenario, the Bank's ASO approximately doubles in value, compared to the results for one-participant defaults. In this simulation, the average loss allocation to the Bank is $37.9 million, and the single largest ASO value is about $240 million.

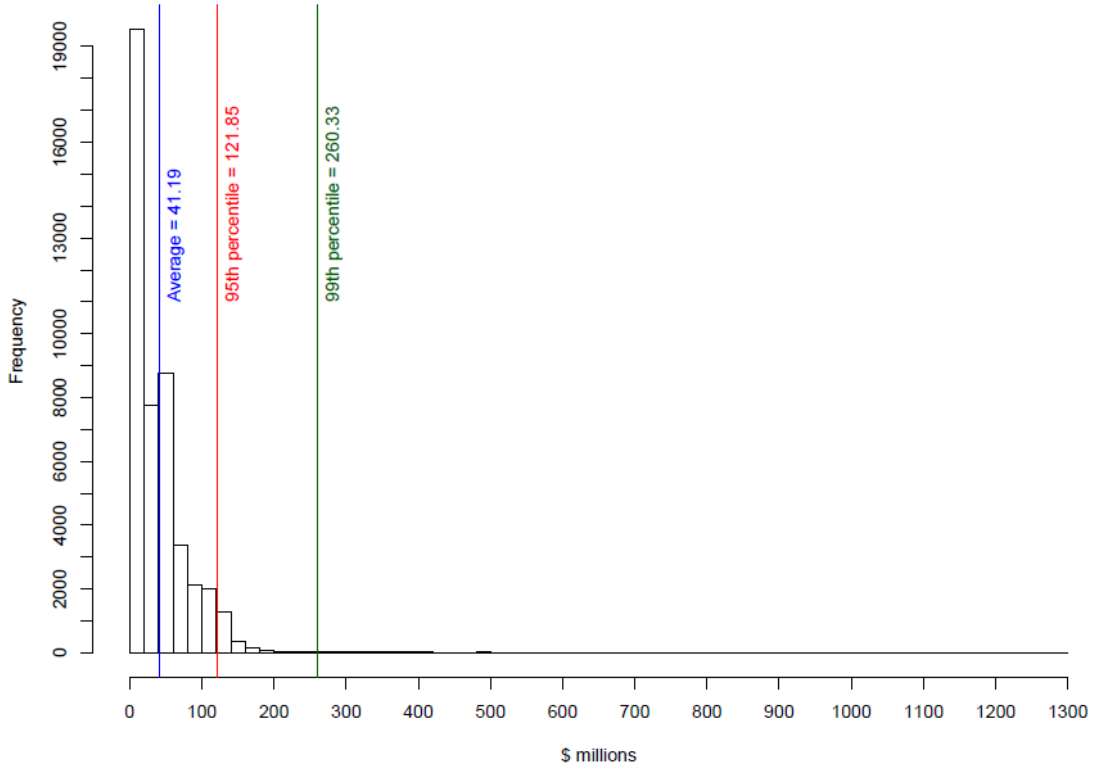
LVTS rules stipulate that, regardless of the number of defaulting participants during one payment cycle, each surviving participant's ASO is bounded by its Max ASO. In the case where there is at least one participant with an actual ASO exceeding its Max ASO, the Bank of Canada will guarantee LVTS settlement by extending a loan in the amount of the difference to the

defaulting financial institutions. The Bank's contribution of residual funds is triggered only by a multiple-participant default.[18]

The simulation results show 1,595 cases (out of all 46,046 defaults; i.e., a likelihood of 3.5 per cent) where the Bank needs to provide funds (in addition to its ASO allocation) to guarantee LVTS settlement under two-participant default conditions.[19] The overall average value of the residual funds is $3.3 million, and 99 per cent of the values fall under $97.5 million. The single largest instance is over $1 billion.

The sum of the Bank's ASO plus its residual funds to guarantee LVTS settlement can be deemed as its total loss in an event of two-participant default. The average total loss to the Bank in this simulation is about $41.1 million. The maximum total loss to the Bank is around $1.3 billion, which is substantial given that the Bank's net income in 2009 was $1.3 billion. However, that single instance seems to be an extremely remote outlier because, as shown in Figure 10, 99 per cent of the Bank's total losses are under $260 million.

