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Changes in Payment Timing in Canada's Large Value Transfer System

by Nellie Zhang

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Abstract

This paper uncovers trends in payment timing in Canada's Large Value Transfer System (LVTS) from 2003 to 2011. Descriptive analysis shows that LVTS payment activity has not been peaking in the late afternoon since 2008, and the improvement was most significant in 2009. Ordinary least squares regressions are conducted to identify various factors that might have contributed to the changes in the payment value time distribution. The main findings include that a larger proportion of high-value payments results in later payment submission and hence settlement; as an important source of intraday liquidity, a higher CDSX payout value tends to speed up LVTS transactions. Several changes in the system parameters—such as increases in the frequencies of the Jumbo algorithm and Jumbo queue expiry—also quickened the settlement. In addition, the results suggest that the temporary exceptional liquidity initiatives introduced in late 2008 and a large increase in settlement balances were major contributors to the earlier settlement of LVTS payments.

JEL classification: G20, E50
Bank classification: Payment clearing and settlement systems

Résumé

L'auteure décrit les tendances qui ressortent de la distribution temporelle des paiements traités par le Système de transfert de paiements de grande valeur (STPGV) au Canada de 2003 à 2011. Une analyse descriptive montre que les opérations de paiement n'ont pas enregistré de pic en fin d'après-midi depuis 2008 et que l'amélioration la plus notable sur ce point s'est produite en 2009. Des régressions par les moindres carrés ordinaires permettent de cerner les facteurs susceptibles d'avoir contribué à modifier la distribution temporelle de la valeur des paiements. Les principaux résultats indiquent qu'une hausse de la proportion des paiements de montant élevé a pour effet de retarder l'envoi et, par conséquent, le règlement des paiements. L'augmentation des paiements en provenance du CDSX tend à accélérer les opérations du STPGV, car ils constituent une importante source de liquidités journalières. Plusieurs changements apportés aux paramètres du système – tels que l'accroissement de la fréquence d'exécution des algorithmes relatifs aux très gros paiements et à l'expiration de l'attente en file – ont aussi favorisé l'accélération du règlement. De plus, les mesures temporaires exceptionnelles d'octroi de liquidités prises à la fin de 2008 et la forte hausse du montant des soldes de règlement ont largement concouru à ce mouvement d'accélération.

Classification JEL : G20, E50
Classification de la Banque : Systèmes de compensation et de règlement des paiements

Non-Technical Summary

Motivation and Question In Canada, the Large Value Transfer System (LVTS) processes large-value, time-critical payments and provides real-time finality. The smooth functioning of the LVTS is central to the well-being of the Canadian financial system. As in any other payments system, the timing of payment transfers in the LVTS is important. First, faster settlement of payments accelerates liquidity recycling and increases the efficiency of the system. Second, an operational disruption would have less impact if payments sent throughout the day were more evenly distributed over time. Using historical data, this paper looks back over a long time horizon to examine how payment timing in the LVTS has evolved from 2003 to 2011, and to identify various factors that might have contributed to the changes in the time distribution of LVTS funds transfers.

Methodology This paper mainly consists of two parts. The first part is a descriptive analysis that provides an overview of how LVTS payments are distributed across the course of a day and how the time distribution pattern has changed from year to year. The second part presents a regression analysis that identifies factors that may explain the changes in the time distribution of LVTS payments.

Key Results and Contributions An examination of data reveals a noteworthy change in the pattern of time distribution of payment values. During the years prior to 2007, especially in 2005 and 2006, the peak of LVTS transaction activity occurred in the late afternoon, between 16:00 and 17:00. In 2007, the concentration started declining. From 2008 to 2011, it was no longer true that payment activity in the LVTS is mostly concentrated in the late afternoon. Compared with all other years in the sample, the quickening of payment settlement in 2009 is the most significant. The general pattern in the time distribution of payment volume shows no major difference from year to year. In the regression analysis, several factors are found to have expedited the settlement of LVTS payments, e.g. the CDSX final pay-outs and increased frequency of the LVTS Jumbo queue and the queue-expiry algorithms. The most notable quickening effects came from the temporary full acceptance of the non-mortgage loan portfolio as LVTS collateral from October 2008 to February 2010, and the changes to the operating framework for the implementation of monetary policy between April 2009 and June 2010. In addition, the analysis identified a few factors that tend to delay settlement in the LVTS, e.g. a larger fraction of high-value payments.

Future Work and Comments For future research, the analysis could be taken further by disaggregating LVTS payments into two payment types: the client-initiated payments versus interbank transfers. Furthermore, the analysis could be converted to a Bayesian regression approach, which would incorporate additional non-sample information (i.e., each decile of payment value settled is strictly smaller than the next decile) into the regression analysis to enhance the efficiency of the estimation.

1 Introduction

The Large Value Transfer System (LVTS) is the major payments system in Canada that processes large-value, time-critical payments and provides real-time finality. The LVTS is used by Canada's other payments clearing and settlement systems, and thus its smooth functioning is central to the well-being of the financial system. As in any other payments system, the timing of payment transfers in the LVTS is important, because (i) the early submission of payments speeds up liquidity recycling and increases the efficiency of the system, and (ii) an operational disruption would have less impact if payments sent throughout the day were more evenly distributed over time, compared to disruptions occurring during the time period when transactions are more concentrated. LVTS transactions data show that before 2007, especially in 2005 and 2006, the peak of LVTS transaction activity (measured by payment value) occurs in the late afternoon, between 16:00 and 17:00. However, the environment in which LVTS operates has changed over time, and LVTS participants have more than likely adjusted their payment behaviours to the changing environment. This paper looks back over a long time horizon to examine how payment timing in the LVTS has evolved over the past nine years.

An examination of data from 2003 to 2011 reveals a noteworthy change in the pattern of LVTS payment activity. After 2007, the concentration of payment value in the late afternoon has been consistently decreasing. In 2006, 15.2% of daily payment value, on average, was sent between 16:00 and 17:00, whereas in 2010 the percentage dropped to 10.8%.[1] Statistics also show that on average, over the course of a day, payments in the LVTS were submitted much earlier in 2009 than in any other year in the sample. In addition, despite the notable changes in the timing of payment value, the general pattern in the timing of payment volume has been quite stable over the years, showing no significant difference from year to year.

This paper focuses on the evolution of the timing of payment value transfered in the LVTS. A regression analysis is conducted to identify factors that are associated with the intraday timing of payment value and that can explain the changes in the general pattern over the years. The response variable is the time at which a given decile of payment value transfered throughout a day was submitted, and a separate regression is carried out independently for each decile of daily payment value. Explanatory variables include LVTS payment volume and value, payment activity in other settlement systems, changes in LVTS operations and monetary policy implementation, and calendar effects on payment flows. The analysis suggests that the improvements in the timing of payment value can

[1] This is a significant drop in the concentration of late-afternoon payments. As a frame of reference, the average percentage of daily payment value transacted per one-hour interval during the general payment exchange period, from 06:00:00 to 18:00:00, is around 8.3%.

be mainly explained by a decrease in the proportion of high-value payments, a temporary acceptance of non-mortgage loan portfolios (NMLP) as eligible collateral in the LVTS, and the large supply of excess settlement balances by the Bank of Canada during the period when monetary policy was implemented at the effective lower bound (ELB).

This paper closely follows two recent studies conducted by researchers at the Federal Reserve Bank of New York. Armantier, Arnold and McAndrews (2008) examine the time distribution of the Federal Reserve's Fedwire funds transfers from 1998 to 2006. They discover that the previously known peak of payment activity in the late afternoon has not only become more concentrated, but also shifted to even later in the day. They consider a number of factors that could affect the changes in Fedwire payment timing, and find that the leading factor is the settlement patterns of private settlement institutions. Other significant determinants of payment timing found in the study include a higher value and volume of payments transfered, larger value of customer payments, and increased industry concentration. Bech, Martin and McAndrews (2012) focus on the liquidity impact on payment timing in Fedwire transfer services during the recent global financial crisis. They show that the provision of large quantities of reserve balances by the Federal Reserve Banks, accompanied by the payment of interest on excess reserves, tremendously reduced delay of payments in Fedwire. Their empirical evidence is consistent with the economic theory that a higher level of settlement liquidity and a lower opportunity cost of holding excess reserves would greatly improve payment timing.

The rest of this paper proceeds as follows. The next section provides an overview of how LVTS payments are distributed across the course of a day and how the distribution pattern has changed from year to year. Section 3 presents regression analysis that identifies factors that may explain the changes in the time distribution of LVTS payments. Discussions of the results are extended through a mechanical exercise in section 4. Conclusions follow in section 5.

2 Descriptive Analysis

The LVTS provides two payment streams for settlement: Tranche 1 and Tranche 2. Tranche 1 is a channel equivalent to real-time gross settlement, where every payment has to be fully secured by eligible collateral or by funds already received; Tranche 2 is one of the main collateral cost-saving features of the LVTS in that payments in Tranche 2 are largely supported by intraday credit. The majority of LVTS payments are sent through Tranche 2, and Tranche 1 is mainly used for high-value and/or time-critical transactions. This paper examines the timing of payment activity in the LVTS as a whole, including both streams.[2,3] However, transactions to or from other settlement institutions, namely the Continuous Linked Settlement (CLS) Bank and CDS Clearing and Depository Services Inc. (CDS), are excluded from the analysis: these transactions are usually confined within certain designated time frames, and they do not reflect LVTS participants' choices of payment timing and very little of participants' liquidity management strategies.[4,5]

The Automated Clearing Settlement System (ACSS) is another major payments system in Canada. It handles all payments not processed by the LVTS, mostly paper-based and small-value electronic payment items. ACSS direct clearers settle their net funds positions through payment exchanges in the LVTS on the next business day, and settlement is typically completed at 12 noon EST. On any given day, the payment flows in the LVTS related to ACSS settlement are well anticipated, i.e. the impact on participants' strategic decisions on liquidity management and payment timing is presumably trivial; unfortunately, however, due to a lack of detailed breakdown of data, they cannot be removed from the analysis, as are CDSX transactions.[6]

[2] For more operational details on the LVTS, such as different risk-management controls under each payment stream, the interested reader can refer to Arjani and McVanel (2006).

