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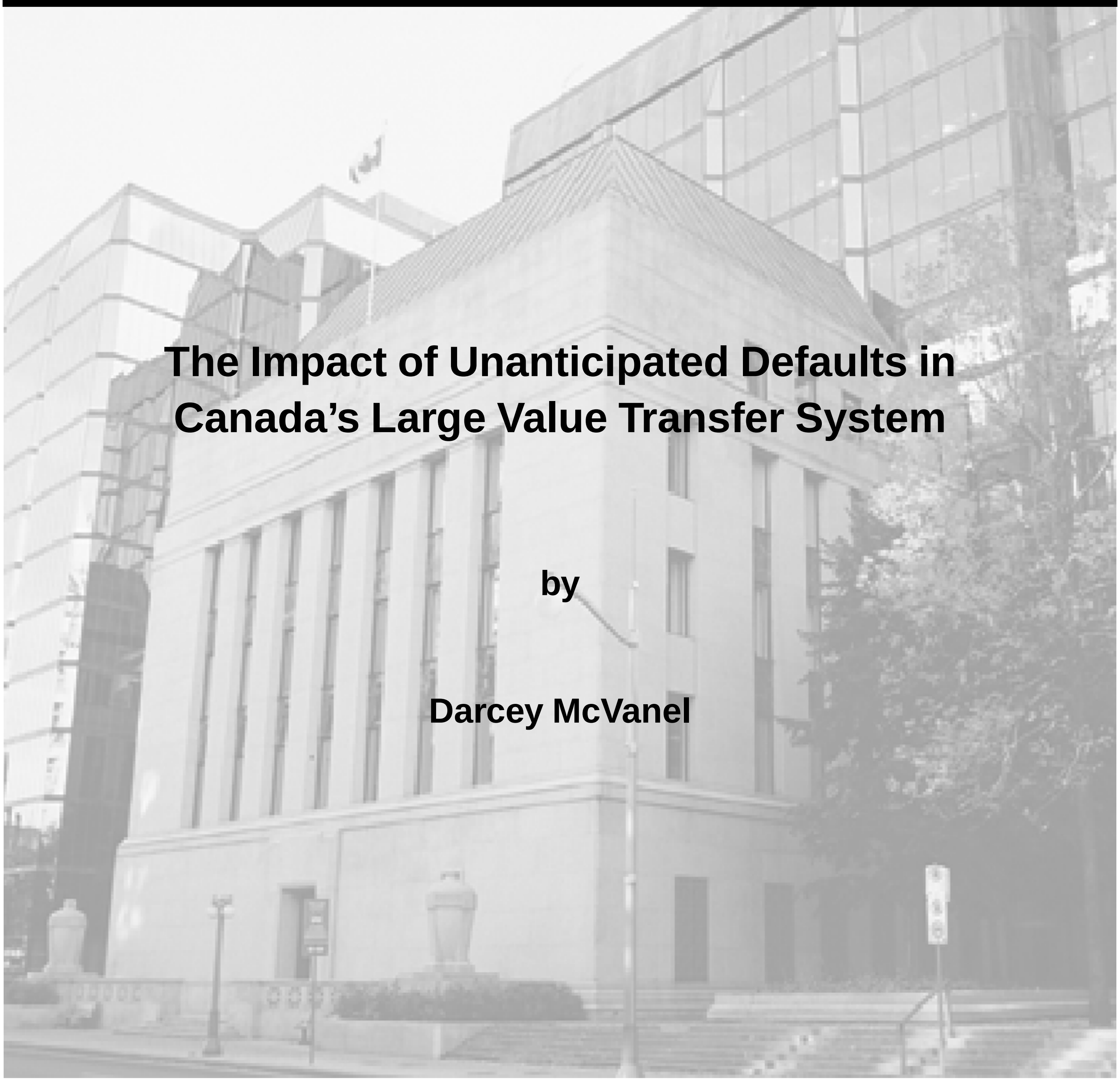

The Impact of Unanticipated Defaults in Canada’s Large Value Transfer System

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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 LVTS is designed to be robust to defaults. Its rules, however, do not ensure that *individual participants* are robust to defaults. The author studies participants' robustness to default empirically by creating unanticipated defaults in LVTS, and finds that all participants are able to withstand their loss allocations that result from the largest defaults she can create using actual LVTS data.

