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# **The Effects of a Disruption in CDSX Settlement on Activity in the LVTs: A Simulation Study**

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A Simulation Study**

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## Abstract

The Large Value Transfer System (LVTS) for settling large payments, and CDSX for settling debt and equity trades, are two of the main settlement systems in Canada. They are closely linked; for example, at the end of the day the final CDSX payment obligations must settle on the Bank of Canada's books, with payments made through the LVTS. CDSX settlement payments account for an important portion of LVTS activity. Therefore, any event that disrupts CDSX settlement may have systemic implications for the LVTS. Through simulation analysis, the authors quantitatively assess the potential impacts of a disruption to CDSX settlement on LVTS activity, and examine the mitigating actions implemented during such an event. Their results indicate that a disruptive event could lead to a considerable amount of rejected payments and payment delays. These findings highlight the importance of business continuity plans to prevent disruptions, contingency measures to ensure that delays are short, and mitigating actions that can be taken to reduce the impacts of a disruption when it does occur.

*JEL classification: E58, G21*

*Bank classification: Payment, clearing, and settlement systems; Financial stability*

## Résumé

Le Système de transfert de paiements de grande valeur (STPGV), qui assure le règlement des gros paiements, et le CDSX, qui prend en charge le règlement des opérations sur titres de dette et de participation, comptent parmi les principaux systèmes de règlement du Canada. Les deux sont étroitement liés; par exemple, en fin de journée, le règlement final des obligations de paiement dans le CDSX doit être effectué dans des comptes tenus à la Banque du Canada, et les paiements connexes transitent par le STPGV. Les paiements de règlement dans le CDSX représentent une part élevée des opérations du STPGV. Par conséquent, toute perturbation du processus de règlement du CDSX peut avoir des répercussions systémiques sur le STPGV. Par une analyse de simulation, les auteurs de l'étude évaluent quantitativement les effets potentiels de ce type d'incident sur l'activité du STPGV, et ils passent en revue les mesures d'atténuation mises en œuvre dans une telle situation. Leurs résultats indiquent qu'une perturbation du processus de règlement du CDSX peut entraîner un nombre considérable de rejets et de retards de paiement. Dans leurs conclusions, les auteurs soulignent l'importance des plans de continuité des opérations, pour prévenir les perturbations, des mesures de contingence, qui permettent de limiter la durée des retards, et des mesures d'atténuation, destinées à réduire les effets des perturbations.

*Classification JEL : E58, G21*

*Classification de la Banque : Systèmes de paiement, de compensation et de règlement; Stabilité financière*

# 1 Introduction

A safe and efficient financial infrastructure is important for the sound operation of the Canadian financial system. The Large Value Transfer System (LVTS) is used for large payments between its participants and CDSX for clearing and settling of debt and equity securities. Both of these systems have been designated as systemically important pursuant to the Payment Clearing and Settlement Act, and are important elements of Canada's financial infrastructure. In addition to being important systems in their own right, the LVTS and CDSX are linked in many ways. For example, many of the LVTS participants are also CDSX participants and large quantities of funds pass through LVTS for final settlement of the net funds positions in CDSX.<sup>1</sup> In the past, there have been instances where operational events have caused CDSX settlement to be delayed.<sup>2</sup> Such delays have the potential to disrupt the normal functioning of the LVTS. However, business continuity plans exist to prevent events from occurring, and contingency measures can ensure that such events are short when they do occur. In addition, actions can be taken to mitigate the effects of a CDSX delay. The operator of CDSX, the participants, and the Bank have long recognized the importance of the link between CDSX and the LVTS created by CDSX settlement; however, prior to our study, the effects on the LVTS of a delay to CDSX settlement have not been quantitatively assessed.<sup>3</sup> Our aim is to understand the potential impacts on LVTS activity of a disruption to CDSX settlement, and to explore the contingencies and mitigating actions that can prevent or reduce the impacts.

The Bank of Canada plays an important role as the settlement agent for CDSX. At the end of the business day, each participant in a negative CDSX funds position must make pay-ins to the Bank of Canada.<sup>4</sup> The Bank collects the pay-ins and then makes the pay-outs on behalf of the CDSX operator to those participants in a positive end-of-day CDSX funds position. The LVTS participants can anticipate whether they will be in a positive or negative CDSX position. Participants plan their LVTS activity, taking into account the anticipation of either making a pay-in or receiving a pay-out for CDSX settlement. If the anticipated CDSX settlement payment is not received as expected at the end of the day, the participants' end-of-day activity in the LVTS

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1. There are other links between CDSX and LVTS. For example, LVTS collateral is pledged through CDSX, and there is a mechanism to allow funds to be transferred between CDSX and LVTS.
  2. Operational events are disruptions that prevent participants from sending or receiving payments due to, for example, technical problems or human errors.
  3. Freedman (1999) describes the links between the LVTS and the Debt Clearing Service (DCS), a system that preceded CDSX.
  4. We refer to the payments owed to the CDS Clearing and Depository Services Inc. (CDS) in order to settle a negative funds position as pay-ins, and those payments owed from CDS to the CDSX participants with positive funds positions as pay-outs.

will be affected. The participants can take action to mitigate the impact. Examining the potential effects on the LVTS payment activity when the CDSX settlement funds are not available helps us better understand the interdependencies between these two systems.

On occasion, the CDSX settlement pay-outs are delayed: for example, the Bank of Canada could be unable to send the CDSX pay-outs because it experiences an operational event at the end of the day; a participant may experience an outage that prevents it from making its CDSX pay-in; or an event at CDS could prevent settlement from being completed. Contingency measures are available to ensure that delays are short. In addition, mitigating actions can be implemented to reduce the impact of a delay. This study allows us to assess the possible effects if CDSX settlement could not be completed and mitigating actions were not taken.

Previous researchers have examined how liquidity is used in large-value payments systems. Theoretical studies (for example, Angelini 1998; Bech and Garratt 2003; Buckle and Campbell 2003) and empirical studies (for example, McAndrews and Rajan 2000; McAndrews and Potter 2002) examine how participants use received payments as a source of liquidity. In our work, we examine how a shock to the expected receipt of liquidity through a settlement payment can affect late-day LVTS activity. Our study contributes to the literature by highlighting the interlinkages between two important payments systems, and the impacts one system can have on the other.