[3] Alternatively, this study could focus only on Tranche 2 payments, which represent the majority of LVTS payment activity and reflect most of the participants' payment behaviour. However, this study includes both payment streams for two reasons: first, it helps provide an overall system-wide portrait of payment timing in the LVTS; second, the difference between excluding and not excluding Tranche 1 payments from the analysis is very small. Tranche 1 payments are mainly used for transactions payable to the Bank of Canada (e.g., CDSX transactions and payments related to the settlement of the CLS Bank), because the bilateral credit limits granted by the Bank of Canada in Tranche 2 are quite low and cannot support high-value transactions. After transactions related to the settlement of CDSX and the CLS Bank are removed, on average each day, Tranche 1 payments (excluding those sent by the Bank of Canada) account for 4.40% of the total value and only 0.28% of the total volume in the LVTS.

[4] The CLS Bank's payment cycle consists of several target times for processing pay-ins and payouts. For details of daily operations of the CLS Bank, please refer to Miller and Northcott (2002).

[5] CDSX is an electronic system, owned and operated by the CDS, for clearing and settling debt, equity and money market transactions in Canada. In this paper, funds transfers to and from CDS are referred to as *CDSX transactions*. In this study, the LVTS transactions used for settling CDSX final funds positions are identified by approximation, because the payment flow data used do not carry indicators of purpose of each transaction; they are approximated by all the payments to and from the Bank of Canada through Tranche 1, sent between 16:00 and 17:00 EST. The caveat of this estimation is that not all the payments to and from the Bank of Canada during this hour are CDSX transactions; they might include funds transfers resulting from the PM auction of federal government (Receiver General) balances, which usually occurs at 16:15 EST.

[6] The majority of the variables in this paper are computed from transaction-level data, e.g. the time distribution of payment value and volume, and the times at which every decile of daily payment value is submitted. However, historical data on ACSS settlement are available only in the daily total of pay-ins or payouts of each financial institution. Approximation in this case is not carried out, because it would be even less accurate. LVTS participants do not have as tight a designated time frame to submit ACSS-related payments to the LVTS as they do for CDSX settlement. Any payment exchange between LVTS participants and the Bank of Canada in the morning can be ACSS related, or not. If only payments submitted within a selected time frame are removed from the analysis, many transactions that are truly related to ACSS settlement would have been left out.

In this section, the data used are mainly LVTS payment flows at the transaction level, and they span from June 2003 to December 2011. The sample period consists of 2,162 business days. To accentuate the behaviour component in payment timing, payment submission times are utilized throughout this paper, instead of the settlement times. The vast majority of LVTS payments settle immediately upon submission; the difference between the submission time and the settlement time of a regular payment is only a matter of seconds. However, in the case of Jumbo payments,[7] the elapsed time between submission time and settlement time can be much greater, which is determined by the result of the Jumbo queue algorithm. The term "settlement" is occasionally used in discussions of the results because, first, only a small fraction of transactions in the LVTS are Jumbo payments, and secondly, early submission in general leads to early settlement.

An examination of the time distributions of payment value and volume in the LVTS shows a general persistent pattern through the years. A yearly comparison shows how these time distributions have evolved.

2.1 Time Distribution of Payment Volume

Figure 1 shows the time distribution of the number of payments for each year between 2003 and 2011. Each panel presents the probability distribution function for the average daily percentage of the total number of LVTS payments submitted in each minute during the course of a day. Payments related to the settlement of the CLS Bank and CDSX transactions are not included in the calculations. These percentages are yearly averages, meaning that on a given day, the number of payments is counted for each minute, and for a given minute, the number of payments in that minute is averaged over the number of business days in the year.

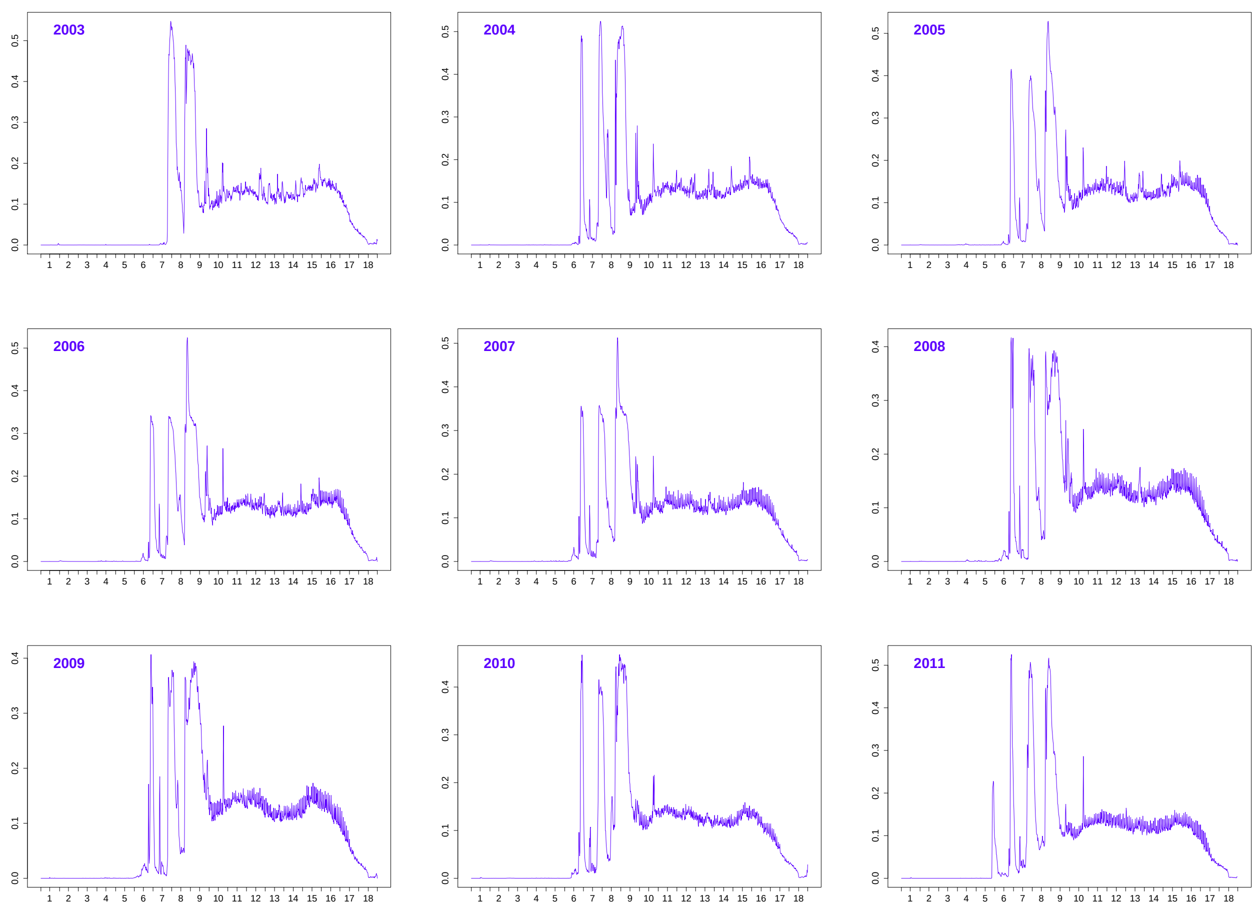
It appears clear that a general pattern in the timing of payments in volume persists through most of the years in the sample. Specifically, there are three major spikes in the early morning, at around 06:30, 07:30 and 08:30, respectively, and a plateau for the rest of day. The three upsurges of payments might be associated with the fact that CLS transactions for all currencies are completed by 06:00 and 08:00 is the deadline for completion of LVTS commencement procedures. For the 06:30 spike, the LVTS participants who are also CLS members might have sorted out non-CLS payment orders that are ready to be submitted overnight, and once the CLS payment cycle ends these payments are released. A similar explanation may apply to the time around the start of the LVTS general payment exchange.

Nevertheless, a couple of exceptions exist. For example, the spike at 06:30 was absent

[7]In the LVTS, only payments that are designated as Jumbo will be queued in the central LVTS Jumbo queue, rather than being rejected by the system, if they fail the initial risk-control tests.

in 2003. And there is an additional smaller spike at 05:30 in 2011; this can possibly be explained by a change in the LVTS rules effective 13 December 2010 that allows non-CLS related payments to be submitted and settled between 00:30 and 06:00.[8]

Figure 1: LVTS Volume Time Distribution by Year



Notes: Each panel shows the average daily percentage of the total number of LVTS payments submitted in each minute for a given year. The horizontal axis displays the time over the course of a day. The vertical axis shows the percentage of the daily number of payments sent during each minute interval. Calculations exclude payments related to the settlement of the CLS Bank and CDSX transactions.

2.2 Time Distribution of Payment Value

The time distribution of LVTS payment value for each year between 2003 and 2011 is reported in *Figure 2*. Each panel shows the probability distribution function for the average percentage of the daily value of LVTS payments transfered during each one-minute interval over the course of a day. The timing of payment value exhibits an overall pattern that is very different from the volume time distribution.

[8]In order to send non-CLS related payments prior to 06:00, a bilateral agreement between sending and receiving participants is required.

In addition to a few spikes at 06:30, 08:30 and noon, for most years in the sample there is a notable concentration of payment value sent in the late afternoon, at around 16:30. Compared to the time distribution of payment volume in *Figure 1*, the fact that the payment volume starts declining but payment value begins to soar after 16:00 suggests that the late-afternoon concentration of payment value might result from a relatively large amount of high-value payments settled late in the day.

