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The impact of unanticipated defaults in Canada's Large Value Transfer System

by

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The views expressed in this paper are those of the author.
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Abstract

Canada’s Large Value Transfer System (LVTS) is designed to meet international risk-proofing standards at a minimum cost to participants in terms of collateral requirements. It does so, in part, through collateralized risk-sharing arrangements whereby participants may incur losses if another participant defaults. The system is designed to be robust to defaults. The system’s rules, however, do not ensure that *individual participants* are robust to defaults. This paper studies participants’ robustness to default empirically by creating unanticipated defaults in LVTS. We find that all participants are able to withstand their loss allocations resulting from the largest defaults we can create using actual LVTS data.

JEL classification: E44, E47, G21
Bank classification: Financial institutions, Canadian payment systems

1. Motivation

Canada's Large Value Transfer System (LVTS) is designed to meet international risk-proofing standards at a minimum cost to participants in terms of collateral requirements. It does so, in part, through collateralized risk-sharing arrangements whereby participants may incur losses if another participant defaults. The system is designed so that there is sufficient collateral prepledged by participants to cover at least the largest possible payment obligation to the system. Therefore, the rules ensure that the *system* is robust to defaults.[1] However, the system's rules do not ensure that *individual participants* are robust to defaults; it is up to participants to manage their own risks to make sure they can withstand potential losses stemming from a default from a solvency perspective. In this paper, we study participants' robustness empirically by creating unanticipated defaults in LVTS.

The system's rules create the incentive for participants to prudently manage their risks vis-à-vis other participants. There is a survivors-pay component to LVTS where participants' losses in the event of a default are governed by the bilateral credit limit (BCL) that they grant to the defaulter, and granting of bilateral credit limits, as well as their size, is completely voluntary. Given the possibility that another participant could default, participants have an incentive to set bilateral credit limits at a size that would create manageable losses for themselves if a default were to occur. Furthermore, in a situation where participants believed that another participant may be in danger of defaulting, it could be in their interest to reduce their BCLs granted to this participant to minimize their loss exposures.

In this paper, we generate a series of unanticipated defaults by individual participants to estimate whether surviving participants would be able to withstand their allocated losses.[2] We first estimate the frequency with which survivors must contribute to cover a defaulter's shortfall and the relative size of these loss allocations, then assess participants' ability to withstand these losses by calculating individual survivors' capital positions following a default.

Results are based on an eight-month sample of LVTS transactions, collateral holdings, bilateral and multilateral credit limits data spanning March to October 2004, provided by the Canadian Payments Association. Each participant's maximum net debit position and the time it was incurred are found using the Bank of Finland Payment and Settlement System Simulator ('the simulator'). Survivors' additional settlement obligations are calculated according to LVTS rules.

We find that the shortfalls resulting from our theoretical defaults are generally small, but there exists substantial heterogeneity in how often individual participants incur shortfalls, each participant's average shortfall size, and the size of shortfalls over different days. Large participants generally incur shortfalls that are much larger than those incurred by small

1. The Bank of Canada guarantees settlement in the extremely unlikely event that more than one participant defaults on a single day and the sum of the exposures exceeds participants' prepledged collateral, so the system is robust to even multiple defaults on a single day. This provides for intraday finality of payments.
2. We believe that loss allocations would likely be larger when a default is unanticipated since, as already described, participants anticipating a default may have incentives to reduce the BCLs granted to a failing institution.

participants. These factors create a large degree of variability in participants' loss allocations. In both absolute and relative terms, participants' loss allocations are generally small, but when we compare losses to assets and capital, we see that small participants take on relatively much more risk than large participants. Nevertheless, we find that all participants are robust to the defaults generated here.

This paper contributes to the literature in two respects. First, most previous work has focused on losses to survivors in uncollateralized netting systems; this paper considers losses in a risk-proofed and collateralized system. Second, it applies the simulator to a default analysis, whereas most previous studies have focused on questions of liquidity usage or operational risk.[3]

This paper is organized as follows. Section 2 provides an overview of LVTS's risk controls and default-resolution procedures. Section 3 compares this study to previous literature. Section 4 explains our procedure for generating defaults. Sections 5, 6 and 7 describe the findings, and the impact of key assumptions. Finally, the appendices contain proofs of the efficacy of LVTS's risk controls and additional tables and figures.

2. LVTS framework

To understand the default and loss-allocation procedures used in this paper, it is useful to review the main concepts and risk controls within LVTS.

- LVTS is a real-time electronic payment system which provides certainty of settlement on a continuous basis for all payments that have passed the risk controls. It uses caps, collateral, loss-sharing arrangements and a residual guarantee by the Bank of Canada to provide intraday finality and irrevocability of payments.
- It is a collateralized deferred net settlement system. Unlike in real time gross settlement systems in which defaults cannot occur inside the system (because settlement of payments involves the immediate transfer of funds across the books of the settlement institution), default is possible in LVTS.[4]
- LVTS consists of one fully defaulter-pays payment stream and one partially survivors-pay stream. In the partially survivors-pay stream, a participant is able to incur a larger net debit position than the collateral it holds. Thus survivors may have to contribute to cover losses in the event of a default.
- The risk controls are designed so that there will be sufficient collateral to cover the largest net debit position possible, or put differently, at least the default of the largest net debtor.
- The system will always settle because the Bank of Canada provides a residual guarantee that, in the unlikely event of multiple defaults on a single day, if survivors' prepledged collateral does not cover the defaulters' losses, the Bank will cover the difference.

3. See Bank of Finland website (http://www.bof.fi/eng/3_rahoitusmarkkinat/3.4_Maksujarjestelmat/3.4.3_Kehittaminen/3.4.3.3_Bof-pss2/) for links to studies employing the simulator.

4. However, the collateralized risk controls in the system and the residual Bank of Canada guarantee provide for certainty of settlement even where there are multiple defaults.

2.1 Collateralization

In LVTS, participants cannot have a net debit position if it is not collateralized. Thus, participants first pledge collateral to the Bank of Canada to support their LVTS activity, then apportion parts of it to collateralize each of the defaulter-pays Tranche 1 (T1) and the partially survivors-pay Tranche 2 (T2).[5] Collateral pledged to the Bank by a participant but not apportioned to LVTS is referred to as excess collateral.