JEL classification: E44, E47, G21
Bank classification: Financial institutions; Payment, clearing, and settlement systems

Résumé

Le Système de transfert de paiements de grande valeur (STPGV) a été conçu pour répondre aux normes internationales en matière de limitation des risques tout en réduisant au minimum les coûts au titre des garanties exigées des participants. Cet objectif est atteint grâce notamment à un mécanisme de partage des risques reposant sur la mise en garantie de titres et servant à répartir les pertes entre les participants en cas de défaillance de l'un d'eux. De par sa conception, le STPGV est assez robuste pour absorber les chocs de ce type, mais ses règles ne visent pas à mettre les *participants eux-mêmes* à l'abri des défaillances. L'auteure examine empiriquement la résilience des participants en simulant des défauts de paiement imprévus au sein du STPGV. Elle constate que tous les participants sont en mesure d'absorber leur quote-part des pertes résultant des plus grosses défaillances qu'elle a pu créer en se fondant sur les données du STPGV.

Classification JEL : E44, E47, G21
Classification de la Banque : Institutions financières; Systèmes de paiement, de compensation et de règlement

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] The system's rules, however, 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 that result from a default. In this paper, I 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. The majority of LVTS transactions go through the survivors-pay component of LVTS, where participants' losses in the event of a default are governed by the bilateral credit limit (BCL) that they grant to the defaulter. The granting of BCLs, as well as their size, is completely voluntary. Given the possibility that another participant could default, participants have an incentive to set BCLs at a size that would create manageable losses for themselves if a default were to occur. Furthermore, in a situation where participants believe that another participant may be in danger of defaulting, it could be in their interest to reduce the BCLs they grant to this participant, to minimize their loss exposures.

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

Results are based on an eight-month (from March to October 2004) sample of LVTS transactions, collateral holdings, and data on bilateral and multilateral credit limits, provided by the Canadian Payments Association. Each participant's maximum net debit position and the time at which it

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 in a single day. This provides for intraday finality of payments.
2. I believe that loss allocations would likely be larger when a default is unanticipated than anticipated since, as already described, participants that anticipate a default may have incentives to reduce the BCLs they grant to that participant.

was incurred are found using the Bank of Finland Payment and Settlement Simulator ("the simulator"). Survivors' additional settlement obligations (ASOs) are calculated according to LVTS rules.

I find that the shortfalls resulting from the 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 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 losses are compared with assets and capital, small participants take on relatively much more risk than large participants. Nevertheless, I find that all participants are robust to the defaults generated.

This paper contributes to the literature in two respects. First, most previous work has focused on losses to survivors in uncollateralized netting systems; I consider losses in a risk-proofed and collateralized system. Second, I apply 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 with the previous literature. Section 4 explains the procedure for generating defaults. Sections 5, 6, and 7 describe the findings, and the impact of key assumptions. Appendix A contains proofs of the efficacy of LVTS's risk controls, and Appendix B shows the times of participants' maximum net debit positions.

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 payments system that 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.
- LVTS is a collateralized, deferred net settlement system. Unlike in real-time gross settlement systems, in which settlement defaults cannot occur inside the system (because settlement of

3. See the 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 that use the simulator.

payments involves the immediate transfer of funds across the books of the settlement institution), settlement 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 pledges to support LVTS activity. Thus, survivors may have to contribute to cover losses in the event of a default. Approximately 88 per cent of LVTS value goes through the partially survivors-pay payment stream.
- The risk controls are designed so that there will be sufficient aggregated collateral in the system to cover at least the largest net debit position possible, or, put differently, at least the default of the largest single net debtor.
- The system will always settle, because all participants contribute to a collateral pool and 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.

2.1 Collateralization

Participants first pledge collateral to the Bank of Canada to support their LVTS activity, and they 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:

$$C1_i = T1NDC_i \ . \tag{1}$$

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

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.
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.

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 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 BCL defaults:

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

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

Each participant can incur a net bilateral debit position equal to the BCL that has been established for it by the grantor. As well as BCLs, 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 systemwide percentage:

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

where there are N LVTS participants.

2.2 Settlement

Throughout the day, individual payments that have passed the risk controls are netted, 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. Through this settlement process, net debtors discharge their credit obligations and net creditors receive Bank of Canada funds.

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6. The percentage, referred to as the systemwide percentage, takes into account the effect of netting.
7. The Bank for International Settlements (BIS) (2003) defines novation as the "Satisfaction and discharge of existing contractual obligations by means of their replacement by new obligations."

Solvent participants that are short funds at the end of the day in LVTS may trade with participants that are long funds to borrow the funds 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:

(i) 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.