We simulate a situation where the pay-ins are completed but the pay-outs are not made. This creates the largest possible impacts, because it means that the Bank of Canada is trapping liquidity. In addition, in the simulation, no contingency measures or mitigating actions are implemented. To quantify the potential effects, we use the Payment and Settlement System Simulator (the BoF-PSS2) developed by the Bank of Finland and adapted to replicate the LVTS. The Bank of Canada has used simulation methodology to conduct other analyses: see, for example, McVanel (2005), Arjani (2006), and Ball and Engert (2007). Researchers at other central banks have also demonstrated the simulator's usefulness in studying a variety of issues related to payments systems.<sup>5</sup>

The results of our simulated disruption to CDSX settlement indicate that it affects end-of-day LVTS activity. In the simulation, the participants experience rejected payments and increased payments delay, and are required to rely less on received payments to fund their outgoing payments. In addition, a disruption to CDSX settlement will likely affect pre-settlement activity

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5. Many research documents on payments systems that use a simulation methodology are available on the Bank of Finland website at <<http://www.bof.fi/en>>.

in the LVTS. Mitigating actions could be used to reduce these potential impacts. We examine past cases where CDSX settlement was delayed in order to understand the mitigating actions that participants take to reduce the impacts of delays. Based on historical events, we find that participants respond to delays by apportioning additional collateral and moving some payments to the Tranche 2 (T2) payment stream. These mitigating actions, along with business continuity plans and contingency responses, are important for ensuring that the Canadian financial system functions smoothly.

The remainder of this paper is organized as follows. Section 2 provides a more detailed explanation of the connection between CDSX and the LVTS. In section 3, we discuss business continuity plans and contingency measures that can prevent operational events, and we examine the mitigating actions that participants have taken in past cases of CDSX settlement delay. In sections 4 and 5, we explain the simulation methodology and discuss the data used. In section 6 we describe the results of the simulation. In section 7 we offer some conclusions and identify areas for further research.

## **2 CDSX Settlement Through the LVTS**

CDSX is one of the main clearing and settlement systems for Canadian-dollar-denominated debt and equity trades and related entitlement payments (for example, maturities, interest, and dividends). It is owned and operated by the CDS Clearing and Depository Services Inc. (CDS). CDSX has been designated as systemically important pursuant to the Payment Clearing and Settlement Act, and is overseen by the Bank of Canada. CDSX has many participants; most of the LVTS participants are also CDSX participants. CDSX participants must arrange to have their end-of-day CDSX funds position settled through the LVTS on the CDSX settlement account at the Bank of Canada so that CDSX is settled in central bank funds.<sup>6</sup>

The LVTS has two payment streams, Tranche 1 (T1) and Tranche 2 (T2). Each tranche is characterized by its own risk controls. CDSX settlement occurs primarily through T1; therefore, our study will focus on T1.<sup>7</sup> In T1, all payments must be collateralized on a dollar-for-dollar basis, or funded by received payments. Each outgoing payment is tested against the available liquidity. If the participant does not have sufficient collateral or received payments, the payment fails the risk controls. Payments that are unable to pass the risk controls may be entered into a

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6. For more information on CDSX, see McVanel (2003).

7. Participants may make their CDSX pay-ins through T2 if the payment can pass the T2 risk controls. In general, the CDSX pay-ins are made through T1. The Bank of Canada makes all its pay-outs through T1.

queue. While some queued payments can subsequently be settled, they are delayed.<sup>8</sup> Since many of the payments in T1 are time sensitive, delays could have undesirable effects.

In CDSX, trade transactions are settled through either overnight batch settlement, real-time trade-for-trade settlement, or continuous net settlement.<sup>9</sup> In addition, CDS receives and processes entitlements. At the end of the day, each participant has a single funds balance. Each CDSX participant will either be owed by CDS or will owe CDS. Final CDSX settlement (payment exchange) takes place on the CDSX settlement account at the Bank of Canada. LVTS payments are sent to the Bank for deposit to the CDSX settlement account; once all payments have been received and reconciled, LVTS payments are sent to those participants who are owed by CDS. Positive CDSX funds positions are paid out only after all pay-ins for the negative positions have been received through the LVTS; this eliminates credit risk. All pay-outs are made through T1 with final CDSX settlement normally occurring by 17:05, the Bank's target time for completing CDSX settlement.<sup>10</sup> Through their cash management activities, LVTS participants are normally able to anticipate whether they will be in a short or long position in CDSX, and thus whether they will need to make a pay-in or will be receiving a pay-out.

In the LVTS, participants can draw on their available CDSX liquidity, prior to CDSX settlement, through a CDSX–LVTS funds transfer. A participant in a positive funds position can request that the Bank transfer the funds to them in the LVTS; this transfer does not introduce credit risk for the Bank. This arrangement allows participants to access the CDSX funds before CDSX settlement; however, it is not frequently used. Anecdotal evidence suggests that this arrangement has been used to move funds associated with the Receiver General auction or large entitlement receipts, or used when a participant accumulates a significant position and needs to access these funds.

After CDSX settlement at 17:05, there is still important LVTS activity. The LVTS general payment exchange period continues until 18:00, at which point the pre-settlement exchange period runs until 18:30. This period allows the participants to make loans among one another in order to bring their net LVTS positions close to zero in preparation for LVTS settlement. While these loans can be made throughout the day, the pre-settlement period is reserved for this

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8. For more information on the LVTS, such as the two payment streams, the queue, and the link between CDSX and the LVTS, see Arjani and McVanel (2006).

9. For more information on CDSX trade processing, see CDS (2006a).

10. All times are in Eastern Standard Time.



activity, according to the LVTS rules. LVTS settlement is scheduled to begin at 18:30 and is targeted for completion by 19:00.

Since CDSX settlement is completed through the LVTS, various operational events could lead to a disruption in CDSX settlement. For example, events affecting participants' ability to make their CDSX pay-ins, CDS's ability to identify the settlement balances, or the Bank's ability to make payments could all prevent CDSX settlement from being completed. We have observed a few such cases where CDSX settlement has actually been delayed. Our study simulates an event that prevents the Bank of Canada from making CDSX pay-outs. This simulation is used as only an example, to quantify the potential impacts of a disruption to CDSX settlement. Regardless of the cause of the event, there are actions that can be taken to prevent the event from occurring, keep the delay short, and mitigate the effect of the event.

### **3 Managing Operational Events**

Settling CDSX through the LVTS on the Bank's CDS settlement account creates an important interdependency between these two systems, the Bank, and the participants. As a result, events that affect CDSX settlement have the potential to have significant impacts on the LVTS. System operators, system participants, and the Bank have developed business continuity plans and contingency measures to prevent operational events from occurring, and to keep them short if they do occur. In addition, participants can take actions to mitigate the effects of an event. In this section, we will describe business continuity arrangements and contingency measures that are available to the Bank, the Canadian Payments Association (CPA), CDS, and the participants to ensure that CDSX settlement is completed. We will also examine the actions that participants have taken in past cases where CDSX settlement has been delayed.