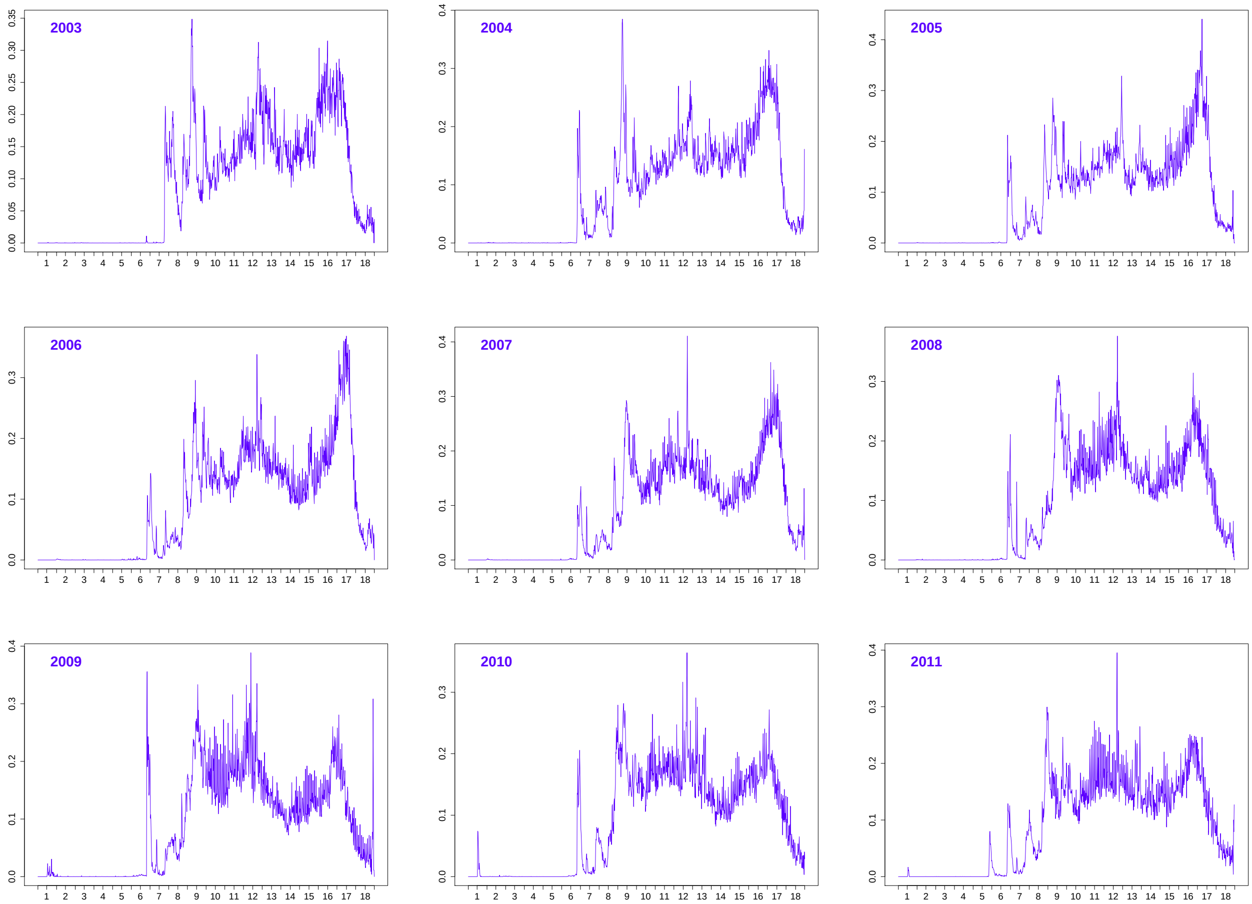
Figure 2 shows that from 2003 to 2006, the peak of payment activity in the late afternoon gradually becomes more concentrated over the years, and in 2006 it not only reaches its highest record but also is shifted to later in the day at 17:00. In 2007, the peak between 16:30 and 17:00 has dropped back to the level similar to that of 2005. However, starting in 2008, the value of funds transfered at 16:30 is no longer the peak of activity over the course of a day; it is comparable to the level at noon. For 2009, 2010 and 2011, it is no longer true to claim that payment activity in the LVTS climaxes in the late afternoon.

It is evident that from 2003 to 2011, the time distribution of payment value in the LVTS has changed much more than that of payment volume. Therefore, this paper focuses on the changes in the timing of payment value. As shown in *Figure 2*, there is a clear improvement in payment settlement timing in and after 2008, relative to the prior period. *Table 1* reports the times at which deciles of daily payment value are submitted on average for each year between 2003 and 2011; the corresponding standard deviation of each mean is listed in parentheses. For all the deciles, payments are in general submitted and settled significantly earlier in 2009 than in all other years. In addition, the variability in the submission times of deciles 4-6 in 2009 is also the lowest among all the years, indicating consistency in the improvement of payment timing within the middle range of the value time distribution. The quickening of settlement in 2009 can be shown more clearly in *Table 2*, which lists the differences in these average submission times between other years and 2009, measured in the number of minutes. Compared to the years prior to 2007, the deciles 3-7 were submitted on average more than one hour earlier in 2009. There are only two places where payments were on average submitted a bit faster relative to 2009, which are the first deciles in 2010 and 2011.

It is not surprising that payment timing in the LVTS was most improved in 2009. Starting in late 2008, several changes to the key policies and rules were launched by the Bank of Canada as new measures to provide liquidity to the Canadian financial system. One of the initiatives was that effective 20 October 2008, the Bank of Canada began temporarily accepting NMLP as eligible collateral for the LVTS and Standing Liquidity Facility purposes; this arrangement provided financial institutions greater flexibility in managing their collateral, and support for generating more liquidity in the system.[9] The

[9]Temporary acceptance of NMLP as eligible collateral for the LVTS is one part of the new measures

Figure 2: LVTS Value Time Distribution by Year



Notes: Each panel shows the average daily percentage of the total value of LVTS payments submitted in each minute for a given year. The horizontal axis displays the time over the course of a day. The vertical axis shows the percentage of daily total value of payments sent during each minute interval. Calculations exclude payments related to the settlement of the CLS Bank and CDSX transactions.

other major adjustment was made to the operating framework for the implementation of monetary policy; one of the components in the change was that the Bank of Canada would provide excess settlement balances, significantly more than required by the LVTS participants, to create the incentive for the overnight rate to trade at the bottom of the operating band. One hypothesis is that the large increase in the settlement balances reduced much of the participants' need to economize on intraday liquidity by delaying payments, and therefore payments are being submitted and settled more quickly.

Showing the evolution of payment timing in the LVTS from a somewhat different per-

that the Bank of Canada introduced in October 2008 to provide exceptional liquidity to the Canadian financial system. Other liquidity initiatives taken by the Bank of Canada at the same time include providing significant ($10 million) term liquidity to the financial sector through Term Purchase and Resale Agreement (PRA) operations; improving the distribution of liquidity by extending Term PRA transactions to Primary Dealers; and temporarily offering a new Term PRA facility for Primary Dealers on a direct basis and for other money market participants on an indirect basis.

Table 1: Average Submission Times of Deciles of Daily Payment Value in LVTS

Decile	2003	2004	2005	2006	2007	2008	2009	2010	2011
1	08:27:42	08:30:13	08:33:53	08:45:02	08:47:43	08:47:56	08:26:15	08:24:03	08:18:42
	(00:16:10)	(00:19:01)	(00:17:17)	(00:15:32)	(00:17:27)	(00:14:55)	(00:18:49)	(00:14:14)	(00:12:17)
2	09:37:53	09:41:19	09:36:10	09:46:22	09:43:22	09:31:30	09:09:37	09:16:55	09:20:56
	(00:26:19)	(00:28:11)	(00:24:39)	(00:24:37)	(00:25:32)	(00:23:29)	(00:24:17)	(00:21:28)	(00:19:22)
3	10:59:08	10:59:18	10:53:17	10:58:26	10:51:01	10:35:57	10:07:45	10:18:45	10:31:23
	(00:26:32)	(00:26:31)	(00:24:07)	(00:25:39)	(00:24:22)	(00:24:30)	(00:26:48)	(00:22:31)	(00:23:36)
4	11:57:53	12:01:29	11:54:18	11:56:25	11:46:02	11:34:42	11:04:09	11:16:40	11:27:23
	(00:22:50)	(00:26:36)	(00:26:11)	(00:24:13)	(00:24:53)	(00:22:33)	(00:20:15)	(00:22:39)	(00:23:26)
5	12:49:51	13:00:25	12:53:58	12:53:26	12:41:35	12:23:18	11:51:55	12:11:53	12:23:03
	(00:25:43)	(00:32:17)	(00:30:16)	(00:32:32)	(00:32:03)	(00:27:09)	(00:19:46)	(00:25:33)	(00:23:22)
6	13:56:13	14:05:22	14:04:33	14:02:18	13:49:52	13:28:01	12:49:07	13:08:30	13:25:31
	(00:33:15)	(00:31:43)	(00:31:48)	(00:36:21)	(00:38:14)	(00:34:50)	(00:29:12)	(00:33:10)	(00:25:01)
7	15:02:49	15:08:56	15:13:52	15:19:11	15:10:01	14:42:55	14:10:07	14:25:38	14:35:20
	(00:27:30)	(00:27:03)	(00:26:36)	(00:28:25)	(00:31:49)	(00:32:49)	(00:34:01)	(00:32:13)	(00:24:39)
8	15:52:13	16:03:41	16:08:09	16:19:18	16:12:38	15:49:15	15:30:17	15:37:30	15:41:13
	(00:22:29)	(00:20:37)	(00:17:45)	(00:18:07)	(00:21:14)	(00:23:16)	(00:23:46)	(00:22:00)	(00:17:11)
9	16:33:27	16:40:38	16:42:36	16:55:26	16:51:57	16:35:18	16:29:10	16:34:40	16:30:50
	(00:20:23)	(00:15:47)	(00:12:55)	(00:11:54)	(00:15:31)	(00:17:41)	(00:15:28)	(00:16:59)	(00:14:32)
10	18:16:19	18:14:05	18:15:56	18:19:10	18:18:08	18:16:21	18:12:39	18:14:58	18:16:14
	(00:12:44)	(00:09:57)	(00:08:17)	(00:05:24)	(00:08:19)	(00:08:33)	(00:11:44)	(00:12:48)	(00:04:32)

Note: The corresponding standard deviation of each mean is listed in parentheses.