(ii) 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]:

$$NDA_i = min[(|T1MNP_i + T2MNP_i| - SF_i), (C1_i + C2_i)]. \tag{4}$$

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. For the latter case, 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 pledges for LVTS purposes. 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* 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 the residual shortfall will have an upper bound of $maxOCS_i$.

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10. Appendix A provides proof that there will be sufficient collateral to cover one but not necessarily multiple defaults.
11. Recall from equation (3) that each participant's *T2NDC* is equal to the sum of BCLs received multiplied by the systemwide percentage.

2.5 Loss allocation to survivors

If any one participant *i* defaults, each participant that granted a BCL 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]:

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

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

2.6 Feature of LVTS under analysis

I have shown that, in most circumstances, the BCLs granted to a participant can allow collateral shortfalls (equation (7)) and defaults. The system is robust to defaults. 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. However, the impact of losses on participants' capital adequacy is not known with confidence. This study estimates that impact.

3. Comparison with Previous Literature

In his 1992 and 1993 papers, Engert considers risk controls in payments systems that provide for a system's robustness to default at a minimum cost in terms of collateral requirements. Through a theoretical model, Engert finds that when a payments 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 that falls into this category, it is important to empirically test whether participants are robust to defaults.

12. In this formula, BCL_{ji} represents the largest BCL 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 BCLs granted to the defaulter during the day.

Previous researchers have studied the potential for contagion following an initial default in uncollateralized netting-based payments systems (good examples are Northcott 2002; Humphrey 1986; and Angelini, Maresca, and Russo 1996). 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 fulfill payment of its obligation. The researchers make assumptions about key factors such as unwind rules, provisional credit granted to customers, and the ability of the remaining participants to withstand the losses resulting from the initial default to determine whether there are any subsequent defaulters. Sensitivity analysis is performed, and the researchers are able to determine frequencies and magnitudes of knock-on defaults.

As with the previous studies, my aim is to study the effects of initial defaults on the payments system. A number of differences exist from the previous studies, however, based mainly 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, I find each participant's largest net debit position during the day and assume that it is shut down at that time. If the participant has a net debit position, the participant will be a defaulter. Accordingly, a larger number of defaults, and larger net debit positions, occur using this method than if participants' end-of-day positions had been used.
- 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 previous studies. Defaulters' collateral is taken into account when determining the losses to survivors.
- Payments that have cleared in LVTS are not unwound. Therefore, losses 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, I do not expect knock-on defaults to occur in this study.

In a recent paper, Galos and Soramäki (2005) 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, but that 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. The Bank of Canada will then acquire the collateral as remuneration for the advance. In the latter case, survivors that granted a BCL to the defaulter will have to contribute to cover the shortfall according to the formula used in equation (8).

In this study, I 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. I 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]

I run T1 and T2 transactions together through the simulator and obtain each participant's maximum net debit position, and the time at which 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 with the participant's collateral and, if the former is greater, the participant has incurred a shortfall. The number and value of shortfalls for each participant are recorded. In each case, survivors' losses (ASOs) are calculated. The average and maximum losses of each surviving participant are compared with their assets and regulatory capital requirements to assess whether the survivor can withstand the loss.

13. Each participant's end-of-day collateral holdings are used each day for simplicity and in most cases represent its maximum collateral holdings for that day.
14. The data contain only transactions that have passed the LVTS risk controls, so I can run simulations without incorporating credit limits. I can 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 B1 in Appendix B.

5. Findings

5.1 Data

The period of study spans the 170 business days from 1 March to 29 October 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 co-operative 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 billion. Total assets of each participant are reported in Table 1.

Box 1: LVTS Participants

1. Alberta Treasury Branches Financial (ATB)
2. Bank of America National Association (BOA)
3. Bank of Canada (BOC)
4. Bank of Montreal (BMO)
5. Bank of Nova Scotia (BNS)
6. BNP Paribas (Canada) (BNP)
7. Caisse centrale Desjardins du Québec (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. Toronto-Dominion Bank (TD)

Transactions, collateral, and BCL 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 the data sample.
- Collateral data contain each participant's value of collateral apportioned and pledged, and the date and time effective.
- BCL data contain the grantee, grantor, value, date, and time effective of each BCL, which are used to calculate participants' ASOs.

16. State Street Bank and Trust Company is excluded from the analysis because it joined LVTS only in October 2004.

Table 1: 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

Note: All participants with assets exceeding $200 billion are classified as large participants. This methodology results in five "large" participants and eight "small" participants.
Source: The Office of the Superintendent of Financial Institutions and participants' websites.