#### **3.1 Continuity planning and contingency measures**

The Bank, the participants, the CPA, and CDS have continuity plans and contingency responses that reduce the likelihood that CDSX settlement would be delayed for an extended period of time. Continuity plans can prevent an event from occurring, while contingency measures can allow payments to be made in an alternative way even when an operational event affects normal payment processing.

To maintain uninterrupted operations, LVTS participants, including the Bank, have redundant components, such as routers, telecommunications links, and backup power supplies; they also have disaster recovery plans and maintain alternative operating sites. The LVTS rules require that the participants, including the Bank of Canada, maintain a backup site at which payments

can be processed. These arrangements ensure that payment activity is not interrupted under many different conditions. CDS also has business continuity plans, which include backup data centres, such that transaction data is not lost during events. In addition, CDS splits critical business functions between two sites. These continuity plans assist in keeping the frequency of events disruptive to CDSX settlement low.<sup>11</sup>

Despite these continuity plans, operational events do happen. Contingency measures help minimize their impacts, allowing payments to be made when normal processes and procedures cannot be used.<sup>12</sup> We will describe these contingency measures herein.

If a participant's proprietary payments system is experiencing an outage, they can manually enter payments into the Society for Worldwide Interbank Financial Telecommunications (SWIFT), the principal messaging service provider for financial institutions around the world and for critical systems, such as the LVTS. Once the payment is entered as a SWIFT message, it is treated as any other LVTS payment. In addition, participants can use the LVTS Direct Network to enter payments directly into the LVTS. This bypasses proprietary links with the LVTS and the SWIFT messaging system. Participants can also ask another participant whose system is functioning properly to act on their behalf. In many different events, participants can move payment operations to their alternative site.

A contingency that can be used in many different situations is direct entries on the books of the Bank of Canada. The CDS rules (CDS 2008) specifically mention these entries as an alternative for LVTS payments for settlement. The Bank could make entries, after LVTS settlement has begun, to settle the CDSX funds position into each participant's settlement accounts, which are held at the Bank.

In response to various events, LVTS settlement could be delayed to allow sufficient time for CDSX to settle, and if necessary for late-day LVTS activity to be completed. However, LVTS settlement must be completed to allow sufficient time for participants to prepare their systems for the start of Continuous Linked Settlement (CLS), which begins at 00:30.<sup>13</sup>

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11. For more information on the Bank's continuity plans, see Allenby (2003).

12. One possible response to an event is to wait for a resolution. Waiting may be the best response if an event occurs and the delay is expected to remain short. Once the event is resolved, payments can be exchanged using normal payment procedures. If waiting for a resolution is not a viable option, contingency responses will be implemented.

13. CLS is used for foreign exchange transactions. For more information, see <<http://www.cls-group.com/>>.

In sum, there are business continuity and contingency measures that can prevent an event from disrupting CDSX settlement and keep any delays short. CDS (2006b, 2007, 2008) and LVTS Rules (Canadian Payments Association) explain additional contingency measures. The Bank will work with the participants, the CPA, and CDS to find the best resolution to any operational event.

### **3.2 Mitigating action taken in historical delays to CDSX settlement**

In addition to contingency measures to prevent an event, there are many actions participants can implement to mitigate the event's effect. For example, participants could delay LVTS payments until CDSX settles, move payments to T2, or apportion additional T1 collateral. In this section, we analyze historical events to examine which actions the participants implemented to manage situations where CDSX settlement was delayed.

There have been a number of CDSX settlement delays, ranging from a few minutes to a few hours.<sup>14</sup> For the historical analysis we examine those cases between March 2004 and September 2006 where CDSX settlement delay was 15 minutes or longer. The average duration of the delay we examine is 35 minutes. In these cases, the value of CDSX pay-outs that were delayed ranges from \$1.42 billion to \$9.76 billion.<sup>15</sup>

To identify how participants react to a delay in CDSX settlement, we compare their activity on days where CDSX settlement occurred as expected (the base case) with days where CDSX settlement was delayed. For the base case, we use the 65 business days from 1 June 2006 to 31 August 2006.<sup>16</sup> We examine three mitigating actions that we expect the participants might take in response to a CDSX settlement delay: delay payments until CDSX settlement is completed, move payments to T2, and apportion additional collateral to facilitate T1 payments. Though not studied here, the participants might implement other mitigating actions, such as changing the order of payments to better use existing liquidity.

We begin by examining whether participants delay payments to T1 by waiting for CDSX settlement. Table 1 lists the value and volume of payments that were sent after actual CDSX

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14. On one occasion, LVTS settlement was also delayed.

15. A few of these cases involved Bank of Canada events.

16. We use this same period when we simulate an event affecting CDSX settlement. This three-month period is representative of the payment activity in the LVTS and the CDSX settlement values. Owing to the gradual increase in payment flows over time, this comparison period may have higher T1 activity than event days that occurred earlier in the March 2004 to September 2006 period. Some of the increase in payment flows is due to growth in early morning CLS activity.

settlement. It is important to keep in mind that the delay may change the amount of time between CDSX settlement and LVTS close, which may affect the number and value of payments sent between these times on the event days. We compare the event days with the 65-day base-case period.

**Table 1**  
**Daily T1 Payments after CDSX Settlement**

	Base case		Historical event days	
	Value	Volume	Value	Volume
Average	2,683	16.80	1,647	9.57
Median	2,372	16.50	1,087	6.50
Minimum	146	4.00	1.4	1.00
Maximum	10,805	37.00	5,167	32.00
Standard deviation	2,011	7.85	1,672	8.70

Note: All measures of value are in millions of dollars.

We observe that the value and volume of T1 payments sent after the delayed CDSX settlement is generally lower on days of historical events than on base-case days.<sup>17</sup> In the base case, 16.8 payments worth \$2.68 billion are sent after the normal CDSX settlement time. However, on average, during the event days, 9.5 payments worth \$1.64 billion are sent after CDSX settlement occurs. There is a significant amount of variation on both the base-case and event days. Despite the variation, only four event days have larger values after the CDSX settlement time than the average value in the base case. We also see fewer payments made between the normal settlement time and the time when the delayed settlement actually occurs. If, during an outage, participants delayed their T1 payments until CDSX settlement was received, we would expect to find more payments than usual occurring after the late CDSX settlement. This does not appear to be the case. The participants might have sent fewer payments. These results suggest that the participants do not wait to receive the CDSX funds before sending T1 payments. Because T1 payments are time sensitive, participants may not be willing to delay their payments until after CDSX settlement is completed. Alternatively, the participants might have sufficient T1 liquidity to complete their LVTS activity without waiting for the CDSX settlement funds.