In T1, each participant *i* apportions collateral to cover its own obligations. Its maximum allowed net debit position, referred to as its T1 net debit cap ($T1NDC_i$) is set equal to the value of the collateral (minus haircuts) that it has pledged to cover these obligations ($C1_i$). Thus each participant *fully* collateralizes its own T1 obligations.

$$C1_i = TINDC_i \ . \quad (1)$$

In a default, this collateral would be used to cover the defaulter's position, so this stream is referred to as defaulter-pays.

In T2, participants determine how much exposure they are willing to take on vis-à-vis other participants and extend lines of credit accordingly. Each participant *i* must then apportion collateral ($C2_i$) equal to a percentage (θ) of the largest bilateral credit limit (BCL) it has extended to any other participant *j* ($max_j(BCLij)$).[6] This value is called the participant's maximum additional settlement obligation ($maxASO_i$), which is the maximum amount that the participant will have to contribute if one or more participants to which it has granted a bilateral credit limit defaults.

$$C2_i = max_j(BCL_{ij}) \bullet \theta = maxASO_i . \quad (2)$$

In the event of a default, the defaulter's own T1 and T2 collateral will be used first to settle its net debit position. However, if there is a shortfall, survivors' collateral will be used to cover the defaulter's residual T2 obligations. Thus, although T2 is considered to be a survivors-pay tranche, there is a defaulter-pays element as well.

Each participant can incur a net bilateral position debit equal to the bilateral credit limit that has been established for it by the grantor. As well as bilateral credit limits, each participant has a multilateral net debit cap. Each participant *i*'s maximum permitted multilateral T2 net debit position, its T2 net debit cap ($T2NDC_i$), is set equal to the sum of the credit lines received from all participants, multiplied by the system-wide percentage.

$$T2NDC_i = \sum_{j=1}^{N-1} BCL_{ji} \bullet \theta , \quad (3)$$

where there are N LVTS participants.

5. Eligible LVTS collateral includes Bank of Canada funds and government and highly-rated corporate bonds. The usable value of collateral is the market value of each security less a certain amount (a "haircut") to account for market risk.

6. The percentage, referred to as the system-wide percentage, takes into account the effect of netting.

2.2 Settlement

Throughout the day, individual cleared payments are netted and novated and replaced by a net obligation to receive or pay funds.[7] At the end of the day, participants' T1 and T2 positions are combined to yield a final multilateral net position that they must settle. The Bank of Canada facilitates settlement by debiting the settlement accounts of the participants that are in a multilateral net debit (short) position and crediting the accounts of participants that are in a multilateral net credit (long) position.

Solvent participants that are short funds at the end of the day in LVTS may trade with participants that are long funds to obtain the balances needed for settlement. As well, such participants may obtain the funds necessary to settle by taking a *fully collateralized* discretionary advance from the Bank of Canada (at the Bank Rate). Under this option, the participant pledges collateral to the Bank of Canada with a value equal to its deficit position at the close of LVTS and the Bank of Canada credits its settlement account with the funds. The duration of this loan is one day (to be paid back by 6 p.m. the following day).

Participants are allowed to use all the collateral that they have apportioned in LVTS to cover their discretionary advance, namely the collateral that they have apportioned to support their own T1 obligations and the collateral that they have apportioned to T2 to cover the lines of credit they have granted to others. As well, they may apportion their excess collateral in support of their discretionary advance.

2.3 Default

A participant is deemed to be in default if it cannot meet its end-of-day net debit position. A default can occur under two circumstances.

1. The participant is in a net debit position at the end of the day and has insufficient collateral to cover this position, i.e., it has a collateral shortfall.
2. The participant has been suspended from further participation in LVTS during the current LVTS cycle *and* has a net debit position that must be settled.[8] This will occur if a participant is closed by its regulator.

In the event of the default of any participant i, the Bank of Canada will seize the defaulter's apportioned collateral and grant a non-discretionary advance to participant i (NDA_i) equal to the lesser of (i) the absolute value of the participant's combined Tranche 1 and Tranche 2 multilateral net positions ($T1MNP_i$ and $T2MNP_i$, respectively), less any funds the participant is holding in its settlement account at the Bank of Canada (SF_i), or (ii) the participant's apportioned collateral.[9]

$$NDA_i = min[(|TIMNP_i + T2MNP_i| - SF_i), (C1_i + C2_i)]. \tag{4}$$

7. The BIS definition of novation is the following. "Satisfaction and discharge of existing contractual obligations by means of their replacement by new obligations..."
8. If a participant is suspended from further participation in LVTS but is shut-down with a positive position, it will not be declared in default because it does not owe funds to the system.
9. The balance of a participant's settlement account at the Bank of Canada will normally be zero.

In other words, the Bank of Canada will lend the lesser of the actual position that the participant must settle or the collateral the participant has apportioned to cover its position. If it is the latter, survivors will be required to cover the shortfall.[10]

2.4 The ability of participants to generate a shortfall

A participant can incur a larger net debit position than the collateral it must hold. Note that participant *i*'s maximum net debit position ($maxNDP_i$) is the sum of its T1 and T2 net debit caps.[11]

$$maxNDP_i = T1NDC_i + \left(\sum_{j=1}^{N-1} BCL_{ji} \bullet \theta\right). \tag{5}$$

The minimum value of collateral pledged by participant *i* will have to cover its position is:

$$C1_i + C2_i = T1NDC_i + (max_j(BCL_{ij}) \bullet \theta). \tag{6}$$

Thus a participant could incur a position exceeding the value of its own collateral. The maximum own-collateral shortfall for any participant i ($maxOCS_i$) is equal to equation (5) minus equation (6), or:

$$maxOCS_i = \left(\sum_{j=1}^{N-1} BCL_{ji} - max_j(BCL_{ij})\right) \bullet \theta. \tag{7}$$

The maximum own-collateral shortfall also represents the maximum losses to be divided among survivors. In the case of a default where the defaulter has a collateral shortfall, a non-discretionary advance will be granted with a value equal to the defaulter's apportioned collateral ($C1_i + C2_i$), and the survivors will contribute funds to cover the residual shortfall, where residual shortfall will have an upper bound of $maxOCS_i$.