As previously described, I also benchmark shortfalls against total assets and capital:

- Information on federally regulated deposit-taking institutions and foreign bank subsidiaries is obtained from the website of the Office of the Superintendent of Financial Institutions (OSFI 2005a, b). Information on monthly assets is obtained from participants' consolidated balance sheets, and information on quarterly Tier 1 and total capital is obtained from participants' capital adequacy reports.

- For ATB, information on annual total assets, Tier 1, and total capital is obtained from its *2004/2005 Annual Report* (Alberta Treasury Branches Financial 2005).[17]

17. The time period for these data is from 31 March 2004 to 31 March 2005.

- For BOA, information on annual total assets, Tier 1, and total capital is obtained from its *2004 Annual Report* (Bank of America National Association 2005).[18]
- For CCD, information on total assets and equity (the best estimate of regulatory capital for this institution) is obtained from its *2004 Annual Report* (Desjardins Group 2005).
- For CUCC, information on total assets and members' equity (an estimate of regulatory capital) is obtained from its *2004 Annual Report* (Credit Union Central of Canada 2005). 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.[19] Recall that, since participants are assumed to be closed at the time of their largest net debit position, the methodology is expected to yield defaults in almost all cases; that is, for most participants on most days. Indeed, defaults occur in 2,167 of the 2,210 potential cases. These defaults result in 1,026 shortfalls.

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

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

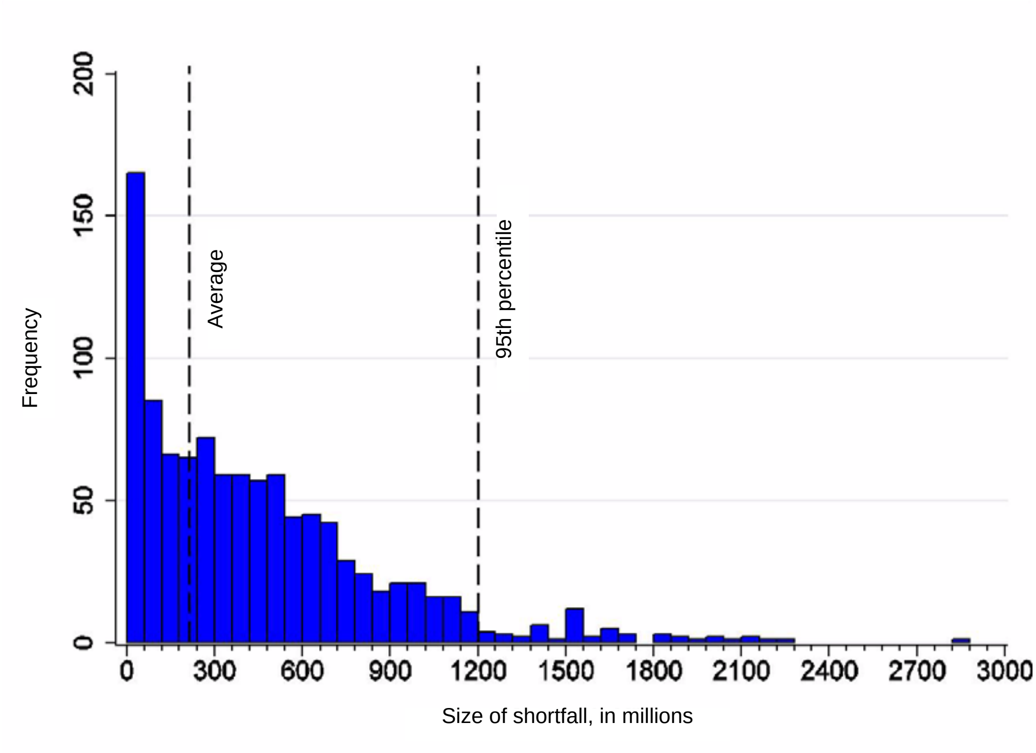
Figure 1 illustrates the size distribution of shortfalls for all participants in the 46 per cent of cases where shortfalls are incurred. As shown, most shortfalls are relatively small. Considering the size of shortfalls more closely provides the following conclusions:

- 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.

18. It is relevant to use figures for the Bank of America National Association rather than the Canadian bank branch.
19. 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 that of all participants.
- The largest single shortfall in the sample is nearly $2.9 billion. However, 95 per cent 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.