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17. This result may, in part, be due to the gradual increase in LVTS activity that generally occurs over time. The gradual increase would result in higher activity in the base case than on some of the event days that occurred earlier in the sample.

In response to a CDSX settlement delay, participants appear to use liquidity that is available in T2 by moving some payments from T1 to T2. On the historical event days, we find that the use of T2 appears to increase slightly in the period after normal CDSX settlement.<sup>18</sup> The value and volume sent through T2 after 17:05 is, on average, higher for the event days than for the base-case period. The fact that we observe higher T2 value and volume on the event days supports the finding that participants move payments to T2 when the CDSX pay-outs are delayed. There is some variation in the T2 values. For example, on some event days the T2 value after CDSX settlement is lower than the average in the base case. One event day has a particularly large T2 value and volume: \$49 billion and more than two thousand payments. Removing this day reduces the difference between the base-case and the event days. However, the average and median values continue to be above those of the base case. In addition, we cannot determine which T2 payments participants would have sent through T1 had the event not occurred.

Another possible response to a CDSX delay is for participants to increase the collateral apportioned to T1 in order to replace the liquidity expected from CDSX settlement. Table 2 summarizes the frequency and value of changes to T1 collateral that occur after 17:05 on base-case and historical days. The participants appear to add collateral to T1 in delay situations. On the 65 base-case days, there are 45 collateral increases, an average of 0.69 increases per day. On the historical event days, there are 22 such increases, an average of 1.57 per day. The average value of the collateral increase is also higher on event days.

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18. The gradual increase in LVTS activity could make this result stronger, since event days that occurred earlier in the sample would be expected to have had even lower T2 activity than is seen in the base case.

**Table 2**  
**Changes to T1 Collateral in Base-Case and Historical Event Days after 17:05**

	Base case	Historical event days	
	T1	T1	T1*
Average daily volume	0.69	1.57	0.86
Standard deviation volume	0.71	1.80	0.86
Average value	227	625	458
Minimum value	1	24	24
Maximum value	2,500	3,000	3,000
Standard deviation value	397	718	838

Note: All measures of value are in millions of dollars.

\* Excludes the changes to Tranche 1 Net Debit Cap as a result of pledging additional collateral specifically for making CDSX pay-ins.

Four of the historical events are related to problems that participants experienced pledging or apportioning additional collateral to make their CDSX pay-ins. In these cases, the increases to affected participants' collateral are not a behaviour response to the delay. To isolate the potential behavioural responses, we remove the changes to collateral. The results are provided in the rightmost column of Table 2. This correction causes the value and volume of the collateral increases to fall. However, the value remains above the base-case value. On event days, participants appear to apportion collateral to T1 to help mitigate the effects of the delay. Although there is a significant amount of variation, this result indicates that participants will, on occasion, apportion collateral to T1 to ease the impact of a delay to CDSX settlement.

In summary, the historical analysis indicates that participants respond to delays in CDSX settlement in two ways. First, participants do not delay payments in T1, but may move some payments to T2. Second, participants appear to apportion additional collateral to T1. While not studied herein, participants could implement other actions.

Although continuity plans and contingency responses exist to ensure that CDSX settlement can be completed and mitigating actions can reduce the impact, we are interested in quantifying the potential effects of a disruption to CDSX settlement.

## **4 Simulation Methodology**

In this study, for computational simplicity and to measure the largest possible effect, we simulate a situation where all the CDSX pay-ins are made and an event occurs that prevents CDSX pay-outs from being made. A situation like this could happen if the Bank faced an operational event

at a time between CDSX pay-ins and pay-outs. As noted earlier, this type of event is rare, owing to the continuity plans and contingency measures in place. In addition, mitigating actions can be implemented to reduce the impacts of an event. Nevertheless, we use the simulation to quantify the potential effects of an event where CDSX settlement is prevented and mitigating actions are not taken.

In the simulation, the Bank of Canada acts as a liquidity trap: the Bank has received the CDSX pay-ins but cannot provide liquidity to those expecting it from the CDSX pay-outs. No mitigating actions are taken; for example, any payments that are unable to settle in the simulation are not resubmitted at a different time. The LVTS begins its pre-settlement period, as scheduled, at 18:00 and begins LVTS settlement at 18:30.<sup>19</sup> LVTS settlement takes place. The scenario that CDSX does not settle and LVTS does, although extreme, means that we identify the payments affected by the outage. We do not make assumptions about the responses taken to ensure that CDSX settlement is completed, although, as noted earlier, contingency measures exist. For this reason, the simulation illustrates a worst-case scenario.

An advantage of a simulation methodology is that it allows us to replicate what actually occurred in the LVTS and compare it with the results obtained under different conditions. Changes in behaviour, however, could result in a different outcome than those simulated. It is difficult to accurately assume and simulate all the possible mitigating actions that each participant would implement. Therefore, while the simulation gives an indication of what the effects of an unexpected event could be, the results should be interpreted with caution, since mitigating actions and contingency measures would alter the actual outcomes.

The simulation is conducted using the payments system simulator developed by the Bank of Finland and adapted to replicate LVTS conditions. The data contain all settled transactions, their submission time, and the credit available to each participant throughout the day. The simulation analysis involves the following steps:

- Benchmark values of the metrics are obtained by running the actual data through the simulator under normal operating conditions. These values represent the levels actually experienced in the base-case scenario. We also use this benchmark for the historical analysis that was presented in section 3.2.

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19. This assumption means that any payment in the queue at 18:00 will be rejected according to the LVTS rules. Therefore, in our study these payments appear as rejected payments.

- The CDSX pay-outs sent by the Bank of Canada are identified and removed from the dataset. Outage metrics are obtained by rerunning the simulation without the CDSX pay-outs from the Bank.
- The base-case and outage metrics are compared to quantify the effects when the CDSX pay-outs are not completed in the LVTS.

To compare the base case with the simulated outage case, two measures are used to assess the reliance on received payments as a source of liquidity and delay.

First, we use a turnover ratio (TR), as in Leinonen and Soramäki (1999), to measure the value of payments that are settled per dollar of collateral that is used. This measure is defined as:

$$TR = \frac{\text{value of outgoing payments}}{\text{collateral required}}.$$

A larger turnover ratio indicates that more payments could be sent using a given amount of collateral. When the CDSX pay-outs are removed, we expect that the turnover ratio will decrease, due to fewer outgoing payments (some payments are unable to pass the risk controls) and more reliance on collateral.