Figure 10: Two-Participant Default – Bank of Canada's Total Loss



[18] McVanel (2005) shows a detailed proof of the LVTS risk-control model such that the total value of the collateral pledged to the system is always sufficient to cover the exposure in a one-participant default.
[19] The likelihood increases to 8 per cent among the defaults where both defaulting participants have positive OCS values.

4.2.5 Unsettled payments

In a two-participant default scenario, simulation results also show an insignificant impact on the volume and value of LVTS settlement. There are a total of 4,424 unsettled transactions in all 46,046 simulations, 0.0004 per cent of the total payments actually sent in the sample period. The maximum total value of unsettled payments of any participant on any day in the simulation is $432.5 million.

5 Conclusions

In this study, using a simulation approach, we examine the impact of an unanticipated participant failure in the LVTS. Two scenarios are examined: one-participant and two-participant defaults. The analysis includes loss allocations from the defaulter's OCS, the possible impact of collateral devaluations, potential knock-on effects on surviving participants, and the Bank's exposure to participant defaults.

Our results show the impact of defaults in worst-case scenarios. In reality, there are mechanisms already in place at the Bank to help mitigate unexpected market risks. For example, a haircut is applied in the valuation of every security pledged as LVTS collateral. Under extreme circumstances, the Bank will carry out an intraday revaluation of LVTS collateral in response to extraordinary market conditions. Also, a regulator likely would avoid closing a financial institution in the middle of an LVTS payment cycle.

We analyze the usage by LVTS participants of securities issued by other participants as collateral, and find that such collateral is commonly used for LVTS purposes; large users typically pledge over $1 billion of this type of collateral.

The simulation results show that loss allocations from defaulter OCSs are generally small, consistent with the findings of previous default studies. Even when two participants default on the same day, in 95 per cent of the cases any surviving participant's ASO is under $241.5 million.

We also find that the possible impact of collateral holdings under default conditions is generally insignificant and would be readily absorbed. In the simulation of one-participant defaults, none of the surviving participants incurs an average total loss of more than 5 per cent of their respective Tier 1 capital; and with the limit on securities issued by other participants hypothetically raised to 50 per cent, only one small participant shows an average total loss equal to 7 per cent of its capital and others each have a relative loss of under 3 per cent. However, under extreme circumstances, collateral holdings can yield a large total loss to some surviving

participants (those who are heavy users of the securities issued by other participants as collateral).

The LVTS was designed to ensure that collateral pledged by participants would be sufficient to cover the default of a single participant. However, we find that, if the indirect effects of a default are included, collateral might not be sufficient. The simulation results show that surviving participants do incur end-of-day collateral shortfalls from time to time, in both one-participant and two-participant default scenarios, but very rarely. Furthermore, the majority of these shortfalls are not direct consequences of the default, and the average SCS value is found to be small in value relative to survivor Tier 1 capital.

The Bank of Canada's losses are, on average, small in all simulations. For example, in a two-participant default scenario, the likelihood of the Bank providing residual funds to guarantee the LVTS settlement is around 3.5 per cent and the average residual coverage is $3.3 million. Overall, 99 per cent of the Bank's total losses are under $260 million. However, in the most extreme default case, the total loss to the Bank could amount to as much as $1.3 billion.

In both simulation scenarios, participant defaults show negligible effects on surviving participants in terms of the value and volume of the transactions that remain unsettled. Overall, we find evidence that the LVTS is a robust system against default risks.