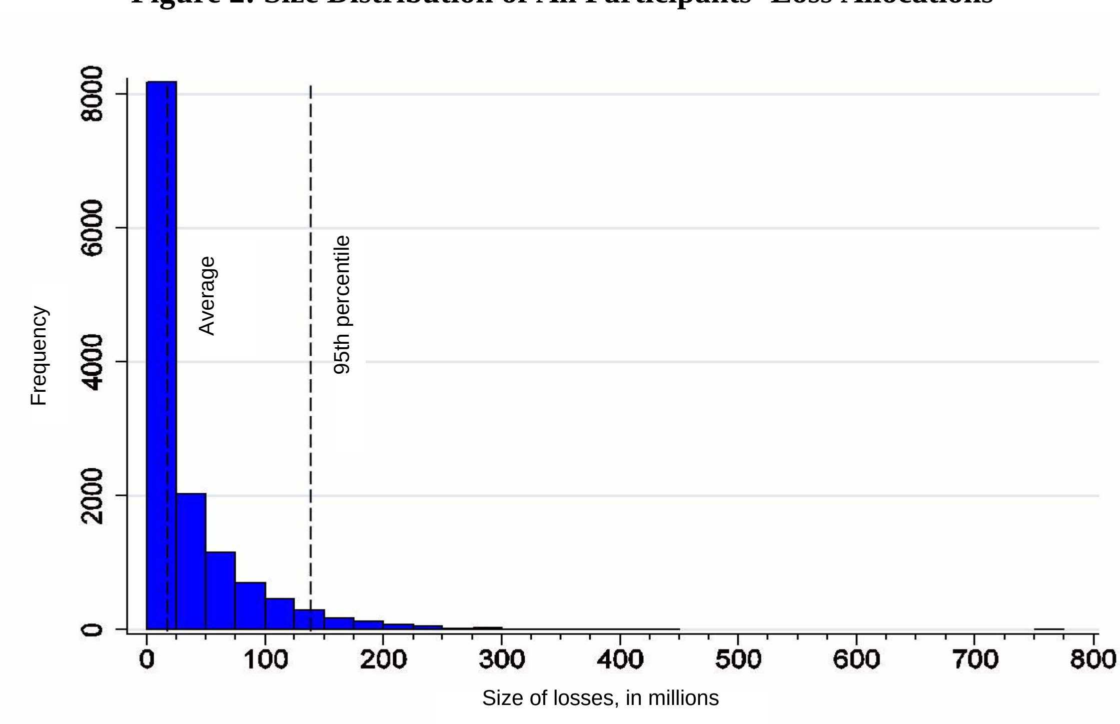
Recall from equation (7) that participants can incur a maximum shortfall equal to a fixed percentage of the amount by which their T2 net debit cap exceeds their T2 collateral. On average, participants incur actual shortfalls that are very small—just 18.1 per cent of the maximum possible. On each participant's worst day, shortfalls are, on average, 81.3 per cent of the maximum possible. Accordingly, average stresses on the system are small. However, at times, participants utilize most of the credit granted to them.

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 BCL that it has granted to the defaulter. Figure 2 illustrates the distribution of survivors' losses. As with shortfalls, 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 that are better able to bear them.
- The largest loss allocation any participant receives on any day is $753.7 million. However, 95 per cent of losses are $136 million or lower.