Second, in order to measure the delay faced by participants, we use an average queue value (AQV), which is the average time-weighted value of payments in the central queue at any given time throughout the day. A similar measure is used in Arjani (2006). It is expected that the removal of the CDSX pay-outs will increase the AQV. This measure is defined as:

$$AQV = \frac{\sum_{i=1}^T Q_i}{T},$$

where  $Q_i$  represents the total value of payments in the queue in each one-second interval and  $T$  represents the total number of seconds in an LVTS day. Because the AQV is time weighted, it increases as payments, even if they are small, spend a long time in the queue, or it increases when large values are in the queue, even if they are settled from the queue quickly. Both the duration of the delay and the value delayed are incorporated into the AQV.

The simulated outage will lead to some payments that are unable to pass the LVTS risk controls and are rejected from the system. We use two measures to assess the magnitude of the rejected payments.



The first measure allows us to compare the rejected payments with the value of the CDSX pay-outs, and is calculated as:

$$\frac{\text{value of rejected payments}}{\text{value of CDSX payouts}} .$$

This ratio measures the value of unsettled payments as a share of the CDSX pay-outs that were expected. It quantifies the portion of the CDSX pay-out that was required for all the LVTS payments to pass the risk controls and settle. If all payments could settle, even when CDSX was not completed, then this ratio equals zero. As this value increases, more of the CDSX funds were needed in order to settle LVTS payments. For example, if this ratio equals 0.25, payments that were rejected had a value equal to a quarter of the value of the CDSX pay-outs; a quarter of the CDSX pay-out value was required for all the LVTS payments to settle. This ratio could potentially be larger than one if payments that were unable to pass the risk controls due to the disruption to CDSX were also needed to fund LVTS payments.

The second measure enables us to examine the portion of the payments submitted after the expected CDSX settlement time that were unable to pass the risk controls.<sup>20</sup> This measure is important, since only the payments made after CDSX settlement can be affected by the simulated outage. We calculate this measure as:

$$\frac{\text{value of rejected payments}}{\text{value of payments submitted after expected CDSX settlement time}} .$$

If this measure is equal to one, then all payments made after the CDSX settlement time relied upon receipt of the CDSX funds in order to settle. If this measure is equal to zero, then all payments made after CDSX settlement time could be made without the CDSX funds; there was sufficient liquidity from other sources to ensure that all the LVTS payments settled.

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20. Usually, CDSX settlement is completed by 17:05. We find the precise time that CDSX settlement was completed on each day and examine the payments submitted after that time.

## 5 Data

The sample period selected for this study spans the 65 business days from 1 June 2006 to 31 August 2006. This three-month period is representative of the payment activity in the LVTS and the CDSX settlement positions. This study uses payment-by-payment transactions data and intraday credit-limit data obtained from the CPA, as well as payment instructions data regarding the CDSX settlement account held at the Bank of Canada.

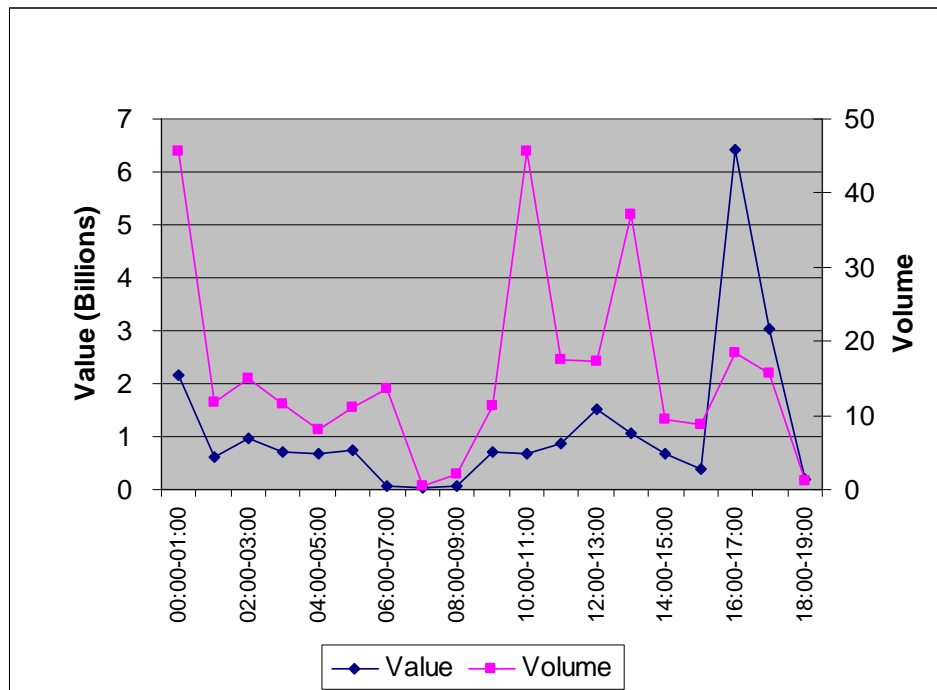
In this period, the LVTS settled over 1.2 million payments worth nearly \$11 trillion. The T1 payment stream accounted for 1.6 per cent of payment volume and 13.0 per cent of payment value in LVTS. The average daily value of T1 activity was over \$21 billion. T1 activity ranged between \$1.9 billion and approximately \$54 billion. CDSX settlement pay-outs totalling nearly \$227 billion were transferred from the CDSX settlement account at the Bank of Canada to LVTS participants. On average, there were seven CDSX pay-outs worth \$3.5 billion on each business day. This amounts to 2.3 per cent of T1 volume and 16.2 per cent of T1 value. The largest CDSX settlement pay-out to a single participant was \$7 billion, while the daily maximum to all participants was over \$16 billion.<sup>21</sup> Days with large LVTS activity or large CDSX funds balances usually correspond to government payments, entitlement payments, or merger and acquisition activity.

Throughout the day, the value and volume of payment activity varies. Chart 1 indicates the average value and volume of payments that were sent during each hour. In terms of volume, it peaks in the early CLS period between 00:00–01:00, and again at 10:00–11:00 and 13:00–14:00, as a result of government banking activity. In terms of value, it peaks during the 16:00–17:00 period, when the Receiver General auction is settled and when CDSX settlement pay-ins take place. Value remains relatively high over the course of the 17:00–18:00 period. The pattern of the T1 payment flows is consistent with overall LVTS flows, and suggests that the end-of-day period is important for overall payment operations.

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21. On the day when CDSX pay-outs were worth over \$16 billion, the T1 payments were worth \$50.9 billion. The CDSX pay-outs represent 31 per cent of the LVTS value on that day.

**Chart 1**  
**Average Value and Volume, by Time of Day**



On average, 17 payments worth \$2.6 billion are made after CDSX settlement, while, on average, the total T1 activity is \$21.5 billion. In other words, each day during the sample period, approximately 12 per cent of the average T1 value occurs after CDSX settlement. This suggests that the payment activity after CDSX settlement is an important portion of the total T1 activity. It is likely that the CDSX settlement funds help to fund this end-of-day activity in T1.