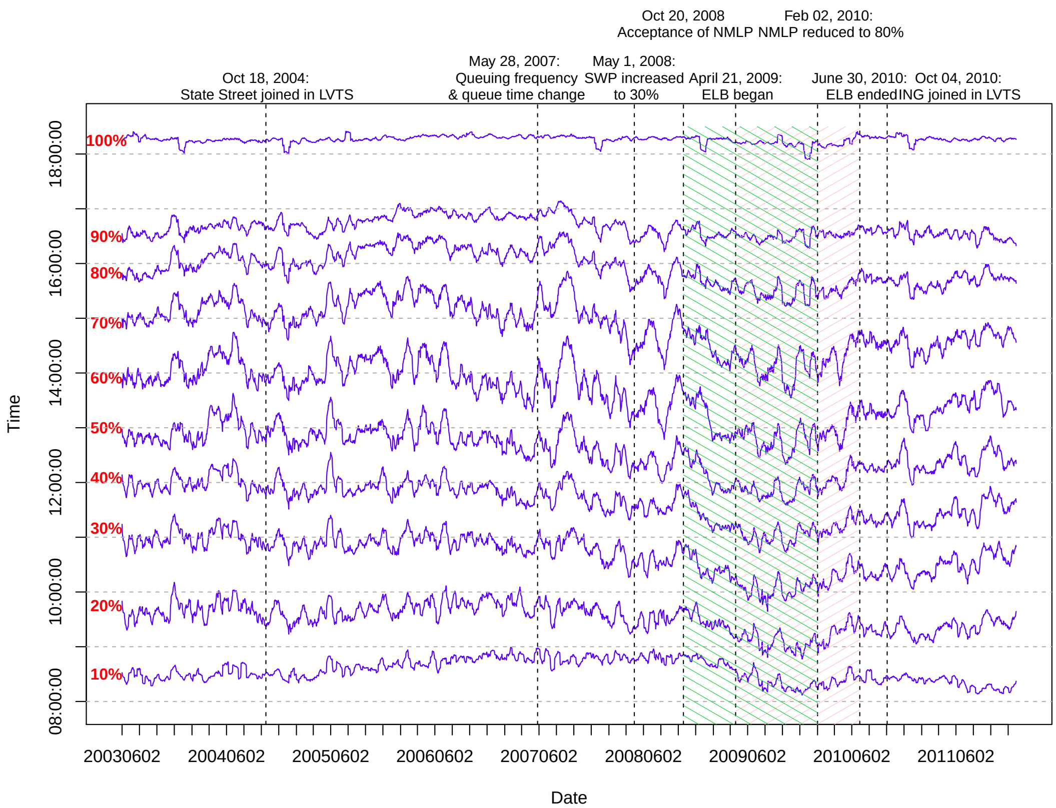
Table 2: Differences in Average Submission Times (in Minutes)

Decile	2003-2009	2004-2009	2005-2009	2006-2009	2007-2009	2008-2009	2010-2009	2011-2009
1	1.45	3.97	7.63	18.78	21.47	21.68	-2.20	-7.55
2	28.27	31.70	26.55	36.75	33.75	21.88	7.30	11.32
3	51.38	51.55	45.53	50.68	43.27	28.20	11.00	23.63
4	53.73	57.33	50.15	52.27	41.88	30.55	12.52	23.23
5	57.93	68.50	62.05	61.52	49.67	31.38	19.97	31.13
6	67.10	76.25	75.43	73.18	60.75	38.90	19.38	36.40
7	52.70	58.82	63.75	69.07	59.90	32.80	15.52	25.22
8	21.93	33.40	37.87	49.02	42.35	18.97	7.22	10.93
9	4.28	11.47	13.43	26.27	22.78	6.13	5.50	1.67
10	3.67	1.43	3.28	6.52	5.48	3.70	2.32	3.58

Note: The differences are subtractions of the average submission times in 2009 from those of other years.

spective, *Figure 3* reports the deciles of daily payment value as a time series throughout the sample period. Several major events that might have had an impact on the timing of LVTS payments are marked on the top of the graph, such as the entry of new participants into the system, the increase in the system-wide percentage (SWP), the changes of LVTS queuing frequency and maximum queue time, the acceptance of NMLP as eligible LVTS collateral, and the changes to the implementation of monetary policy at the ELB for the overnight interest rate. The deciles in general exhibit a downward trend between July 2007 and the end of June 2010, most notably after the NMLP was allowed for LVTS collateral and during the period when monetary policy was implemented at the ELB. This result is consistent with the observation of earlier payment submission times after 2007, when comparing the yearly portraits of the probability distribution function of the percentage of the daily payment value. Additionally, after the NMLP was introduced, three deciles, namely the 6th, 7th and 8th, became more separated than they were in the past prior to the policy change. This result confirms the findings in *Figure 2* that the value of funds transfered in the LVTS has become much less concentrated in the late afternoon, notably in 2008.

Figure 3: Deciles of LVTS Payment Value Time Distribution



Notes: A thirteen-day centered moving average is used. Calculations exclude payments related to the settlement of the CLS Bank and CDSX transactions.

Figure 3 shows a noticeable liquidity effect of some previous events on the changes in the timing of LVTS payment value; however, there might be other factors that exert influence on the evolution of time distributions as well, such as the value and volume of payments settled in the LVTS, and the amount of payment activity in other payments systems that use the LVTS for final settlement. The relative effects of various factors will be further explored in the next section.

3 Regression Analysis

3.1 Model and Data

Drawing on Bech, Martin and McAndrews (2012), nine linear regressions are separately estimated for each decile of daily payment value under 100 percent. The sample data used are the same as in section 2, spanning from 2 June 2003 to 30 December 2011. In each regression, the dependent variable is the time at which a given decile of payment value has been submitted on each day, measured in the number of seconds since the day's LVTS opening. Each of the nine regressions uses the same set of explanatory variables, which capture LVTS payment value and volume, payment activity in other settlement systems (i.e., the CLS Bank and CDSX), changes in LVTS operations, changes in collateral and monetary policies, and calendar effects. Definitions of all explanatory variables are provided in the appendix. The estimation is conducted in levels because unit root tests (both Phillips-Perron and augmented Dickey-Fuller tests) reject the null hypothesis of non-stationarity in the submission time deciles. *Table 3* reports summary statistics for some selected explanatory variables.

Table 3: Summary Statistics of Explanatory Variables

	Mean	Median	Standard Deviation	Minimum	Maximum
Number of Payments (thousands)	20.916	20.548	4.556	3.093	41.819
Payments >= \$10 Million [b]	0.925	0.927	0.011	0.858	0.953
CLS Canadian-Dollar Value (billion \$)	5.159	4.708	2.277	0.000	18.777
CDSX Payout Value (billion \$)	3.849	3.509	2.453	0.000	19.287
Uncollateralized Overnight Loans (billion \$)	3.593	3.500	1.437	0.067	9.646
Repayments of Overnight Loans (billion \$)	3.593	3.503	1.443	0.030	9.647
Bank of Canada Target Rate (%)	2.334	2.500	1.411	0.250	4.500
Deviation of CORRA from Target Rate (%)	-0.006	-0.0025	0.022	-0.283	0.127
HHI of LVTS Value [c]	0.188	0.190	0.009	0.150	0.220

[b] Payments greater than or equal to \$10 million are the share of daily total value that reach or go beyond the threshold, excluding payments related to the settlement of the CLS Bank and CDSX.
[c] HHI of LVTS value is the *Herfindahl-Hirschman Index*, a measure of the concentration of payment activity among the LVTS participants.

Specifically, the following equations are estimated:

$$\begin{aligned} d_t^1 &= \beta_0^1 + V_t \cdot \beta_V^1 + F_t \cdot \beta_F^1 + O_t \cdot \beta_O^1 + M_t \cdot \beta_M^1 + \beta_{16}^1 \cdot HHI_t + N_t \cdot \beta_N^1 + \epsilon_t^1 \\ d_t^2 &= \beta_0^2 + V_t \cdot \beta_V^2 + F_t \cdot \beta_F^2 + O_t \cdot \beta_O^2 + M_t \cdot \beta_M^2 + \beta_{16}^2 \cdot HHI_t + N_t \cdot \beta_N^2 + \epsilon_t^2 \\ &\ldots \\ d_t^9 &= \beta_0^9 + V_t \cdot \beta_V^9 + F_t \cdot \beta_F^9 + O_t \cdot \beta_O^9 + M_t \cdot \beta_M^9 + \beta_{16}^9 \cdot HHI_t + N_t \cdot \beta_N^9 + \epsilon_t^9, \end{aligned}$$

where $d_t^i, i \in 1, 2, \ldots, 9$ denotes the time at which the i^{th} decile of daily total payment value is submitted on day t; V_t is a vector of four variables associated with the transaction value and volume in the LVTS on day t, including the value of uncollateralized interbank overnight loans, and the share of high-value payments on that day; F_t is a vector of two variables: the CLS Bank Canadian-dollar transaction value and CDSX final payout value on day t; O_t is a vector of five dummy variables indicating previous changes in LVTS operations, including the entries of new direct participants; M_t is a vector of four explanatory variables related to the exceptional liquidity initiatives introduced in October 2008 and past changes in the implementation of Canadian monetary policy, including the dummy variables indicating the ELB period and the time during which NMLP was fully accepted as LVTS collateral; N_t is a set of eleven calendar dummies that control for various calendar effects, including the days of the week, the day after a Canadian holiday, the beginning and end of each month, and the corporate and fiscal year-end.