Figure 2: Size Distribution of All Participants' Loss Allocations

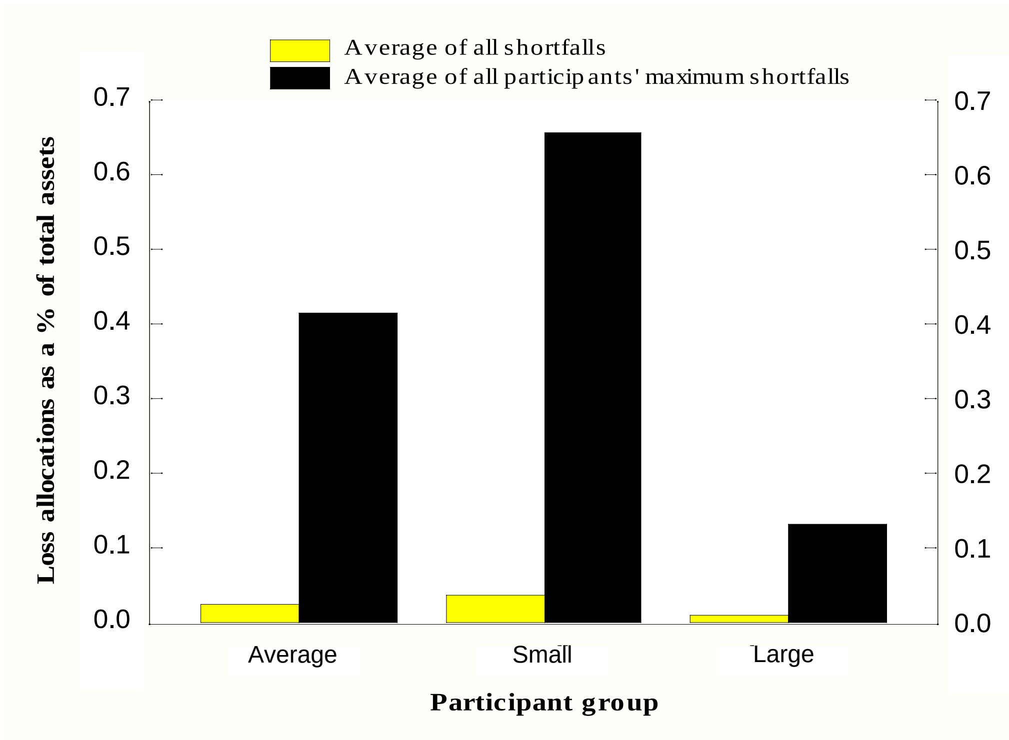


Result 4: Small participants take on the greatest losses compared with asset size.

To scale loss allocations for each participant, I compare losses with 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 per cent. When the largest loss allocation that each participant incurs on any day is considered, the loss-to-asset ratio increases to only 0.4 per cent.

Figure 3 illustrates average and maximum loss-to-asset ratios for all participants, and also when grouped as large or small participants.[20] 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.

Figure 3: Participants' Losses as a Percentage of Total Assets



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

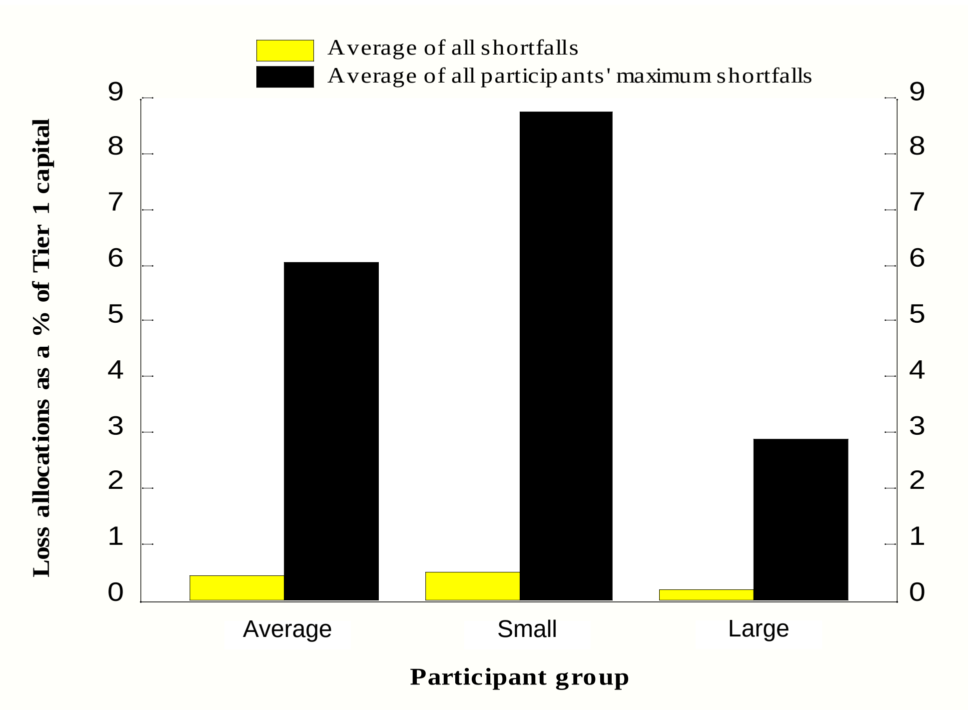
Result 5: Losses compared with capital are generally small but lead to noticeable increases in leverage in some cases. Nevertheless, participants are, in all cases, robust to defaults.