## 6 Results

### 6.1 Simulation results: CDSX settlement funds and end-of-day LVTS activity

We simulate a situation where the Bank of Canada experiences an outage after all the CDSX pay-ins have been received and the outage prevents the Bank from making the CDSX pay-outs. Some outages affecting participants or CDSX can also prevent CDSX settlement from being completed. We do not make assumptions about the mitigating actions or contingency responses that are implemented. The simulated outage results in payments that are unable to pass the risk controls, a decrease in the use of received payments as a source of liquidity, and payment delays.

In the simulated outage, some payments are rejected (they are unable to pass the risk controls when they are submitted, or they expire from the queue). The simulated outage results in rejected payments on 32 of the 65 days examined. The average daily value that is unable to settle is \$1.11 billion. Up to 13 payments worth \$5.0 billion are rejected on one particular day.

Our results indicate that an important portion of the CDSX pay-outs is needed for all subsequent LVTS payments to settle. We measure the value of rejected LVTS payments relative to the value of the CDSX pay-outs. This measure provides an indication of the share of the CDSX pay-outs that was required for all LVTS payments to settle. On average, LVTS payments equal in value to 13.2 per cent of the CDSX value are rejected by LVTS. If we examine only the days with rejected payments, this value increases to 26.7 per cent. This figure indicates that, on average, the value of rejected payments is more than a quarter of the value of the CDSX pay-outs. On two days, the rejected payments amount to more than 80 per cent of the value of the CDSX pay-outs. The results suggest that the CDSX pay-outs are an important source of funding for end-of-day LVTS activity.

Our findings also indicate that, without the CDSX pay-outs, an important portion of the late-day activity is rejected. Since the simulated outage affects CDSX settlement, only those LVTS payments that are submitted after CDSX settlement may be affected by the simulated outage. Therefore, we are interested in the effect of the outage on these post-CDSX settlement payments, the LVTS payments submitted after CDSX settlement should have occurred.<sup>22</sup> We find that, on average, 18.1 per cent, by value, of the post-CDSX payments are rejected. If we focus only on the days with rejected payments, the average value increases to 36.1 per cent. These results imply that a sizable portion of the post-CDSX LVTS payments needs the liquidity provided by CDSX settlement in order to pass the risk controls. The unexpected loss of liquidity caused by the simulated outage can cause a significant disruption to normal LVTS activity.

Several factors will influence whether all payments pass the risk controls on a particular day. We are able to identify some of these influences by comparing the base case on days when all payments settle with days when some payments do not settle. The results are not surprising: the CDSX value and the value of payments made after CDSX settlement are important. The larger the CDSX pay-outs or the late-day LVTS activity, the larger the impact of the outage.

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22. CDSX settlement generally is completed by 17:05. To identify the post-CDSX payments, we identify the time that CDSX settled on each day and examine the payments submitted after that time.

Some participants may be more likely than others to have payments rejected. In particular, the amount of collateral apportioned to T1 will influence whether a participant experiences rejected payments in our simulation. The simulation does not allow participants to apportion additional collateral to T1 during the simulated outage. Otherwise, the value and volume of rejected payments would obviously decline.

Even on days when all payments are able to settle, the removal of the CDSX pay-outs can have important effects on the LVTS. In particular, in the outage case, LVTS participants rely more on their T1 collateral to fund their outgoing payments than in the base case, as indicated by a lower turnover ratio. Recall that the turnover ratio measures the value settled per dollar of collateral used. A lower turnover ratio indicates less reliance on received payments, and more on collateral. In the outage case, it indicates that fewer payments could be sent per dollar of collateral; the CDSX funds were used to fund outgoing payments in the base case. Table 3 shows the turnover ratio for the base and outage cases. The average turnover ratio in the base case was \$2.31; this means that, for every dollar of collateral that was needed, the participants were able to settle \$2.31. In the outage case, the turnover ratio falls to \$2.10.

**Table 3**  
**Turnover Ratio**

	Turnover ratio	
	Base case	Outage
Average	2.31	2.10
Median	2.20	2.09
Minimum	1.50	1.39
Maximum	3.66	3.28
Standard deviation	0.54	0.41

The turnover ratio depends on the value of the total T1 activity and on the CDSX pay-outs. The days with relatively larger T1 activity have larger turnover ratios because there are more payments, which participants can use as a source of liquidity, rather than relying on collateral. In the base case, the days with the largest CDSX pay-outs have smaller turnover ratios. This result may reflect the need to use collateral to make the large CDSX pay-ins. When we simulate the outage, the turnover ratio decreases, with the biggest decreases occurring on the days with the largest CDSX pay-outs. The decline in the turnover ratio when CDSX pay-outs are large suggests that the large-value pay-outs were used to settle payments.

Furthermore, the simulated outage may result in more delay than was observed in the base case. When a payment fails to pass the risk controls, it may be placed in the queue if it meets certain conditions. The queue tries to settle such payments at regular intervals and when the participant receives a payment. However, while some queued payments can subsequently be settled, they are delayed. In a real outage, given that T1 payments are often time sensitive, participants would most likely want to take action to avoid delay. For example, the participants may move payments to T2 or apportion additional collateral.

We find that the payment delay resulting from the simulated outage can be material. In this analysis, we measure delay by calculating the AQV.<sup>23</sup> Recall that this measure is a time- and value-weighted measure of payments in the queue. Table 4 reports the AQV in the base and outage cases. The base-case AQV is very low, reflecting the infrequent use of the queue in T1; indeed, it is used on only 6 out of 65 days. Also, in the base case the queue is not used at all after CDSX settles.<sup>24</sup> In the simulated outage, however, the queue is used more often, on 39 out of 65 days. The increased use of the queue in the outage case implies that the CDSX pay-outs are important for the post-CDSX activity.

The difference between the base and outage cases is more pronounced when we look at the average of the AQV over the sample period. The AQV increases from \$8,200 in the base case to \$27.3 million in the simulated outage. The median value is smaller than the average, suggesting that, on some days, there is a significant change in the use of the queue, and this influences the average values. Even the lower median value is well above the base-case AQV. These results highlight that an outage affecting CDSX settlement can result in significant delays. Payment delays could be disruptive to normal operations.

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23. The LVTS rules discourage excessive use of the queue. In this simulation, we have not restricted its use.

24. The lack of use of the queue after CDSX settlement in the base case may itself reflect the benefits that the CDSX funds offer for completing payments. However, the queue is not frequently used in T1 regardless of the day or time of day.