2.5 Loss allocation to survivors

If any one participant i defaults, each participant that granted a bilateral credit limit to that participant will have to contribute funds to cover participant *i*'s shortfall. Participant *j*'s additional settlement obligation (ASO_j), is calculated according to the following formula:[12]

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10. Proof that there will be sufficient collateral to cover one but not necessarily multiple defaults can be found in Appendix A.
11. Recall from equation 3 that each participant's T2NDC is equal to the sum of BCLs received multiplied by the system-wide percentage.
12. In this formula, BCL_{ji} represents the largest bilateral credit limit participant j has granted to defaulting participant i at any time during the day of default. This is important because participants can increase or decrease their BCLs granted during the day and contribute based on their maximum bilateral credit limits granted to the defaulter during the day.

$$ASO_j = OCS_i \bullet \frac{BCL_{ji}}{\sum_{j=1}^{N-1} BCL_{ji}} . \quad (8)$$

Therefore, survivors cover the defaulter's shortfall, with each survivor contributing in proportion to the bilateral credit limit that it has granted to the defaulter.

2.6 Feature of LVTS under analysis

We have seen that, in most circumstances, the bilateral credit limits participants are granted allow them to theoretically generate shortfalls (equation (7)), and that a participant will default if either it has a shortfall it cannot cover or if it is closed by its regulator at a time that it has a net debit position. We know that the system is robust to defaults - each participant fully collateralizes its maximum ASO, and the combination of survivors' ASOs would cover the entire shortfall (equation (11)). LVTS's rules give participants the ability and incentive, not the requirement, to limit their maximum potential losses to a size that they can manage from a solvency perspective. We now estimate the impact of losses on participants' capital adequacy in this study.

3. Comparison to previous literature

In his 1992 and 1993 papers, Engert considers risk controls in payment systems that provide for a system's robustness to default at a minimum cost in terms of collateral requirements. Through a theoretical model, he finds that when a payment system is designed such that survivors share in a defaulter's losses, a system's robustness to default does not necessarily indicate that the same is true for individual participants. Since LVTS is a system which falls into this category, it is important to empirically test whether or not participants are robust to defaults. We will do that here.

Previous studies have explored the potential for contagion following an initial default in uncollateralized netting-based payment systems (Northcott (2002), Humphrey (1986) and Angelini et. al. (1996) are good examples). They assume that the defaulter cannot pay the funds owed to cover its position, and that the participant does not have any collateral to use to fulfil payment of its obligation. The authors make assumptions about key factors such as unwind rules, provisional credit granted to customers and the ability for the remaining participants to withstand the losses resulting from the initial default to determine whether there are any subsequent defaulters. Sensitivity analysis is done, and the authors are able to determine frequencies and magnitudes of knock-on defaults.

As with the studies mentioned, the intention here is to study the effects of initial defaults on the payment system. However, there are a number of differences from the studies mentioned above, mainly based on the fact that LVTS is a collateralized netting system.

- Rather than assuming that each participant that ends the day with a net debit position defaults, we find each participant's largest net debit position during the day and assume that it is shut down at this time. If the participant has a net debit position, it will be a defaulter. Accordingly, we have a larger number of defaults, and larger positions, using this method than if we had used participants' end-of-day positions.

- Because a defaulters' own collateral is first used to cover its net debit position, losses do not accrue to survivors in all cases of default as they do in the studies mentioned. Defaulters' collateral is taken into account when determining the losses to survivors.
- Payments that have cleared in LVTS are not unwound. Therefore, rather than determining losses based on unwinding, they are determined based on actual LVTS loss allocation rules, and are not offset by funds recovered from the accounts of customers.

Based on these differences, we do not expect knock-on defaults to occur in this study.

A recent paper by Galos and Soramäki (2005), is also very relevant to this study. The authors explore what the potential for systemic risk in TARGET2 would be if it were designed as either an uncollateralized deferred net settlement (DNS) system or a collateralized DNS system much like LVTS. They find that under all scenarios the potential for systemic risk is low, however, the loss sharing rule is important. The most effective loss sharing rule is one in which banks share in losses relative to their size.

4. Methodology and choice parameters

If a participant is closed by its regulator during the LVTS day, it will immediately become ineligible for further participation in LVTS. Other participants will continue to clear and settle payments among themselves for the remainder of the day. At the end of the day, the net position of the closed participant as of its time of closure will have to be settled. If this is a net debit position, the participant will be declared in default. The Bank of Canada will grant a non-discretionary advance equal to the lesser of the defaulter's net position or the value of its collateral apportioned to T1 and T2. In the latter case, survivors that granted a bilateral credit limit to the defaulter will have to contribute to cover the shortfall according to the formula in equation (8).

In this study, we create defaults by assuming that each participant is closed by its regulator at the time it incurs its largest combined T1 and T2 net debit position on each day. We find each participant's largest combined net debit position rather than its largest T2 (survivors-pay) net debit position because at settlement, each participant must settle its combined T1 and T2 position and can use all its collateral to do so. For settlement purposes, a net credit position in T1 will offset a net debit position in T2, or vice versa. The maximum potential shortfall between a participant's net debit position and its collateral occurs when the participant incurs its largest combined T1 and T2 net debit position.[13]

We run T1 and T2 transactions together through the simulator and obtain each participant's maximum net debit position, and the time it occurs, from the simulator's output statistics.[14,15] If this is a net debit position, this is an instance of default. The net debit position is then compared to the participant's collateral and, if the former is greater, the participant will have incurred a shortfall. The number and value of shortfalls for each participant are recorded. In each case, survivors' losses (additional settlement obligations) are calculated. The average and maximum losses of

13. Each participant's end-of-day values of collateral are used each day for simplicity and in most cases represent its maximum collateral holdings for that day.

each surviving participant are compared to their assets and regulatory capital requirements to assess whether the survivor can withstand the loss.

5. Findings

5.1 Data

Our period of study spans the 170 business days from March 1 to October 29, 2004. Over this period, the average daily volume and value of payments were 17,063 and $130.2 billion, respectively.

The names and abbreviations of the fourteen institutions that participated in LVTS during the sample period are listed in Box 1.[16] This group contains eight domestic banks (ATB, BMO, BNS, CIBC, LAR, NAT, RBC, and TD), two foreign bank subsidiaries (HSBC and BNP), one foreign bank branch (BOA), one cooperative financial group (CCD), one central finance facility for Canadian credit unions (CUCC), and Canada's central bank (BOC). Participants are classified into 'large' and 'small' participants with the threshold being assets of $200 million. Total assets of each participant can be found in Table 2 of Appendix B.