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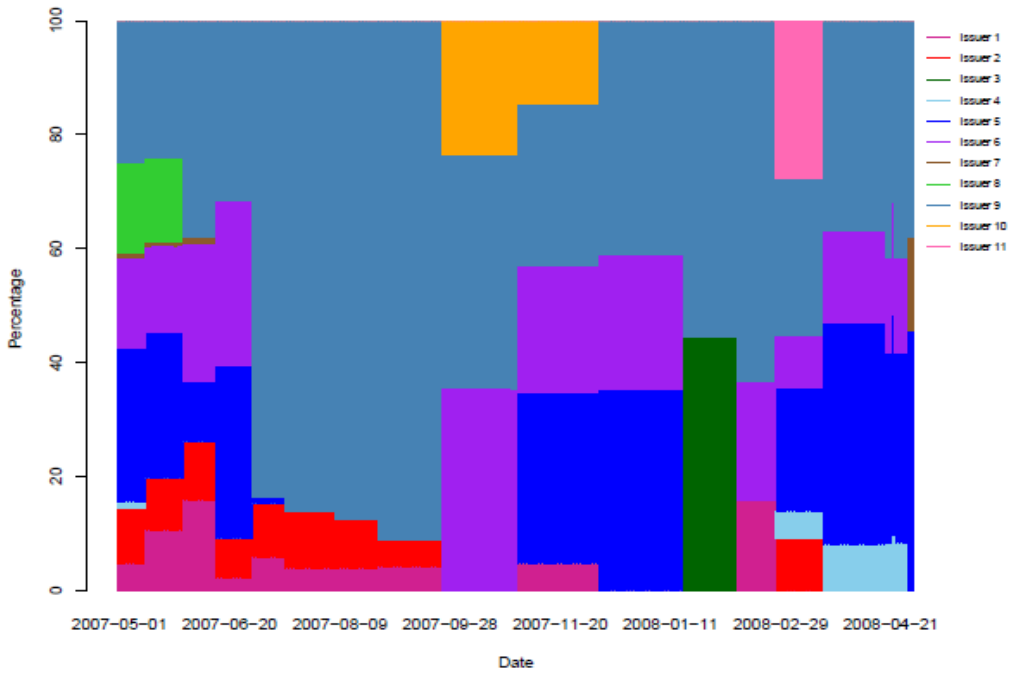
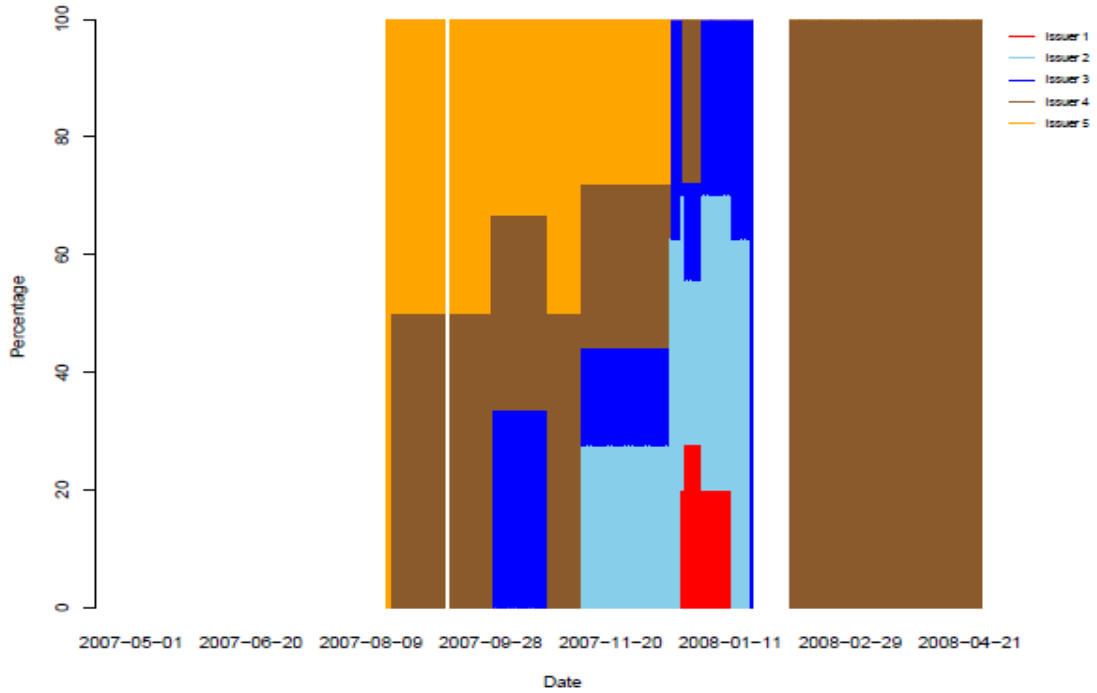
Appendix A: Securities Issued by Other Participants Pledged as Collateral