**Table 4**  
**Average Queue Value**

	Average queue value	
	Base case	Outage case
Average	8.2	27,300
Median	0.0	1,255
Minimum	0.0	0.0
Maximum	326	325,000
Standard deviation	43	52,500

Note: All measures of value are in thousands of dollars.

The value of T1 activity and the value of the CDSX pay-outs influence how payment delays are affected by the outage. In the simulated outage, the queue is used more heavily, and the AQV is higher, on days when the T1 value is relatively large or on days when the CDSX pay-outs are large. On relatively large-value LVTS days, we see a higher value of payments made after CDSX settlement, which leads to more payments in the queue, and more delay during the simulated outage. On larger-value CDSX days, the increases in AQV are also higher, since a larger amount of liquidity is removed from the LVTS, resulting in payments that cannot settle immediately.

We have seen that the simulated outage has important effects on the end-of-day LVTS activity for the system as a whole. However, the magnitude of the effects on individual LVTS participants may differ, depending on a number of factors; for example, whether the participant is the recipient of a CDSX pay-out, the amount of collateral that they apportion to T1, and how much they transact late in the day.

Overall, an outage that causes the CDSX settlement funds to be unavailable in the LVTS, where mitigating actions and contingency measures are not taken, has important effects on subsequent LVTS activity. The simulation identifies impacts on the ability of payments to pass the risk controls, the level of delay, and the use of collateral relative to received payments as a source of liquidity. Participants can take actions in an effort to mitigate these impacts. However, our analysis reveals that the magnitude of the delays and rejected payments that the participants would need to manage in an outage can be important.

## 6.2 CDSX settlement funds and pre-settlement activity

So far, the simulation analysis has focused on quantifying the impacts of an outage. In this section, we will examine whether the CDSX settlement funds contribute to pre-settlement activity in the LVTS. Our results indicate that LVTS participants may be using the liquidity provided by CDSX settlement funds to facilitate their pre-settlement transfers. Participants use the pre-settlement transfers to bring their LVTS positions close to zero. The CDSX funds contribute to the participants' end-of-day position in the LVTS, and thus might allow a participant to make these pre-settlement transfers. Without the CDSX settlement funds, the LVTS positions are changed and the pre-settlement activity will be affected.

The pre-settlement transfers are one form of interbank lending. At the end of each day, some participants may end up in a positive end-of-day position, and others in a negative one. During the pre-settlement period, participants who need funds can borrow from others who have excess funds, in order to bring a negative LVTS position close to zero. During this time, participants can also exchange LVTS payments for payments in the Automated Clearing and Settlement System (ACSS).<sup>25</sup> Pre-settlement activity contributes to the monetary policy operations of the Bank of Canada, but is not vital to the day-to-day business of the LVTS participants.<sup>26</sup> Our analysis focuses on LVTS payments sent after 18:00, because the LVTS rules indicate that only pre-settlement payments should be sent through the LVTS at that time.<sup>27</sup> Since either T1 or T2 can be used to make pre-settlement payments, we will examine the payments that occur after 18:00 in both of them. The CDSX pay-outs contribute to the end-of-day LVTS position, which takes into account both T1 and T2 balances. For the pre-settlement payments, we are interested in the CDSX funds not only as a source of liquidity, but also as contributing to the participants' net LVTS position, and to their ability to make interbank loans in order to bring their positions close to zero.

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25. These exchanges can influence the final ACSS positions. For more information on these exchanges, see Canadian Payments Association (2007).

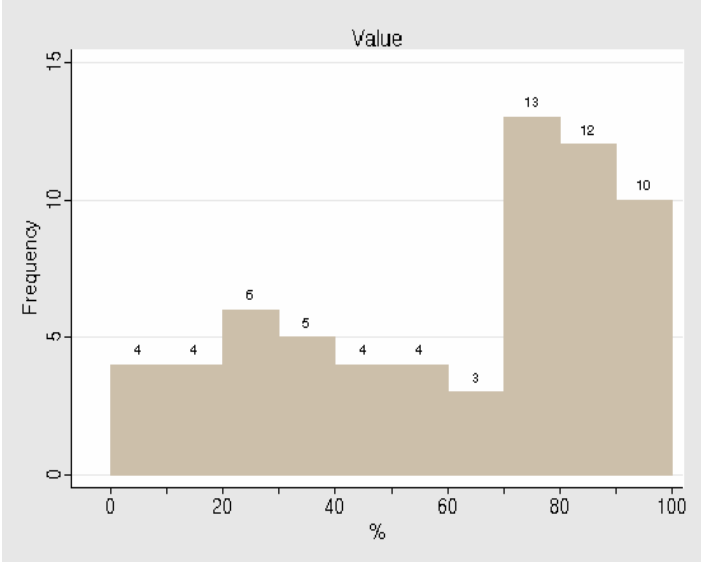
26. For more information, see Bank of Canada (2007).

27. Although interbank lending may take place before the pre-settlement period, all payments that occur after 18:00 should be pre-settlement payments. It is possible that some regular payments take place after 18:00; however, they should be few. Since some pre-settlement payments may occur early and some regular payments late, it is difficult to accurately identify all the pre-settlement payments.



Our results indicate that the CDSX recipients are heavily involved in pre-settlement activity, providing evidence that CDSX pay-out funds are important for pre-settlement activity. Chart 2 shows the number of days for which CDSX recipients made a percentage of the pre-settlement payments. For example, on 35 of the 65 days, the CDSX recipients made over 70 per cent of the pre-settlement payments. On average, 61.4 per cent of the pre-settlement payments are sent by CDSX pay-out recipients. This large share indicates the importance of the CDSX settlement funds for pre-settlement activity. In an outage, participants who expected to receive CDSX pay-outs and make pre-settlement loans might be unable to do so when CDSX settlement is disrupted. These pre-settlement transfers, although participants are not required to make them, are an important component of the end-of-day LVTS settlement activity, helping to bring settlement balances near zero. Our analysis suggests that the removal of the CDSX funds could significantly affect this pre-settlement activity. Without the CDSX settlement funds, the LVTS participants may not need to, or be willing to, borrow and lend during the pre-settlement period.

**Chart 2**  
**Share of Pre-Settlement Payments Sent by Recipients of CDSX Funds**



## 7 Conclusions

There are several interdependencies between CDSX and LVTS. For example, the Bank of Canada acts as the settlement agent for CDSX and many of the LVTS participants are also CDSX participants. In order to complete CDSX settlement, large values of funds pass through the Bank of Canada near the end of the LVTS day. The LVTS participants can anticipate whether they will receive a CDSX pay-out, and will plan their activity based on this expectation.

Therefore, an unanticipated event that affects CDSX settlement can have impacts on LVTS activity.