Box 1: LVTS Participants

1. Alberta Treasury Branches (ATB)
2. Bank of America National Association (BOA)
3. Bank of Canada (BOC)
4. Bank of Montreal (BMO)
5. The Bank of Nova Scotia (BNS)
6. BNP Paribas (Canada) (BNP)
7. Caisse Central Desjardins du Quebec (CCD)
8. Canadian Imperial Bank of Commerce (CIBC)
9. Credit Union Central of Canada (CUCC)
10. HSBC Bank Canada (HSBC)
11. Laurentian Bank of Canada (LAR)
12. National Bank of Canada (NAT)
13. Royal Bank of Canada (RBC)
14. The Toronto-Dominion Bank (TD)

Transactions, collateral and bilateral credit limits data are used to determine participants' maximum positions, shortfalls and loss allocations.

- The transactions data contain the sender, recipient, value, tranche and submission time for each transaction that was successfully cleared by LVTS during our data sample. Transactions that were rejected by LVTS are excluded from our data set.[17]

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14. Our data contain only transactions successfully cleared by LVTS, so we are able to run our simulations without credit limits, with the only outcome being that the few transactions that were actually queued in LVTS would have later actual clearing times than is found by the simulator. (Very few transactions are queued daily, meaning that the impact of queuing on our results is minimal.) We are able to combine T1 and T2 in one simulation to find participants' combined maximum net debit position because credit limits are not applied.
15. To view patterns in the time at which participants incur their largest shortfalls, see Figure B.1 in Appendix B.
16. State Street Bank and Trust Company has been excluded from our analysis since it joined LVTS in October 2004.
17. Rejected transactions are either those that were unprocessable because they contained errors or those that failed the risk controls and were not eligible for queuing. In the second case, we would expect participants to resubmit at a later time.

- Collateral data contain each participant's value of collateral apportioned and pledged and the date and time effective.
- Bilateral credit limits data contain the grantee, grantor, value, date and time effective of each BCL.

As previously described, we also benchmark shortfalls against total assets and capital.

- We obtain information for federally regulated deposit taking institutions and foreign bank subsidiaries from the website of the Office of the Superintendent of Financial Institutions. Monthly assets are from participants' consolidated balance sheets, and quarterly Tier 1 and total capital are from participants' capital adequacy reports.
- For ATB, we obtain annual total assets, Tier 1 and total capital from its 2004/2005 Annual Report.[18]
- For BOA, annual total assets, Tier 1 and total capital are obtained from its 2004 Annual Report.[19]
- For CCD, we obtain total assets and equity (our best estimate of regulatory capital for this institution) from its 2004 Annual Report.
- For CUCC, we obtain total assets and members' equity (an estimate of regulatory capital) from its 2004 Annual Report. These figures represent aggregates of the credit unions and caisses populaires affiliated with CUCC.

5.2 Results

The sample contains 170 days and 13 potential defaulters.[20] Recall that since participants are assumed to be closed at the time of their largest net debit position, we expect our methodology to yield defaults in almost all cases; that is, for most participants on most days. Indeed, defaults occur in 2167 of the 2210 potential cases. These defaults result in 1026 shortfalls.

Result 1: Shortfalls are relatively frequent and on average small. However, there is considerable variability across participants and days.

Recall that we consider a participant to have incurred a shortfall in each instance that its position at the time of closure exceeds its apportioned collateral. We find that shortfalls occur relatively frequently -- in 46% of cases. Individual participants' instances of being in a shortfall position range from 0% to 95% of days. Large participants incur shortfalls 15% more frequently than small participants.

Figure 1 illustrates the size distribution of shortfalls for all participants in the 46% of cases where shortfalls are incurred. As shown, most shortfalls are relatively small. Considering the size of shortfalls more closely provides the following conclusions:

- The average shortfall size for all participants is $210.4 million, with a standard deviation of $181.7 million.
- Shortfalls are on average four times larger on participants' worst days than on average days.

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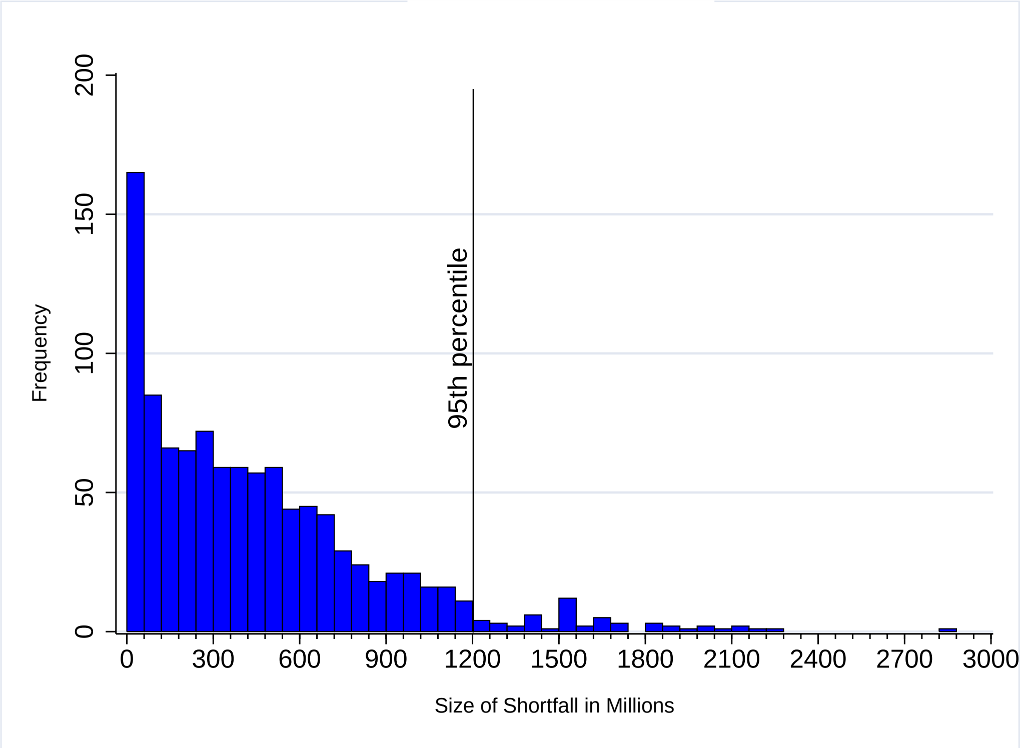
18. The time period of these data span from March 31, 2004 to March 31, 2005.
19. It is relevant to use figures for Bank of America National Association rather than the Canadian bank branch.
20. The Bank of Canada is not a potential defaulter.