3.1.1 LVTS Value and Volume

The daily total number of payments used in the regressions excludes transactions related to the settlement of the CLS Bank and CDSX. With all else equal, one may anticipate that a larger amount of payments suggests a smaller average size of payments and therefore may, overall, accelerate the settlement. Alternatively, it might also be true that a higher volume of payment transfers implies greater operational costs, and payments are delayed simply because in general it takes more time and effort to process a greater amount of payments.

The daily total value of LVTS payments was originally included in the estimation, but due to its high correlation with the daily volume of payments (with the correlation coefficient being 0.61), it was later removed from the regressions. One reason for keeping transaction volume, rather than value, in the analysis is that there is another independent variable to control for the value of payments to a certain extent, namely the share of daily value being high-value payments. Payments greater than or equal to \$10 million are defined as high-value transactions in this paper, because throughout the sample period, the payment value at the daily 90th percentile is less than \$10 million. The hypothesis is that large individual payments require more intraday liquidity to pass the risk controls, and are therefore more likely to be queued and to result in delayed settlement.

The uncollateralized interbank overnight loans and next-day repayments are identified by a customized version of Furfine algorithm as used in the study by Hendry and Kamhi (2007).[10] The repayments of uncollateralized overnight loans are not included as an explanatory variable in the regressions, for two reasons: first, to avoid multi-collinearity; second, these repayments are known to LVTS participants from the previous day's transactions, so the liquidity impact on payment timing on any given day of having to pay back

[10] There have been increasing concerns about the accuracy of "Furfine-based" algorithms as well as the ability of these algorithms to correctly identify uncollateralized overnight interbank transactions. Discouraging results are found in an assessment conducted by Armantier and Copeland (2012). Using data on the Fed funds market from 2007 to 2011, they estimate the average type I and type II errors to be fairly high. However, in the current paper, the uncertainty of the "Furfine-imputed" interbank loans might be reduced by the fact that the algorithm is only applied to the transactions between 16:00 and the time when the LVTS closes, because the majority of interbank overnight loans occur later in the day. In addition, a recent study by Rempel (2014) proposed improvements of the Furfine algorithm that can lower the upper bound on the estimated rate of false positives, and the refined results suggest that the interest rates inferred from the Furfine algorithm do provide reasonable estimates of the overnight lending cost in the interbank market. Due to these concerns, the results reported in this paper that are related to using the algorithm's output shall be interpreted with caution.

the overnight loans is presumably trivial. All else being equal, one can expect that a larger amount of overnight loans would be associated with slower LVTS settlement, since they in general reflect higher demand for intraday liquidity throughout the day.

3.1.2 Other Payments Systems

Two variables associated with the settlement of the CLS Bank and CDSX are included in the regressions: the daily total value of Canadian-dollar settlement through the CLS Bank and the value of end-of-day payouts sent by CDSX over LVTS to the LVTS direct participants with a net credit position. A simulation study conducted by Embree and Millar (2008) shows that CDSX payouts are a critical source of intraday liquidity for LVTS activity at the end of the day; therefore, one may expect that a higher value of CDSX payouts would be associated with faster LVTS settlements.

As to the value of all Canadian-dollar legs settled by the CLS Bank, Armantier, Arnold and McAndrews (2008) conjecture that the creation of the CLS Bank might have expedited the domestic payments in host countries, since it finishes settlement so early in the day. An alternative hypothesis is that a higher level of the CLS payment activity inevitably draws on more intraday liquidity, and hence, all else equal, a larger amount of transactions settling through the CLS Bank tends to slow down the transfer of LVTS payments.

3.1.3 LVTS Operations

Effective 5 December 2005, the frequency of executing the LVTS Jumbo algorithm was increased from every 20 to every 15 minutes.[11] As of 28 May 2007, the maximum amount of time for any Jumbo payment to stay in the queue was shortened from 65 to 35 minutes; on the same day, the frequency of the queue-expiry algorithm was increased from every hour to every half-hour. A dummy variable is included in the regressions to indicate the time period after the date of each of these changes. These modifications to the LVTS central queueing arrangements increased the frequency of payment offsetting, expedited liquidity recycling and lowered the cost of liquidity for participants, and thus one should expect they would result in an earlier settlement of payments.

Another change in LVTS operations occurred on 1 May 2008, when the system-wide percentage was increased from 24% to 30%. A dummy variable is included in the regression for all dates after the change. The system-wide percentage is used in determining the maximum multilateral net debit position that a LVTS participant can incur in Tranche 2; specifically, an increase in the system-wide percentage leads to a higher net debit cap

[11] The central queueing mechanism in the LVTS is known as the "Jumbo only" algorithm, which only allows payments that are designated as Jumbo to be queued in the system after they fail the initial risk-control tests. For more details, please see Arjani and McVanel (2006).

for all participants. Therefore, one can hypothesize that this change may accelerate the submission and settlement of LVTS payments.

During the nine years of the sample period, there are two entry events of a new participant. The State Street Bank and Trust Company (State Street) joined the LVTS on 18 October 2004, and ING Bank of Canada became a new direct participant in the LVTS on 4 October 2010. Two dummy variables are included in the regressions for all dates after each new entry. The addition of a new member to the system may lead to later settlement of payments, because it usually takes a transition period for a new participant to familiarize itself with operational rules and procedures, to learn to optimize intraday liquidity, and to establish business relationships with other direct participants in the system, etc. As for the existing participants, they also face an adjustment: the change to collaboration with a new system member from an established routine with its correspondent bank in the past may contribute to relatively slow payment processing.

3.1.4 Liquidity Measures and Monetary Policy

As mentioned in section 2, in October 2008, the Bank of Canada launched a number of new measures to provide extraordinary liquidity to the Canadian financial system. Among them is the temporary acceptance of NMLP as eligible collateral for the LVTS, and in this paper it is used as a representative initiative to indicate the liquidity effect of all other arrangements introduced during the same period. A dummy variable is included in the regressions for all dates from 20 October 2008 to 2 February 2010. These exceptional liquidity measures were introduced to smooth the flow of credit and to enhance the functioning of money markets. For instance, temporary acceptance of the non-mortgage loan portfolio as LVTS collateral allowed LVTS participants to use marketable securities that have collateral value outside the LVTS for other purposes, such as borrowing in short-term funding markets or entering into Term PRA with the Bank of Canada. Therefore, these liquidity initiatives are expected to result in earlier settlement of LVTS payments.

A significant change in the operating framework for the implementation of monetary policy occurred between 21 April 2009 and 30 June 2010. As part of the key changes of setting an ELB on the overnight interest rate, the Bank of Canada provided excess settlement balances, significantly more than required by LVTS participants, to create incentives for the overnight rate to trade at the bottom of the operating band that was pegged at the target rate. Specifically, during that period, the daily level of settlement balances was targeted at $3 billion, expanded from a small quantity of $25-$50 million usually supplied under normal economic conditions. This change, captured with a dummy variable, represents tremendously increased access to intraday liquidity, and hence, one may expect it to accelerate LVTS payments.

The Bank of Canada target rate is included in the regressions to capture any effect monetary policy might have on the timing of LVTS payments. No particular hypothesis is formed with regards to which direction the target rate should influence the payment timing.

Finally, the deviation of CORRA from the Bank of Canada target rate is included in the regressions.[12] It is computed by subtracting the Bank of Canada target rate from CORRA. A positive deviation suggests a higher-than-expected demand for intraday liquidity on money markets, and hence one might expect that it is associated with later payments in the LVTS.

3.1.5 Calendar Effects

A number of dummy variables are included in the regressions to capture predictable weekly, monthly and yearly patterns in LVTS payment flows. They include dummies for Mondays, Wednesdays, Fridays, settlement day for Government of Canada treasury bills, the first two business days of each month, the last two business days of each month, the 2007-2008 global financial crisis, U.S. holidays, the day after a Canadian statutory holiday, financial year-end and corporate year-end. The majority of these calendar dummies are associated with the days on which transaction volume and/or value are known to be higher than usual, and therefore LVTS payments are likely to be submitted later on these days due to a larger demand for intraday liquidity.

3.1.6 Other Control Variables

A constant is included in each regression, and in addition, the *Herfindahl-Hirschman Index* (HHI) of LVTS value is included to control for the concentration of payment activity among the LVTS participants. A more concentrated industrial structure in a payments system means that a larger share of payment value is transferred among relatively few participants, and because more payments are subject to the same liquidity constraint (of each of the few participants), the reduced coordination of payments tends to lead to later settlement. An alternative hypothesis is that, as payment shares move from participants who are less collaborative to those who do (or are more inclined to) coordinate with other system members in sending payments, it could result in greater economization of intraday liquidity and higher efficiency in payment transfers.

[12]CORRA stands for the Canadian Overnight Repo Rate Average. It is one of the two official measures used by the Bank of Canada as proxies for the average cost of overnight funding. It is a weighted average of rates on overnight repo transactions of non-specific Government of Canada securities that occur between 06:00 and 16:00. Although CORRA is a measure calculated at the end of the day, it is fairly predictable. Much of the activity that determines CORRA occurs in the morning or at least by early afternoon; end-of-day transactions do not have a notable impact on its value.