The LVTS is a well risk-proofed system. While the effects of a disruption in CDSX settlement can be significant, events such as the one simulated, and the resulting outcomes, are not likely to occur. Business continuity plans prevent disruptions from taking place, and contingency measures ensure that delays are short. In addition, mitigating actions can be taken to reduce the impacts of events when they do occur. We find that, during historical cases where CDSX settlement is delayed, participants take actions to mitigate the effects of the event. LVTS participants move payments to T2 and apportion collateral to T1 to mitigate the impacts of the event. The participants could also implement other actions.

Through simulation analysis, we quantify the potential impacts of a disruption to CDSX settlement on LVTS activity. We simulate an event where the expected CDSX pay-outs are not sent after all the pay-ins are made. In the simulation, we assume that no contingency responses or mitigating actions are taken. The simulated event has important impacts on the LVTS activity. We find increased payments delay, payments that are unable to pass the risk controls, and potential effects on the pre-settlement activity. Since the potential impacts of such an event are important, this study highlights the importance of the business continuity plans, contingency measures, and mitigating actions that can prevent or reduce them.

The analysis in this study can contribute to a more complete understanding of the interdependencies between the LVTS and CDSX. Further research could examine other interdependencies between these two systems. For example, collateral is apportioned to the Bank of Canada through CDSX, and the LVTS and CDSX have many of the same participants. It could be useful to examine the effects on all the participants of a default by one participant in both the CDSX and the LVTS.

## References

- Allenby, R. 2003. "Business-Continuity Planning in Clearing and Settlement Systems: A Systemwide Approach." Bank of Canada *Financial System Review* (June): 55–58.
- Angelini, P. 1998. "An Analysis of Competitive Externalities in Gross Settlement Systems." *Journal of Banking & Finance* 22 (1): 1–18.
- Arjani, N. 2006. "Examining the Trade-Off between Settlement Delay and Intraday Liquidity in Canada's LVTS: A Simulation Approach." Bank of Canada Working Paper No. 2006-20.
- Arjani, N. and D. McVanel. 2006. "A Primer on Canada's Large Value Transfer System." Available at <[http://www.bankofcanada.ca/en/financial/lvts\\_neville.pdf](http://www.bankofcanada.ca/en/financial/lvts_neville.pdf)>.
- Ball, D. and W. Engert. 2007. "Unanticipated Defaults and Losses in Canada's Large-Value Payments System, Revisited." Bank of Canada Discussion Paper No. 2007-5.
- Bank of Canada. 2007. "A Primer on the Implementation of Monetary Policy in the LVTS Environment." Available at <[http://www.bankofcanada.ca/en/lvts/lvts\\_primer\\_2007.pdf](http://www.bankofcanada.ca/en/lvts/lvts_primer_2007.pdf)>.
- Bech, M. L. and R. Garratt. 2003. "The Intraday Liquidity Management Game." *Journal of Economic Theory* 109 (2): 198–219.
- Buckle, S. and E. Campbell. 2003. "Settlement Bank Behaviour and Throughput Rules in an RTGS Payment System with Collateralised Intraday Credit." Bank of England Working Paper No. 209.
- Canadian Payments Association. LVTS Rules. Available at <[http://www.cdnpay.ca/rules/lvts\\_rules.asp](http://www.cdnpay.ca/rules/lvts_rules.asp)>.
- . 2007. Settlement Exchange Transaction (SET). Available at <[http://www.cdnpay.ca/publications/pdfs\\_publications/prd\\_001.pdf](http://www.cdnpay.ca/publications/pdfs_publications/prd_001.pdf)>.

- CDS Clearing and Depository Services Inc. 2006a. “CDS Financial Risk Model: Version 4.0.” Available at <[http://www.cds.ca/cdsclearinghome.nsf/Downloads/-BL-CDSXRiskModel-Version3.2.1/\\$File/CDS+Settlement+Services+Risk+Model+-+Nov+30,+2006.pdf](http://www.cds.ca/cdsclearinghome.nsf/Downloads/-BL-CDSXRiskModel-Version3.2.1/$File/CDS+Settlement+Services+Risk+Model+-+Nov+30,+2006.pdf)>.
- . 2006b. “Self-Assessment by CDS Clearing and Depository Services Inc. of Its Observance of the CPSS/IOSCO Recommendations for Central Counterparties (2004).” Available at <[http://www.cds.ca/cdsclearinghome.nsf/Downloads/-EN-CPSS-IOSCO2007/\\$File/CPSS-IOSCO+Recommendations.pdf](http://www.cds.ca/cdsclearinghome.nsf/Downloads/-EN-CPSS-IOSCO2007/$File/CPSS-IOSCO+Recommendations.pdf)>.
- . 2007. “Clearing and Depository Controls at CDS.” Available at <[http://www.cds.ca/cdsclearinghome.nsf/Downloads/-EN-ClearingandDepositoryControls/\\$Files/Clearing+and+Depository+Controls+at+CDS\\_E.pdf](http://www.cds.ca/cdsclearinghome.nsf/Downloads/-EN-ClearingandDepositoryControls/$Files/Clearing+and+Depository+Controls+at+CDS_E.pdf)>.
- . 2008. “CDS Participant Rules (Release 2.8).” Available at <[http://www.cds.ca/cdsclearinghome.nsf/Downloads/-EN-CDSParticipantRules2.8/\\$File/Rules\\_2.8\\_EN.pdf](http://www.cds.ca/cdsclearinghome.nsf/Downloads/-EN-CDSParticipantRules2.8/$File/Rules_2.8_EN.pdf)>.
- Freedman, C. 1999. “The Regulation of Central Securities Depositories and the Linkages between CSDs and Large-Value Payment Systems.” Bank of Canada Technical Report No. 87.
- Leinonen, H. and K. Soramäki. 1999. “Optimizing Liquidity Usage and Settlement Speed in Payment Systems.” Bank of Finland Discussion Paper No. 16/1999.
- McAndrews, J. J. and S. M. Potter. 2002. “Liquidity Effects of the Events of September 11, 2001.” Federal Reserve Bank of New York *Economic Policy Review* 8 (2): 59–79.
- McAndrews, J. J. and S. Rajan. 2000. “The Timing and Funding of Fedwire Funds Transfers.” Federal Reserve Bank of New York *Economic Policy Review* 6 (2): 17–32.

- McVanel, D. 2003. "CDSX: Canada's New Clearing and Settlement System for Securities."  
Bank of Canada *Financial System Review* (July): 59–64.
- . 2005. "The Impact of Unanticipated Defaults in Canada's Large Value Transfer  
System." Bank of Canada Working Paper No. 2005-25.