- Large participants incur shortfalls that are on average nearly three-and-a-half times larger in absolute terms than those of small participants.
- The average shortfall size for the participant that incurs the largest shortfalls is approximately four times the average of all participants.
- The largest single shortfall in our sample is nearly $2.9 billion. However, 95% of all shortfalls are under $1.2 billion.

Figure 1: Size distribution of all participants' shortfalls



Result 2: The shortfalls incurred are much smaller than the maximum shortfalls possible.

Recall from equation 7 that participants can incur a maximum shortfall equal to a fixed percentage of the amount by which their T2 net debit cap exceeds their T2 collateral. On average, participants incur actual shortfalls that are very small -- just 3.5% of the maximums possible. On each participant's worst day, shortfalls are on average 15.1% of the maximum possible. The largest shortfall that any participant incurs on any day is just over one quarter of its maximum possible.

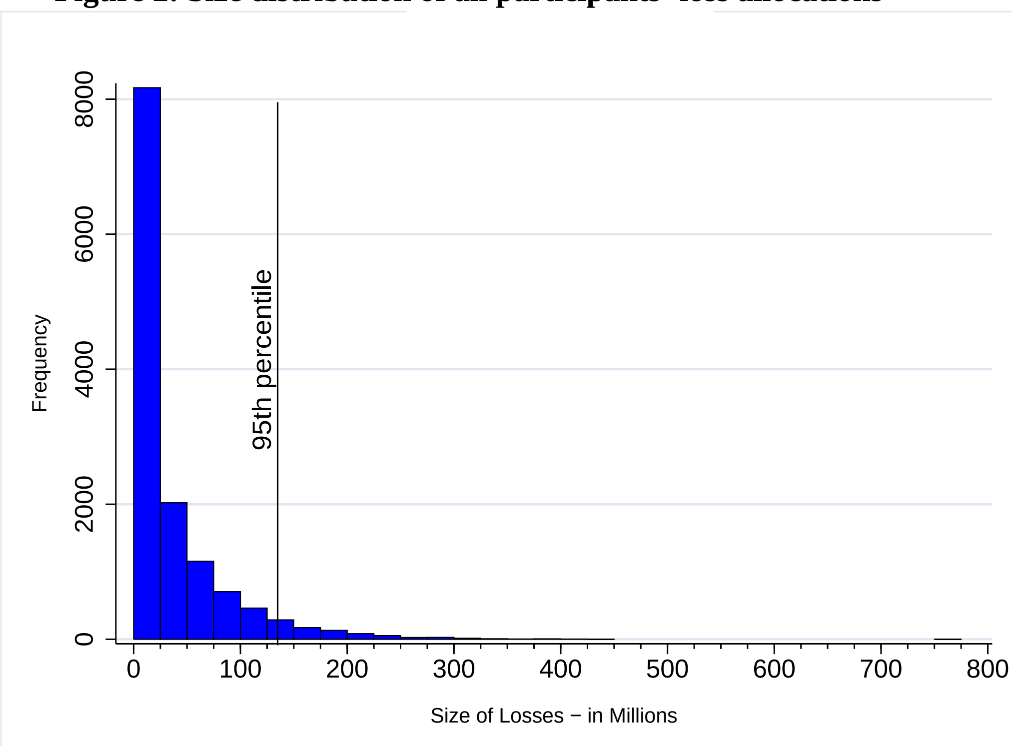
Accordingly, the stresses we see on the system are small compared to what they could be if participants fully used their credit limits granted. Shortfalls and losses generated could be in the range of 4 to 300 times larger than those found here.

Result 3: Survivors' loss allocations are generally small and borne by participants that are most able to withstand them.

Recall from equation (8) that, following a default, each survivor is allocated a share of the defaulter's shortfall in proportion to the size of the bilateral credit limit that it has granted to the defaulter. Figure 2 illustrates the distribution of survivors' losses. As we did for shortfalls, we see that losses are in general small but variable. Specifically,

- The average loss allocation to any participant over the sample period is $16.2 million, with a standard deviation of $38.1 million.
- The average worst loss that participants are exposed to on any day is 15.6 times larger than the average, and amounts to $252.8 million. Therefore, the day that a default occurs could affect the size of participants' losses.
- Large participants' loss allocations are on average 3.7 times those of small participants. Large losses are thus borne by large participants better able to bear them.
- The largest loss allocation any participant receives on any day is $753.7 million. However, 95% of losses are $136 million or lower.