3.2 Results

Estimation results of the nine regressions are integrated graphically in *Figures 4−8*. Every graph contains several panels, and each panel corresponds to an explanatory variable in the regression. The horizontal axis of each panel represents the deciles of daily payment value, or equivalently the numbers for the nine regressions. In a given panel, the nine colored circles indicate the point estimates of the coefficients for this given explanatory variable at each decile. The color of the circle denotes the statistical significance of the coefficient in each regression: red $<=$ 0.1 percent, magenta $=$ 1 percent, green $=$ 5 percent, blue $=$ 10 percent, brown $>$ 10 percent. The two triangles around each coefficient estimate represent the 95 percent confidence intervals. In each regression, estimated standard errors are corrected by the Newey-West method.

In a given regression, a positive (above the line of zero value) coefficient estimate indicates that the corresponding explanatory variable has a positive marginal effect on the time at which the decile of payment value is submitted; a positive marginal effect suggests delay in payment timing. Similar interpretation applies to negative coefficient estimates, which means acceleration in settlement time.

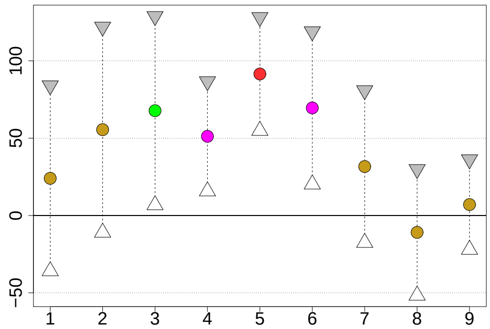
Figure 4 shows regression results for the explanatory variables concerning transaction value and volume in the LVTS. Positive and significant effects show up for the middle deciles of payment volume, 30−60 (*Figure 4a*). The results suggest that, all else equal, an increase in the number of LVTS transfers tends to delay the LVTS payments in late morning and at midday. This result seems to support the hypothesis that higher operational demands generated by a higher volume of transfers could lead to later settlement. In addition, the result may also possibly point toward special cases of certain time-critical payments that cannot easily be split up into smaller transfers; hence, a greater number of these payments would demand more intraday liquidity and take a longer processing time.

The parameters associated with the value of uncollateralized interbank overnight loans are positive and strongly significant for all deciles (*Figure 4b*). The magnitude of the effect is much larger for higher deciles, e.g. at 70% and 80%, than for lower deciles, which is consistent with expectations, since interbank overnight borrowing and lending occur later in the day. The results are consistent with the hypothesis that a larger amount of interbank overnight loans tend to delay the payment timing in the LVTS.

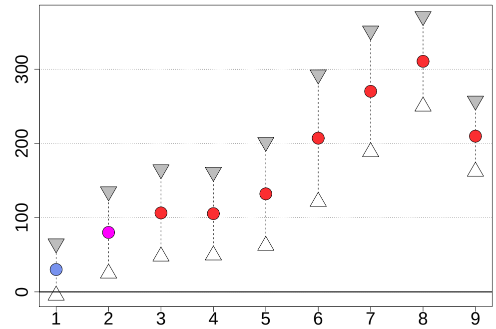
Figure 4c shows that a larger fraction of payments whose value is greater than or equal to \$10 million tends to delay the settlement of LVTS payments throughout most of the day, except the first decile. This result is consistent with expectations.

Regression results in *Figure 5a* suggest that CDSX final payouts expedite LVTS payments throughout the day, except for the first decile. The results confirm the findings by Embree and Millar (2008). It is not surprising to find that the timing of early-day payments

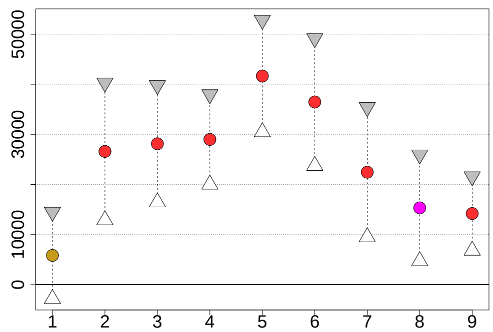
Figure 4: Regressions of the LVTS Value Time Deciles: Value and Volume



(a) Number of Payments



(b) Interbank Overnight Loans

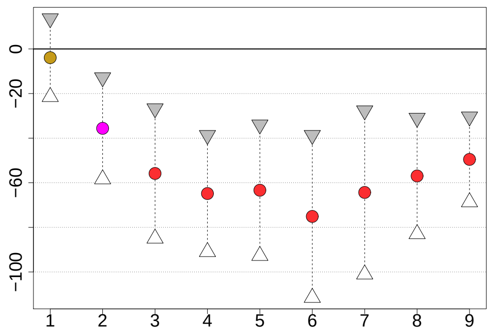


(c) Share of High-value Payments

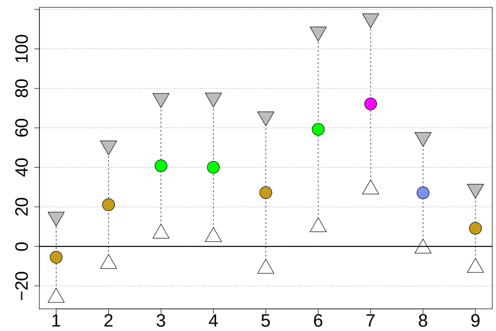
Notes: Nine ordinary least squares regressions are conducted independently, and there are 2,162 observations for each regression. Each panel illustrates the regression result for an explanatory variable. The horizontal axis represents the deciles of daily payment value, or the corresponding regression number. The vertical axis shows the scale for the point estimates of the coefficients. The two triangles around each coefficient estimate indicate the 95 percent confidence intervals. Estimated standard errors are corrected by the Newey-West method. The color of the circle denotes the significance of the coefficient in each regression: red <= 0.1 percent, magenta = 1 percent, green = 5 percent, blue = 10 percent, brown > 10 percent = insignificant.

is also affected, because LVTS participants' end-of-day obligations to CDS (that are settled through the LVTS) are fairly predictable. They can be estimated in the morning or even the day before, since the transactions entered for settlement in CDSX are associated with certain settlement timelines. For instance, provincial bills typically settle on the trade date (T); Government of Canada treasury bills are typically settled two business days after the trade day (T+2), with a few exceptions of settlement on day T; and all provincial bonds settle three days after the trade day (T+3). In addition, CDSX participants have some control over the timing of their trades. In contrast, most of the estimated parameters associated with the total value of the Canadian dollar exchanged over the CLS Bank (*Figure 5b*) are positive, and quite a few are significant. The result is consistent with the argument that a higher level of payment activity in the CLS Bank requires more intraday liquidity early in the day, and is likely to result in delays in the timing of payments later in the day.

Figure 5: Regressions of the LVTS Value Time Deciles: Other Payments Systems that Settle in the LVTS



(a) CDSX Final Payout Value



(b) the CLS Bank Canadian-Dollar Value

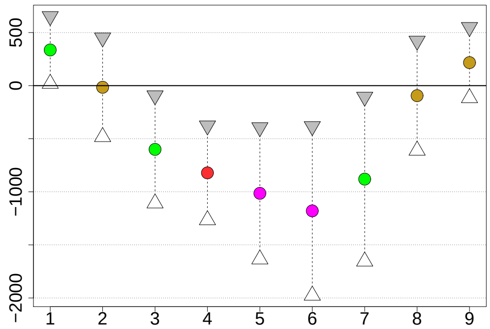
Notes: Nine ordinary least squares regressions are conducted independently, and there are 2,162 observations for each regression. Each panel illustrates the regression result for an explanatory variable. The horizontal axis represents the deciles of daily payment value, or the corresponding regression number. The vertical axis shows the scale for the point estimates of the coefficients. The two triangles around each coefficient estimate indicate the 95 percent confidence intervals. Estimated standard errors are corrected by the Newey-West method. The color of the circle denotes the significance of the coefficient in each regression: red <= 0.1 percent, magenta = 1 percent, green = 5 percent, blue = 10 percent, brown > 10 percent = insignificant.

Figure 6a and *Figure 6b* show that the changes to the LVTS central queuing arrangements seem to have contributed to accelerations in the timing of payment submissions, which falls in line with expectations. Although the Jumbo queue usage has never been high in the LVTS, it is possible that changes in the frequency of the queuing algorithms can have a noticeable impact on LVTS payment timing, because both changes occurred during the peak of the queue usage (between 2005 and 2008), and faster settlement of a small portion of high-value transactions can improve participants' intraday liquidity conditions and help speed up the settlement of other non-queued Jumbo payments and regular payments.[13]

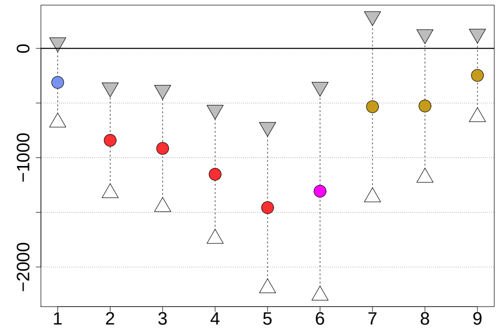
In contrast with the effects of the changes in the LVTS queue parameters, the increase in the system-wide percentage did not seem to affect the timing of LVTS payments (*Figure 6c*). Although most of the parameters associated with this change turn out to be negative in the regressions, they are not statistically significant. The result can be explained by

[13]During the peak of queue usage between 2005 and 2008, the number of queued Jumbo payments was on average 157 per month. There was a sharp decline at the beginning of 2009, and the monthly average from 2009 to 2012 was around 42 payments. Another persistent drop occurred at the beginning of 2013; on average, only 18 Jumbo payments were queued in the system each month from 2013 to October 2014. The shrinkage of Jumbo queue usage can be partially explained by the fact that, during the financial crisis period, the total value of LVTS transactions decreased and the average size of payment also became smaller. In addition, data also show that for a given amount of payments designated as Jumbo, there still have been fewer and fewer actually-queued transactions. This suggests that during the financial crisis, LVTS participants were probably taking precautions to make sure the vast majority of payments, Jumbo or not, passed through risk controls at their initial submission.