Loss allocations are measured against the highest quality Tier 1 capital because it is the most conservative estimate of the resources that banks have to absorb losses. The 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 also when grouped as large and small participants.[21] Participants' average loss-to-capital ratios are very small: losses as a percentage of capital amount to just 0.35 per cent, on average. On the worst days, however, participants' loss-to-capital ratios are 17 times larger. Small average participants' loss-to-capital ratios exceed those of large participants by approximately three times. Thus, two themes that have occurred throughout the results are repeated: (i) the impact of a default on a worst day greatly exceeds that of an average day, and (ii) small participants are more affected by defaults than large participants.

In the worst case, losses can be as high as one-third of capital. Even in the worst case, however, the participant's capital remains better than that 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



21. The Bank of America National Association's capital is used and that bank is considered to be a large participant.

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 to Tranches 1 and 2 in LVTS. Apportioned collateral represents participants' minimum levels of pledged collateral required for LVTS. On average, however, participants pledge approximately three times their apportioned collateral to the Bank of Canada and this excess collateral could be apportioned (or put into use) at any time.[22]

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 the data sample. Losses incurred by survivors and loss ratios also decrease by between 50 per cent and 90 per cent. The implication is that participants' losses become almost negligible as a percentage of their assets. Even the participant that consistently incurs the greatest loss ratios sees its largest loss incurred reduced to less than 1 per cent of its total assets (Table2).

Table 2: Potential Shortfalls and Losses Based on Total Collateral

	Result	**Reduction compared with base case (apportioned collateral) (per cent)**
Shortfalls on percentage of days	8.3 per cent	71
Average shortfall	$20.4 million	90.3
Average of participants' maximum shortfall	$446.0 million	49.0
Average loss	$1.86 million	88.5
Maximum loss	$35.44 million	53.6
Average loss-to-asset ratio	0.002 per cent	90
Maximum loss-to-asset ratio	0.05 per cent	54.5

22. See McPhail and Vakos (2003) for a model of collateral holdings in LVTS that largely explains why participants hold excess collateral. Participants' total collateral needs are a function of the opportunity and transactions costs of collateral, the variance in payments flows, and the cost of payments delay.

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.

(i) Closure occurs during the LVTS day

I have assumed that a participant is closed by its regulator *during* the LVTS day, and my 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 payments system would not be directly affected.

(ii) Shortfalls based on positions actually incurred

As section 5.2 explains, participants incur shortfalls that are small compared with the maximum shortfalls allowed.[23] If a participant were to experience large payment outflows prior to a default (if, for instance, a bank's failure were widely anticipated and a bank run resulted), the participant might incur a shortfall that was close or equal to its maximum allowed shortfall. Increasing participants' shortfalls to the maximum allowed, other things equal, would create losses for survivors that are much larger than the ones found here.

(iii) BCLs granted to the defaulter

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

(iv) 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 per cent and 95 per cent (see Furfine 2003; James 1991; Kaufman 1994). In Canada,

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

recovery rates for bank failures that occurred between 1967 and March 2001 are estimated at 70–80 per cent.[24]

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

7. Conclusion

LVTS 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 the incentives to control their exposures to other participants so as to keep potential losses manageable. In this paper, I have created the largest possible unanticipated defaults based on a sample of actual LVTS activity, and estimated whether participants are adequately controlling their risk to be able to withstand the default of another participant.

I have found that, in general, participants are easily able to withstand their loss allocations. This partly results from the fact that, on average, participants, each of which I 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 I compare losses with assets and capital, small participants take on relatively much more risk than large participants. Nevertheless, I find that all participants are robust to the defaults generated here.

I have also calculated 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 per cent and 90 per cent.

I believe that the losses found in this study are probably larger than would occur if a participant were actually to default. First, I have used the largest shortfalls I can create based on the data to maximize survivors' losses. Second, I have assumed that the default is unanticipated. This

24. From the Canadian Deposit Insurance Corporation annual reports and Bank of Canada staff calculations.

prevents participants from reducing or eliminating BCLs to the defaulter to avoid sharing losses. Finally, I have assumed that survivors do not recover any of their losses. Although the theoretical shortfalls generated in this study are small compared with the maximums that defaulters could incur, I believe that the other three factors, and especially the second, greatly outweigh this fact to create losses that are much larger than what one 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 with the maximums allowed in LVTS? Second, what would be the effect of an anticipated default in LVTS? An anticipated default would likely affect both BCL-setting behaviour and participants' positions. I believe that the impact of an anticipated default would likely be smaller than those 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 in the main text, 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 BCLs to other participants are required to apportion collateral to cover the largest BCL that they grant multiplied by the systemwide 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 as follows:

$$\sum_{j=1}^{N-1} C2_j = \theta \bullet \sum_{j=1}^{N-1} max_i(BCL_{ji}) . \qquad \text{(A1)}$$