Figure 2: Size distribution of all participants' loss allocations

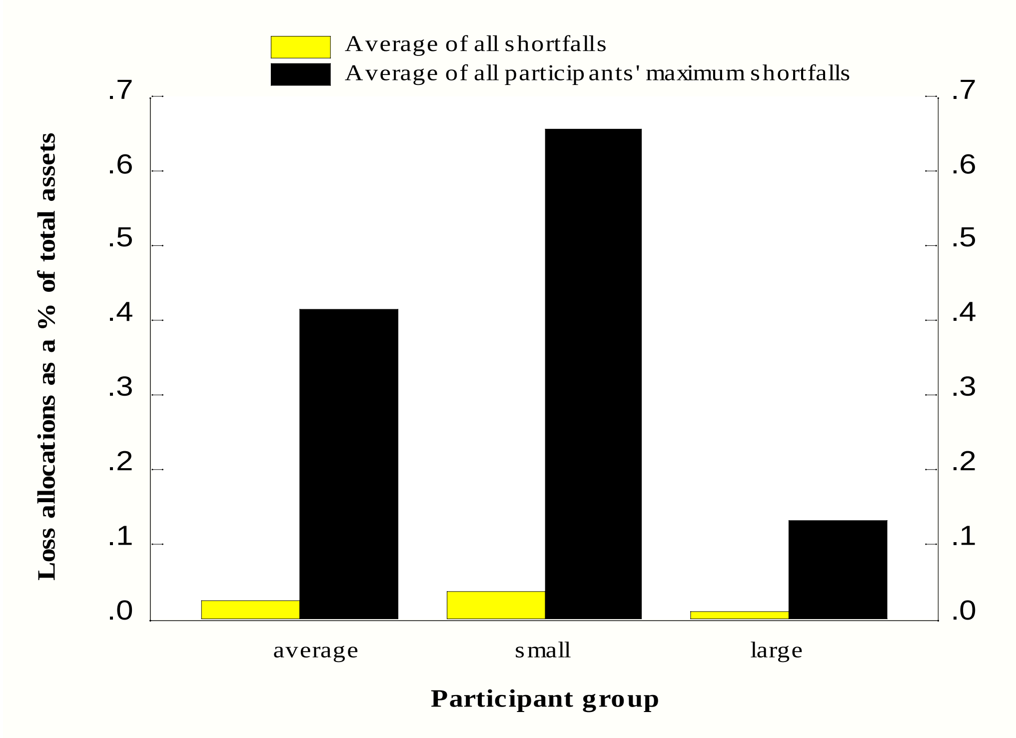


Result 4: Small participants take on the greatest losses compared to asset size.

To scale loss allocations for each participant, we compare losses to each participant's total assets, and refer to loss allocations divided by total assets as loss-to-asset ratios. For participants overall, loss-to-asset ratios are small. The average loss-to-asset ratio for all participants is 0.02%, meaning that the shortfalls generated here would require participants to absorb relatively very small losses. When we consider the largest loss allocation each participant incurs on any day, the loss-to-asset ratio increases to 0.4%. Although this is a significant increase, overall loss ratios remain relatively small.

Figure 3 illustrates average and maximum loss-to-asset ratios for all participants and when grouped by size class, that is large or small participants.[21] Small participants withstand losses that are approximately four times larger as a proportion of assets than large participants, meaning that small participants take on relatively more risk in the system. The loss ratios for all small participants but one, however, are very small. One small participant consistently withstands the largest loss allocations relative to assets, and in the worst case incurs a loss equal to 3.2% of its assets.

Figure 3: Participants' losses as a percentage of total assets



Result 5: Losses compared to capital are generally small but lead to noticable increases in leverage in some cases. Nevertheless, participants are in all cases robust to defaults.

In Canada, federally regulated deposit-taking institutions are required to maintain a minimum level of capital as a buffer against expected and unexpected losses. We measure loss allocations against the highest quality Tier 1 capital because it is the most conservative estimate of the resources banks have to absorb losses. Our results illustrate the capital losses that would result from participants' loss allocations, and whether survivors can withstand their losses.

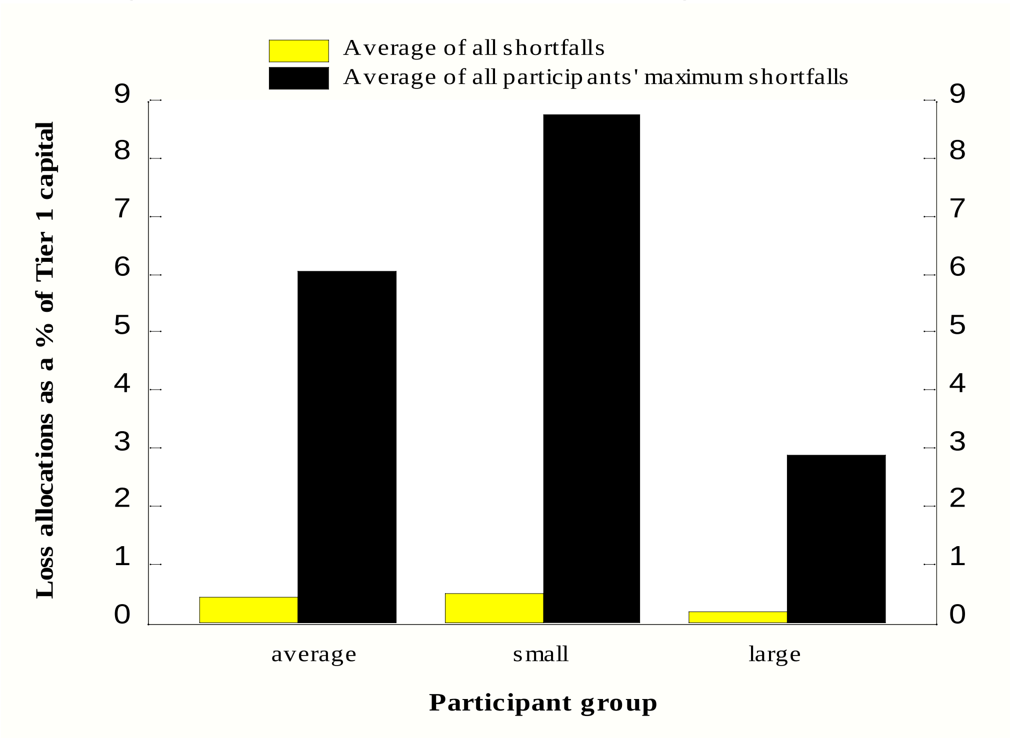
Figure 4 illustrates loss-to-capital ratios for all participants, and when segmented into large and small participants.[22] Participants' average loss-to-capital ratios are very small: losses as a

21. Note that because Bank of America is a branch, it is considered a large participant here as the assets of Bank of America (not the Canadian branch) are used to benchmark its loss allocation.

percentage of capital amount to just 0.35% on average. However, participants' loss to capital ratios are 17 times larger on worst days. We also see that small average participants' loss-to-capital ratios exceed large participants' by approximately three times. Thus, two themes we have seen throughout our results are repeated: (i) the impact a of default on a worst day would be much greater than on an average day; and (ii) small participants take on relatively more risk.

One participant consistently incurs losses as a percentage of capital that are large and exceed those of other participants by a large margin. In the worst case, this participant withstands losses of a third of its capital. Capital after the loss is computed and remains better than that is required by its supervisor. Therefore, even the most significant loss does not cause any participant to subsequently fail.

Figure 4: Participants' losses as a percentage of capital



Result 6: If participants were to use all their pledged collateral to cover their net debit position, shortfalls and losses would be both much smaller and much less frequent.