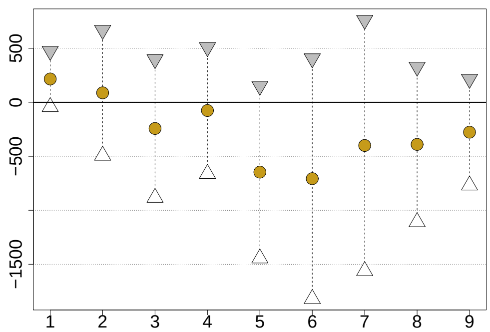
Figure 6: Regressions of the LVTS Value Time Deciles: Changes in LVTS Operations



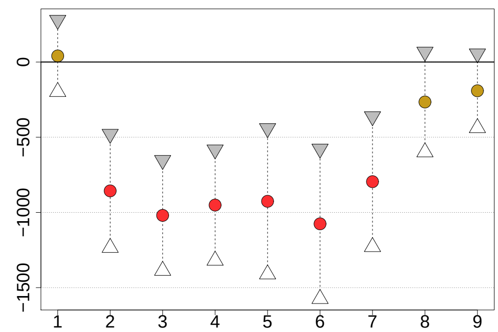
(a) Increase in Jumbo Algorithm Frequency



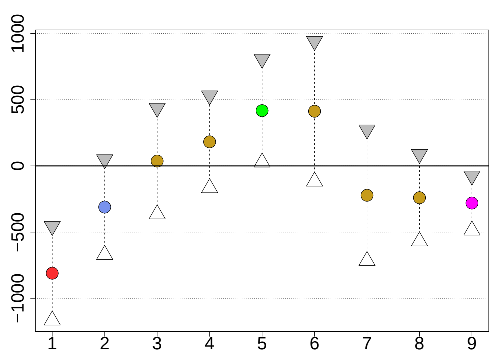
(b) Increase in Queue Expiry Frequency



(c) Increase in System-wide Percentage



(d) State Street Joined the LVTS



(e) ING Joined the LVTS

Notes: Nine ordinary least squares regressions are conducted independently, and there are 2,162 observations for each regression. Each panel illustrates the regression result for an explanatory variable. The horizontal axis represents the deciles of daily payment value, or the corresponding regression number. The vertical axis shows the scale for the point estimates of the coefficients. The two triangles around each coefficient estimate indicate the 95 percent confidence intervals. Estimated standard errors are corrected by the Newey-West method. The color of the circle denotes the significance of the coefficient in each regression: red <= 0.1 percent, magenta = 1 percent, green = 5 percent, blue = 10 percent, brown > 10 percent = insignificant.

the fact that in LVTS Tranche 2, participants are not only constrained by multilateral net debit caps, but also subject to bilateral credit limits that they grant to one another. It is likely that, despite the relaxation of multilateral constraints, payments would have been bounded by the same level of bilateral credit limits as before the system-wide percentage change, and therefore could not go through both risk-control tests any faster.[14]

Finally, it is interesting to observe that the entry of the State Street Bank and Trust Company sped up the settlement of LVTS payments most of the time; the effects are found to be statistically significant for the deciles from 20% up to 70% (*Figure 6d*). This result may be explained by the fact that State Street joined the LVTS quite early in the sample period, and the expected delay of payments might be camouflaged by other events that occurred later in the sample period but quickened the settlement of LVTS payments. In contrast, the effect of ING Bank of Canada joining the LVTS seems to be complicated (*Figure 6d*). It slowed down the payments of the middle deciles, but it expedited the submission of payments in the early morning and at the end of the day.[15]

Regression results suggest that the exceptional liquidity initiatives introduced in October 2008 led to earlier settlement of the 3rd-9th deciles of the LVTS payment value (*Figure 7a*). The result is consistent with the hypothesis that greater flexibility in managing collateral means reduced funding costs and enhanced potential to efficiently generate liquidity; together with all other initiatives, it provided LVTS participants with broad access to intraday liquidity, which would result in a shift toward earlier LVTS payments.

Figure 7b shows that the estimated parameters for deciles below 90 percent are all significant and negative. Thus, the evidence supports the hypothesis that an increase in settlement balances in the LVTS provides participants with extra intraday liquidity that reduces the need to economize funds actively by delaying payments, which contributes to accelerating payment transfers in the LVTS.

Somewhat surprisingly, the deviation of CORRA from the Bank of Canada target rate shifts the distribution of later-day LVTS payments earlier, and its delayed effect on the payments of earlier deciles turns out to be insignificant except for the first 10% of payment value (*Figure 7d*). One possible explanation can be related to the caveat of including this variable, which is mentioned in section 3.1.4. The other possibility is that, as Armantier, Arnold and McAndrews (2008) indicate, the significant quickening effect on payment activity later in the day could suggest that LVTS participants, seeing the cost of overnight interbank lending rising, are anxious to strike a deal as early as they can.[16]

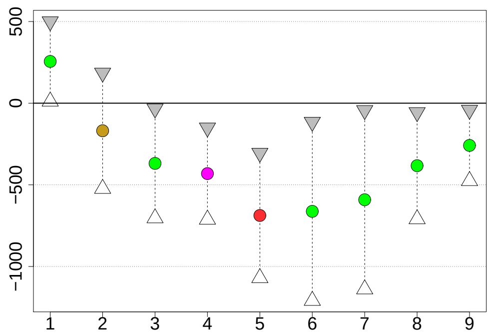
Figure 8a shows that a higher degree of payment concentration measured by the HHI accelerated the submission of LVTS payments, and the effects are significant for all the

[14] Anecdotal evidence shows that bilateral credit limits tend to stay constant for a long period of time, though occasionally participants adjust their cyclical bilateral credit limits to accommodate the unusually high value of transactions.

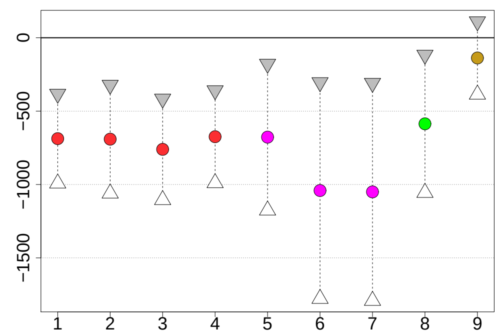
[15] Unfortunately, so far there is not enough anecdotal evidence to suggest one way or the other.

[16] Anecdotal evidence suggests that in the LVTS, uncollateralized overnight interbank loan transactions are mostly concentrated in the late afternoon, up to the system close.

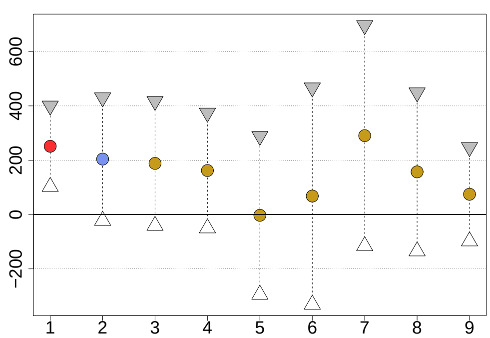
Figure 7: Regressions of the LVTS Value Time Deciles: Liquidity Measures and Monetary Policy



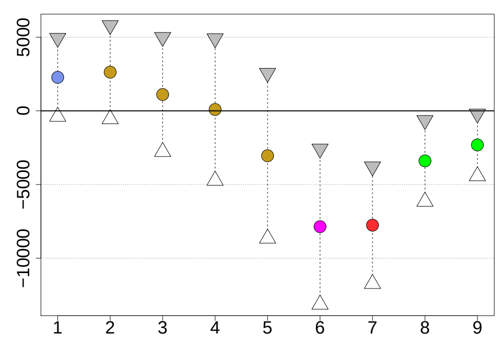
(a) Liquidity Measures in 2008-10



(b) Monetary Policy Implemented at ELB



(c) Bank of Canada Target Rate



(d) Deviation of CORRA from the Target Rate

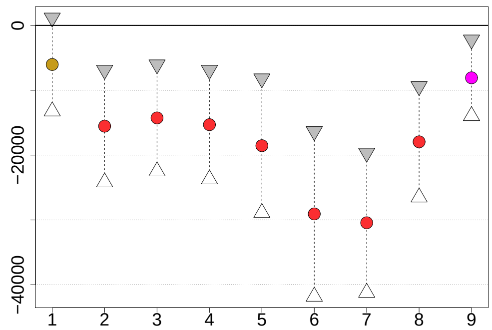
Notes: Nine ordinary least squares regressions are conducted independently, and there are 2,162 observations for each regression. Each panel illustrates the regression result for an explanatory variable. The horizontal axis represents the deciles of daily payment value, or the corresponding regression number. The vertical axis shows the scale for the point estimates of the coefficients. The two triangles around each coefficient estimate indicate the 95 percent confidence intervals. Estimated standard errors are corrected by the Newey-West method. The color of the circle denotes the significance of the coefficient in each regression: red <= 0.1 percent, magenta = 1 percent, green = 5 percent, blue = 10 percent, brown > 10 percent = insignificant.

deciles throughout the day. The result is consistent with the hypothesis that if more payments are concentrated in the hands of a few participants who are more collaborative than others in sending payments, then it could quicken LVTS settlement.