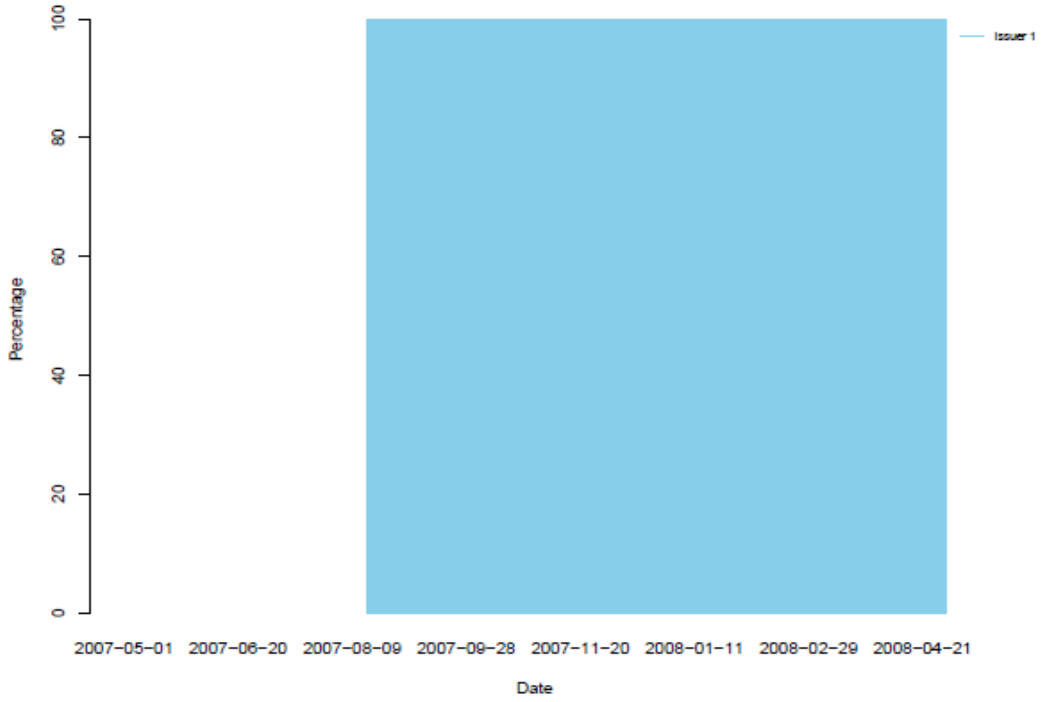
Participant A



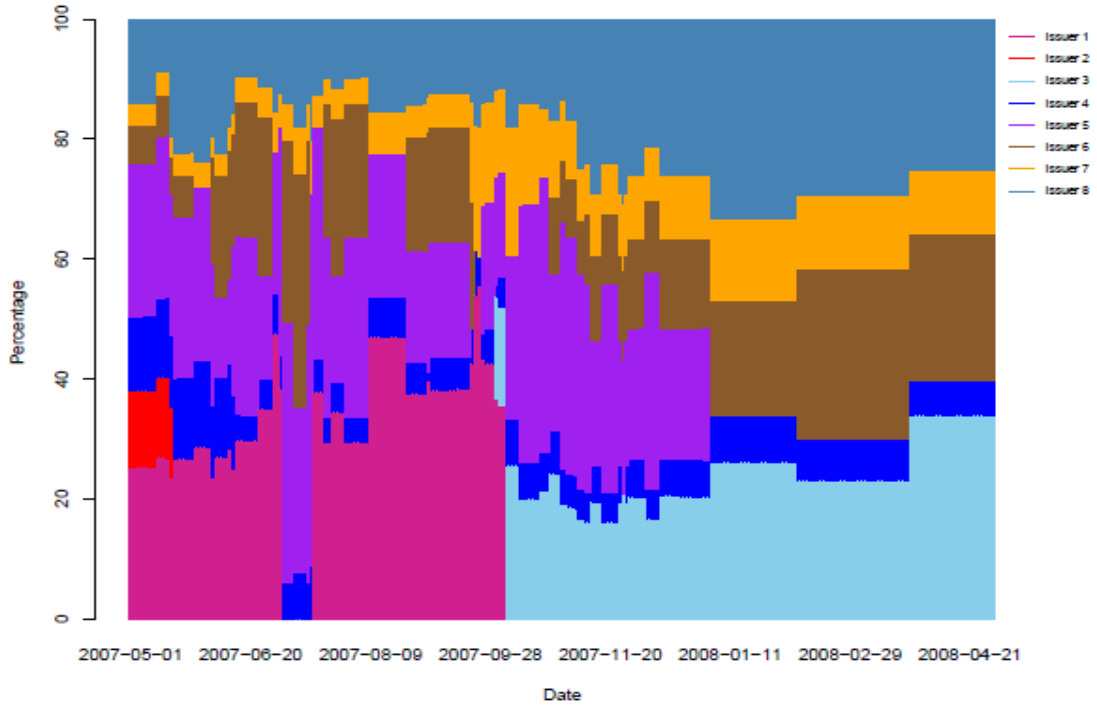
Participant B



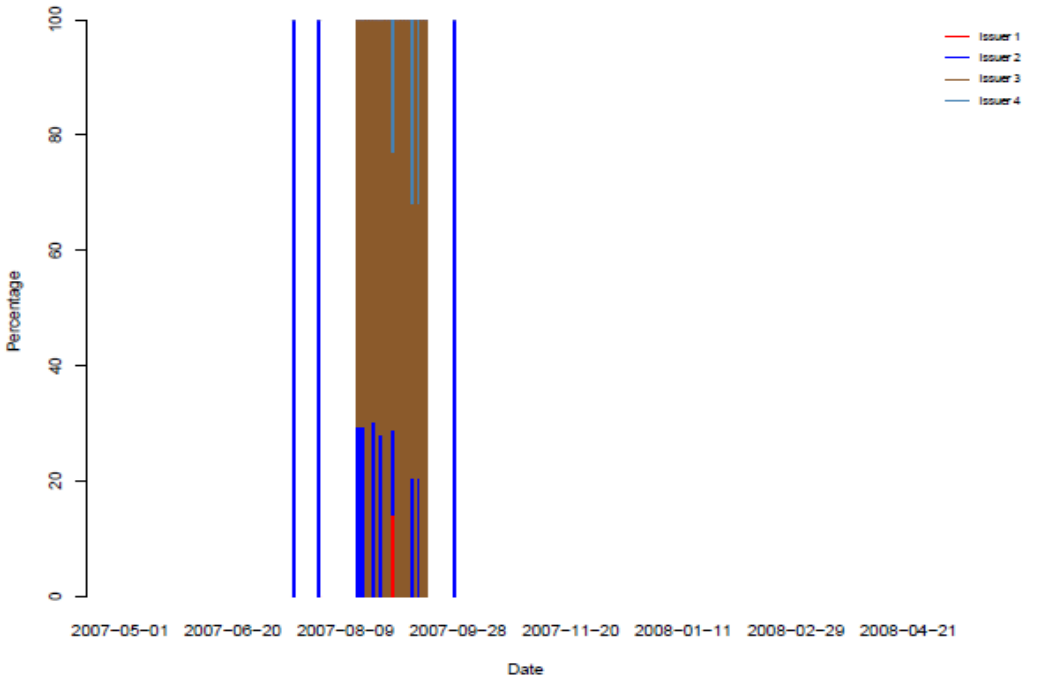
Participant C



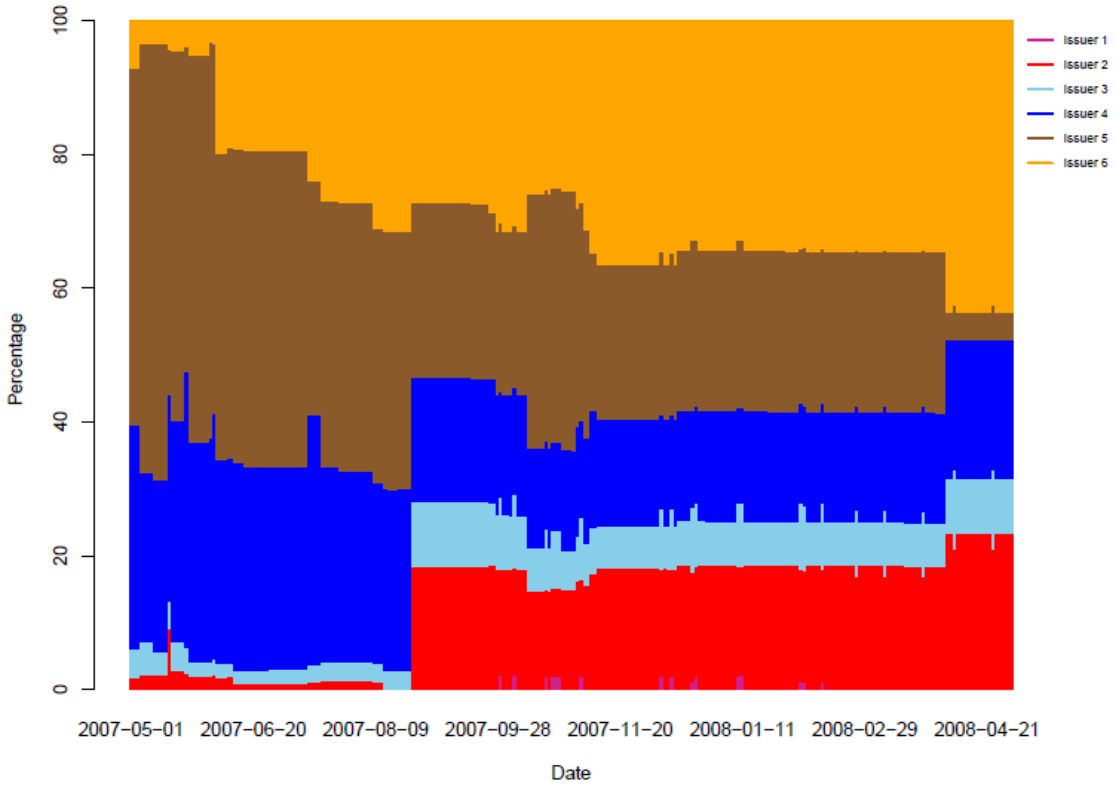
Participant D



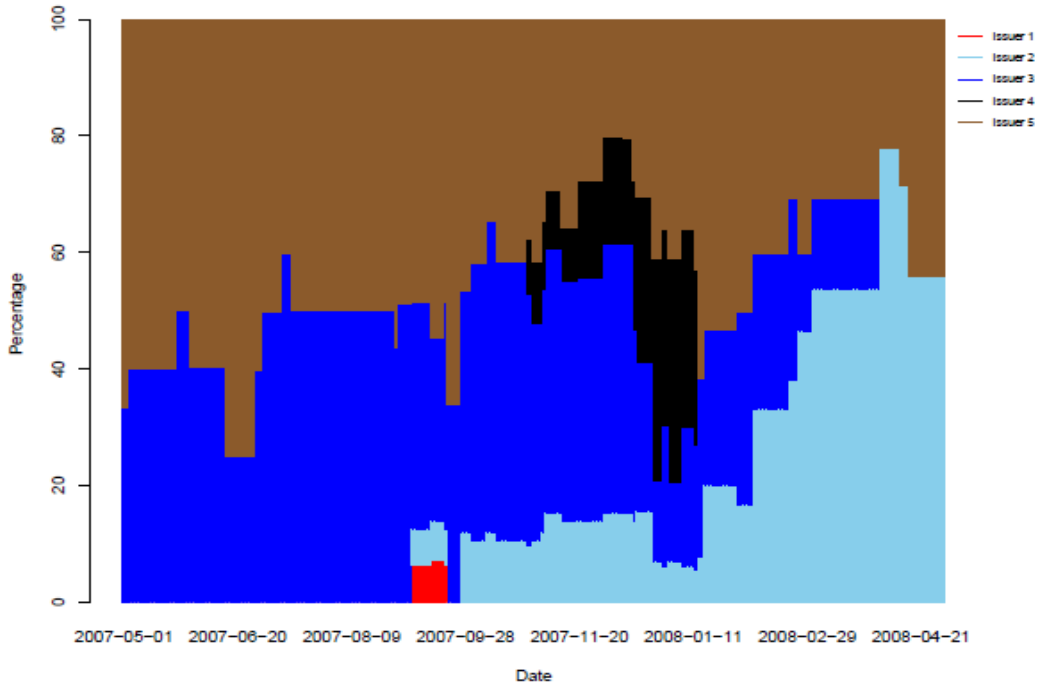
Participant F



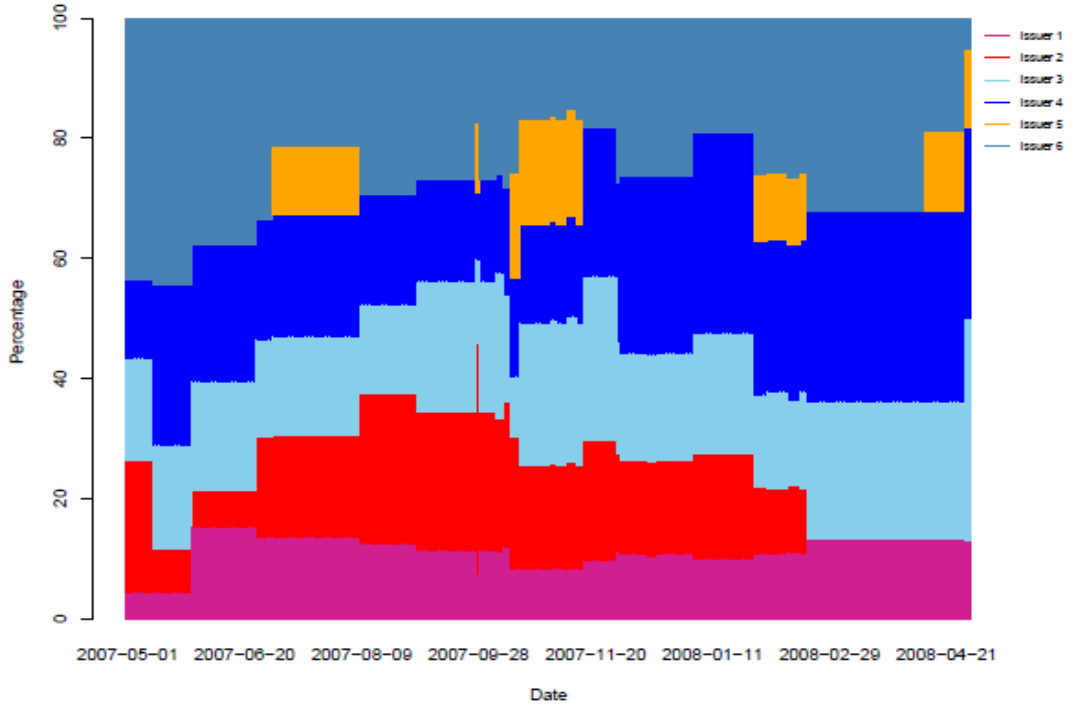
Participant G



Participant J



Participant K



Appendix B: The Simulation Program Used

The simulation program that we used in this study is similar, in principle, to the BoF-PSS2 simulator, in that it fully replicates the functionalities of the LVTS and applies these rules to produce settlement and rejection times on historical data. One main difference is that this program allows additional modules to interrupt the transaction flows, execute atypical or user-defined functions, and then insert the results back into the process.