Recall that shortfalls and losses have thus far been calculated based on the collateral that participants have apportioned in LVTS. Apportioned collateral represents participants' minimum required collateral holdings. However, participants on average hold approximately three times their apportioned collateral as pledged collateral in LVTS and this excess collateral could be apportioned (or put into use) at any time.[23] We now reconsider the results based on participants covering their positions with pledged collateral.

22. Bank of America National Association's capital is used and it is considered to be a large participant.
23. See McPhail and Vakos (2003) for possible reasons why participants may hold excess collateral.

When based on total collateral pledged, the instances and values of shortfalls decrease significantly. In fact, five participants do not incur a shortfall on any day during our data sample. Losses incurred by survivors and loss ratios also decrease by between 50% and 90%. The implication is that participants' losses become almost negligible as a percent of their assets. Even the participant that consistently incurs the greatest loss ratios sees its largest loss incurred reduced to less than one percent of its total assets.

Table 1: Potential shortfalls and losses based on total collateral

	Result	**Reduction compared to base case (apportioned collateral)**
Shortfalls on % of days	8.3%	71%
Average shortfall	$24.8 million	88.2%
Maximum shortfall	$256.3 million	70.1%
Average loss	$1.86 million	88.5%
Maximum loss	$35.44 million	53.6%
Average loss-to-asset ratio	0.002%	90%
Maximum loss-to-asset ratio	0.05%	54.5%

6. Factors affecting shortfalls and losses

The shortfalls and losses to survivors found in this study are based on the assumptions that each participant is closed at the time of its largest net debit position incurred given actual LVTS data and that the default is unanticipated. This section considers the effects of changing particular assumptions central to the analysis.

1. Closure occurs during the LVTS day

We have assumed that a participant is closed by its regulator *during* the LVTS day, and our assumptions make it possible to easily generate unanticipated defaults and have them occur at the worst moment in the day. In all likelihood a regulator would avoid shutting down a participant during the Canadian business day (and during the LVTS day). If a participant were closed outside of LVTS hours, the payment system would not be directly affected.

2. Shortfalls based on positions actually incurred

As is illustrated in Section 5.3, participants incur shortfalls that are small compared to the maximum shortfalls allowed.[24] If a participant were to experience large payment outflows prior to a default (if, for instance, the risk of the bank's failure were known and a bank run resulted), the

24. See equation (8) to understand the maximum shortfalls that participants can incur.

participant might incur a shortfall that was close or equal to its maximum allowed shortfall. Ceteris paribus, increasing participants' shortfalls to the maximum allowed would create losses for survivors that are much larger than the ones found here.

3. Bilateral credit limits granted to the defaulter
The assumption that a default is unanticipated means that bilateral credit limits are likely larger than they would be in the case of an anticipated default. Participants have an incentive to reduce bilateral credit limits to a participant they believe may default in order to minimize their exposure to the defaulter. Other things equal, smaller bilateral credit limits granted to the defaulter would result in smaller losses for survivors than we find here.

4. Recovery rates are not taken into account
In the event that a participant incurred a loss resulting from the default of another participant, it would become an unsecured creditor to the estate of the failed institution. It is likely that the defaulter would recover some portion of its loss. Other studies point to recovery rates of 40% and 95%.[25] In Canada, recovery rates for bank failures occurring between 1967 and March 2001 are estimated at 70-80%.[26]

We have chosen not to reduce participants' additional settlement obligations by expected recovery rates for two reasons. First, participants must meet their entire additional settlement obligation (ASO) on the day a participant defaults. Thus, using participants' entire ASOs to estimate losses illustrates the up-front and maximum obligation that participants will incur before they recover some portion of their funds later. Second, we can be very conservative and not account for recovery from the estate of the failed institution because we do not observe any knock-on defaults.

7. Conclusion

LVTS is a system which incorporates risk controls and a residual guarantee by the Bank of Canada that make it robust to multiple defaults. It employs risk-sharing whereby survivors may be allocated a share of the defaulter's losses in the event of a default. The system's rules give participants both the ability and incentives to control their exposures to other participants so as to keep potential losses manageable. In this paper, we create the largest possible unanticipated defaults based on a sample of actual LVTS activity and estimate whether participants are adequately controlling their risk to be able to withstand the default of another participant.

We find that, in general, participants are easily able to withstand their loss allocations. This partly results from the fact that participants, each of which we consider in turn to be a defaulter, create net debit positions intraday that are much smaller than the maximums possible. In both absolute and relative terms, participants' loss allocations are generally small, but when we compare losses to assets and capital, we see that small participants take on relatively much more risk than large participants. Nevertheless, we find that all participants are robust to the defaults generated here.

25. See Furfine (2003), James (1991) and Kaufman (1994).
26. From the Canadian Deposit Insurance Corporation Annual Reports and Bank of Canada staff calculations.

We also calculate results based on defaulters covering their positions with all their LVTS collateral, including the significant amount of excess collateral most keep in reserve for LVTS purposes. The frequency and size of shortfalls and survivors' losses decrease by between 50% and 90%.

We believe that the losses found in this study are probably larger than we would see if a participant were actually to default. First, we have used the largest shortfalls we can create based on our data to maximize survivors' losses. Second, we have assumed that the default is unanticipated. This prevents participants from reducing or eliminating bilateral credit limits to the defaulter to avoid sharing losses. Finally, we have assumed that survivors do not recover any of their losses. Although the theoretical shortfalls generated in our study are small compared to the maximums defaulters could incur, we believe that the other three factors, and especially the second, greatly outweigh this fact to create losses that are much larger than what we would expect to observe in reality.

There appear to be two important questions for further study. First, why are participants' net debit positions so small compared to the maximums allowed in LVTS? Second, what would be the effect of an anticipated default in LVTS? An anticipated default would likely affect both bilateral credit limit setting behaviour and participants' positions. We believe the impact of an anticipated default would likely be smaller than these considered here, but this requires further analysis.