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

$$\sum_{j=1}^{N-1} maxL_j = \theta \bullet \left(\sum_{j=1}^{N-1} BCL_{ji} - max_j(BCL_{ij}) \right), \qquad \text{(A2)}$$

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 the survivors' maximum possible losses:

$$\sum_{j=1}^{N-1} max_i(BCL_{ji}) > \left(\sum_{j=1}^{N-1} BCL_{ji} - max_j(BCL_{ij}) \right), \qquad \text{(A3)}$$

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 BCL it has granted to any other participant, multiplied by the systemwide percentage. Recall that participants apportion T2 collateral equal to this value, so $maxASO_j = \theta \bullet max_i(BCL_{ji}) = C2_j$. Participants' ASOs vis-a-vis each defaulter are calculated, and if any participant's combined ASOs resulting from the multiple defaults on a single day exceed its maximum ASO, its actual ASO will be set equal to its maximum ASO.

Consider a case where participants *i* and *k* default on the same day. Participant *j*'s actual ASO is as follows:

$$ASO_j = min\left[maxASO_j, \left(OCS_i \bullet \frac{BCL_{ji}}{\sum_{j=1}^{N-1} BCL_{ji}} + OCS_k \bullet \frac{BCL_{jk}}{\sum_{j=1}^{N-1} BCL_{jk}}\right)\right]. \qquad (A4)$$

Therefore, participant *j*'s ASO is the minimum of its maximum ASO 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 (A4), the survivor's calculated share of the losses, exceeds the first term: the collateral of participant *j*. Whether each survivor's calculated ASOs are met (that is, whether survivors cover all losses) depends[1]:

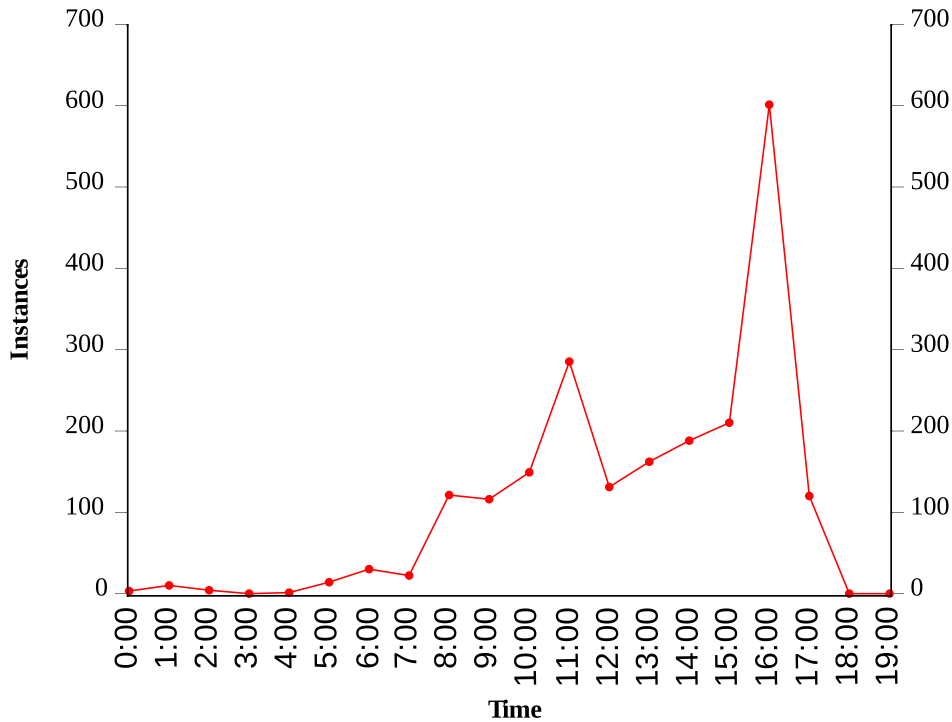
- positively on the size of the largest BCL it has granted to any participant, assuming that the largest BCL is not granted to either defaulter,
- negatively on each defaulter's own collateral shortfall, and
- negatively on the ratio of the BCL that the survivor has granted to each defaulter compared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

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

Appendix B

Figure B1: Time of Participants' Maximum Net Debit Positions



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

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