[20]

This study uses two such additional modules. The first is used to discard any payments and credit limit (bilateral and multilateral) changes, which occur after the time of default and involve the defaulting participant either as the event sender or event receiver (an event herein refers to a payment or a change in credit limits). The second module is used to provide each participant with an internal queue. As discussed in the main text, this feature is crucial to the simulation of payment interruptions, especially when not all transactions are eligible for the central queuing facility as in the LVTS. An unanticipated default affects every surviving participant's liquidity holdings throughout the day, and therefore the surviving participants would rationally adjust their behaviour by deviating from their original payment schedule and instead submitting each post-default payment when sufficient liquidity is available.

Each internal queue is implemented based on the first-in-first-out (FIFO) algorithm. In the simulation, any payment that is rejected by the LVTS is placed at the end a FIFO queue owned by the sending participant. The sending participant will then not attempt to submit any other payment until the rejected payment is settled. In other words, payments that follow the rejected payment will be placed at the end of the queue as well (as opposed to the normal situation of no participant default where these payments were actually settled at the original time of submission). The payment sender continuously attempts to resubmit internally queued payments starting at the front of the queue at any opportunity at which more liquidity becomes available, until all queued payments have been settled or the queue is empty.

[20] There are some minor differences as well. For example, Tranche 1 and Tranche 2 transactions are processed simultaneously in one simulation. In addition, any intraday changes in the BCL granted by the Bank of Canada to a participant are computed dynamically throughout the simulation; i.e., these changes are applied each time a participant's receipt of BCL from another system member is modified.