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Appendix A: Shortfalls and coverage by defaulters

A.1 Coverage of the largest net debtor's position

As noted above, the risk controls ensure that there will be sufficient collateral to cover the default of the largest net debtor. Recall that all participants that grant bilateral credit limits to other participants are required to apportion collateral to cover the largest bilateral credit limit that they grant multiplied by the system-wide percentage, and in the event of one or more defaults will have to contribute up to that amount. Thus the collateral apportioned by all participants, other than the defaulter (participant *i*), to cover defaults is the following:

$$\sum_{j=1}^{N-1} C2_j = \theta \bullet \sum_{j=1}^{N-1} max_i(BCL_{ji}) . \tag{9}$$

Using participant *i*'s maximum own-collateral shortfall from in the text, the maximum loss accruing to surviving participants is the following:

$$\sum_{j=1}^{N-1} maxL_j = \theta \bullet \left(\sum_{j=1}^{N-1} BCL_{ji} - max_j(BCL_{ij}) \right), \tag{10}$$

where $\sum_{j=1}^{N-1} maxL_j$ = the maximum losses from participant *i*'s default that other participants *j* could incur.

Therefore the collateral apportioned by survivors always exceeds survivors maximum possible losses.

$$\sum_{j=1}^{N-1} max_i(BCL_{ji}) > \left(\sum_{j=1}^{N-1} BCL_{ji} - max_j(BCL_{ij}) \right), \tag{11}$$

which must hold because $\sum_{j=1}^{N-1} max_i(BCL_{ji}) \geq \sum_{j=1}^{N-1} BCL_{ji}$ and $max_j(BCL_{ij}) \geq 0$.

A.2 The default of two participants

If more than one participant defaults on the same day, the maximum that each surviving participant *j* will have to contribute to cover the losses of all defaulters on a single day is its maximum additional settlement obligation ($maxASO_j$), which is set equal to the maximum bilateral credit limit it has granted to any other participant, multiplied by the system-wide percentage. Recall that participants apportion T2 collateral equal to this value, so $maxASO_j = \theta \bullet max_i(BCL_{ji}) = C2_j$. Participants' additional settlement obligations vis-a-vis each defaulter are calculated, and if any participant's combined additional settlement obligations resulting from the multiple defaults on a single day exceeds its max ASO, its actual ASO will be set equal to its max ASO.

Consider if participants *i* and *k* default on the same day. Participant *j*'s actual additional settlement obligation is as follows:

$$ASO_j = min\left[maxASO_j, \left(OCS_i \bullet \frac{BCL_{ji}}{\sum_{j=1}^{N-1} BCL_{ji}} + OCS_k \bullet \frac{BCL_{jk}}{\sum_{j=1}^{N-1} BCL_{jk}}\right)\right]. \qquad (12)$$

Therefore, participant j's additional settlement obligation is the minimum of its maximum additional settlement obligation and the sum of its loss allocations to the two defaulters. In the latter case, the Bank of Canada will contribute the difference.

In this case of two defaulters on a single day, it is possible that the second term in equation (12) - the survivor's calculated share of the losses -- exceeds the first term -- the collateral of participant j. Whether or not each other survivor's calculated ASOs are met (whether survivors cover all losses) depends:[27]

- positively on the size of the largest BCL it has granted to any participant, assuming the largest BCL is not granted to either defaulter,
- negatively on each defaulter's own collateral shortfall, and
- negatively on the ratio of the BCL that the survivor has granted to each defaulter compared to its maximum BCL granted, assuming its max BCL is granted to a surviving participant.

Therefore, in the case of multiple defaulters on a single day, the Bank of Canada may have to contribute.

27. Recall that the Bank of Canada will have an ASO equal to 5% of each defaulter's losses in this situation because it has granted a BCL to each participant of 5% of the sum of BCLs received from other participants.

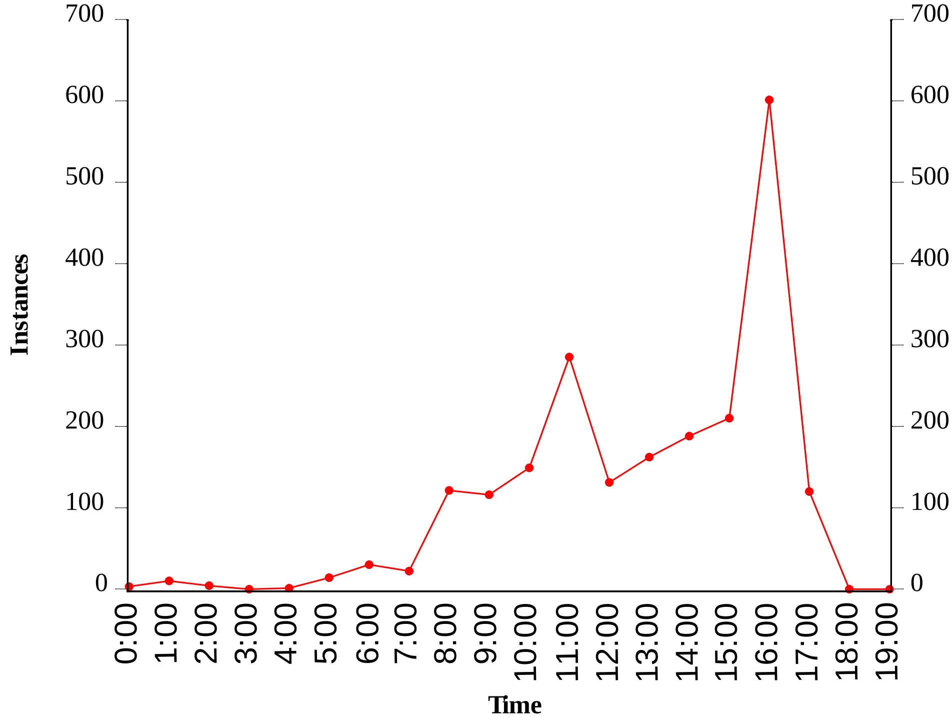
Appendix B: Tables and Figures

Table 2: Assets of LVTS Participants

Rank	Participant	Assets ($ billion)
1	ROYAL	429.26
2	TD	310.55
3	BNS	284.89
4	CIBC	281.72
5	BMO	267.73
6	CCD	103.57
7	NAT	83.45
8	CUCC	74.77
9	HSBC	40.71
10	LAUR	16.50
11	ATB	14.59
12	BOA	4.90
13	BNP	4.26

We classify all participants with assets exceeding $200 billion as large participants. This methodology results in five "large" participants and eight "small" participants.

Figure 5: Time of Participants' maximum net debit positions



The most common time for participants to incur their maximum net debit position is between 4:00 and 5:00 p.m., which corresponds to settlement of Canada's securities clearing and settlement system. The next most common time is between 11:00 and 12:00, which corresponds to settlement of Canada's retail payment system.