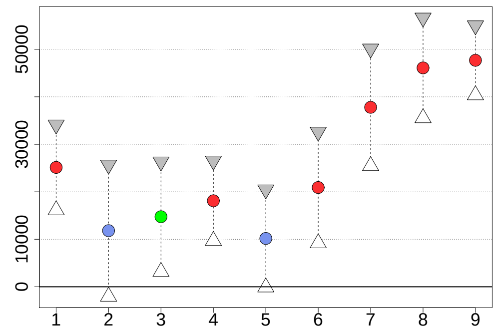
Calendar effects on payment timing in the LVTS are reported in *Figure 10*. Consistent with expectations, the results show that, everything else being equal, the timing of LVTS payments is delayed: (1) at the beginning and end of each month (*Figure 10e* and *Figure 10f*), (2) on Mondays and settlement days for auctions of Government of Canada treasury bills (every second Thursday) (*Figure 10a* and *Figure 10c*), and (3) on the days following a Canadian statutory holiday (*Figure 10i*).

In addition, *Figure 10e* suggests that payments are submitted significantly later on U.S. national holidays, not sooner, which is somewhat surprising because on those days a

Figure 8: Regressions of the LVTS Value Time Deciles: Other Control Variables



(a) HHI of LVTS Value



(b) Constant

Notes: Nine ordinary least squares regressions are conducted independently, and there are 2,162 observations for each regression. Each panel illustrates the regression result for an explanatory variable. The horizontal axis represents the deciles of daily payment value, or the corresponding regression number. The vertical axis shows the scale for the point estimates of the coefficients. The two triangles around each coefficient estimate indicate the 95 percent confidence intervals. Estimated standard errors are corrected by the Newey-West method. The color of the circle denotes the significance of the coefficient in each regression: red <= 0.1 percent, magenta = 1 percent, green = 5 percent, blue = 10 percent, brown > 10 percent = insignificant.

decline in LVTS payment activity is usually expected, given the close economic ties between Canada and the United States.

Despite the fact that payment flows tend to increase in the LVTS at financial year-end (triggered by heightened transaction activity for accounting purposes among financial institutions and corporations), the regression results do not show much of the expected delay effects on the timing of LVTS payments (*Figure 10j*). At corporate year-end, the results indicate that LVTS payments tend to be submitted earlier (*Figure 10k*), which is consistent with expectations. LVTS payment flows possibly fall below normal levels at year-end, because other business activity typically slows down during the holiday season.

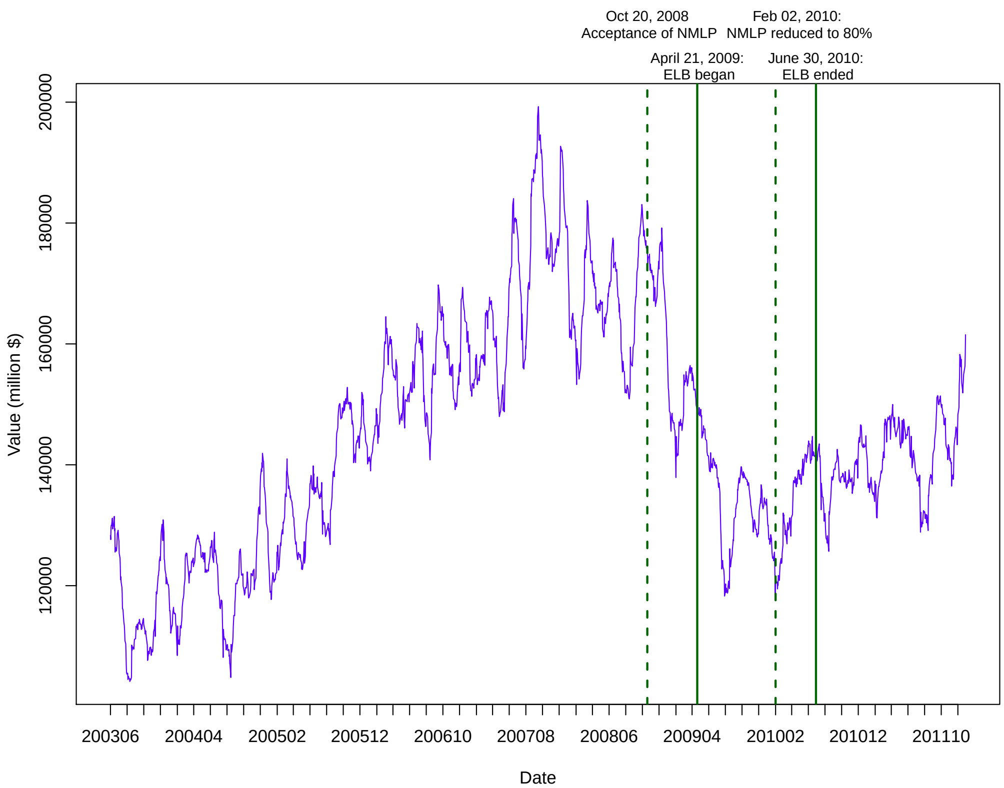
Finally, compared with Mondays, the middle-of-week and end-of-week effects on the timing of LVTS payments do not show as significant in the results (*Figure 10b* and *Figure 10d*). Likewise, all else being equal, the majority of the payment timing is not significantly different during the 2007−08 financial crisis period (*Figure 10g*).

4 Discussion

The regression results suggest that the temporary acceptance of the non-mortgage loan portfolio as LVTS collateral (together with other exceptional liquidity initiatives introduced by the Bank of Canada during the same time period) and the large increase in LVTS settlement balances are the two leading factors in explaining earlier settlement of LVTS payments during the period from late 2008 to 2010. However, a considerable reduction in

LVTS payment activity is also observed after the 2007−08 global financial crisis (see *Figure 9*), which raises the question of whether and how much of the improvement in payment timing is truly driven by participants' adjusted behaviour of sending transactions earlier during this period.

Figure 9: Daily Value of Payment Transfers in the LVTS



Notes: The daily transactions values settled over the LVTS are 21-day moving averages

To answer this question, a mechanical exercise is conducted to break down the quickening effect into two components; one reflects LVTS participants' endogenous behaviour, and the other represents the exogenous changes to overall payment activity in the LVTS. The idea is based on *equation* (1) below:

$$\sum_{i=1}^{N} S_i^t = \sum_{i=1}^{N} \left(P_i^t \times Q_i\right), \tag{1}$$

where S_i^t denotes the cumulative sum of the percentage of daily total payment value system-wise that has been sent by participant i by time t ($t \geq 0, t \leq G$, and G is the closing time for the general payment exchange period); N is the total number of direct participants in the LVTS; P_i^t is the cumulative sum of the percentage of participant i's daily total transaction value sent by time t; and Q_i is the percentage of daily total payment value in the system over the course of a day that is sent by participant i. In the equation, P represents LVTS participants' control over payment timing, an endogenous component, whereas Q indicates participants' shares of transaction amount that are ultimately determined by the underlying real economic activity, an exogenous component.

The exercise starts with calculating $\sum_{i=1}^{N} S_i^t$ for three time periods: the year 2006, the ELB period and the time when the NMLP was accepted as LVTS collateral up to 100%; the ratio of averages of each period is used and t is set to be 16:30. For example,

$$\sum_{i=1}^{N} \left(S_i^t\right)^{2006} = \sum_{i=1}^{N} \left[\left(P_i^t\right)^{2006} \times Q_i^{2006}\right],$$

where $\left(P_i^t\right)^{2006}$ is computed as the average total payment value sent by participant i up to time t on each day in 2006 divided by the average daily total payments sent by i in 2006, then multiplied by 100. The reference year is 2006, because data in that year show the most significant late-afternoon peak in the payment value time distribution (*Figure 2*).

Secondly, four hypothetical values are calculated for $\sum_{i=1}^{N} S_i^t$ by switching one of the two components on the right-hand side of *equation* (1) between the year 2006 and the time period of interest; as above, a ratio of averages of each time period is used and t is set at 16:30. Specifically, the following variables are calculated:

$$\sum_{i=1}^{N} \left(S_i^t\right)^{a} = \sum_{i=1}^{N} \left[\left(P_i^t\right)^{2006} \times Q_i^{ELB}\right] \tag{2}$$

$$\sum_{i=1}^{N} \left(S_i^t\right)^{b} = \sum_{i=1}^{N} \left[\left(P_i^t\right)^{ELB} \times Q_i^{2006}\right] \tag{3}$$

$$\sum_{i=1}^{N} \left(S_i^t\right)^{c} = \sum_{i=1}^{N} \left[\left(P_i^t\right)^{2006} \times Q_i^{NMLP}\right] \tag{4}$$

$$\sum_{i=1}^{N} \left(S_i^t\right)^{d} = \sum_{i=1}^{N} \left[\left(P_i^t\right)^{NMLP} \times Q_i^{2006}\right]. \tag{5}$$

The results are listed in *Table 4*. First, they are consistent with the observation that, starting in 2008, the late-afternoon peak in LVTS payment value time distribution had been retreating; second, the results suggest that participants' behaviour of sending payments earlier seems to have a larger effect on faster LVTS settlement at the end of the day during the ELB and NMLP periods. For example, $\sum_{i=1}^{N} \left(S_i^t\right)^{a} = 78.26\%$, calculated based on the actual distribution of payment activity among LVTS participants during the ELB period, but assuming the same percentage of payment value submitted by each participant by 16:30, as in 2006 (behavioural component). The result suggests that if participants' payment behaviour remained the same as in 2006, even though the aggregate payment flow in the LVTS decreased after the financial crisis (meaning overall fewer payments to settle each day), on average only 78.26% of the daily payment value would have been submitted by 16:30, which is much lower than the actual amount $\sum_{i=1}^{N}\left(S_i^t\right)^{ELB} = 84.44\%$. Almost identical results are found for the time period when the NMLP was fully accepted as LVTS collateral. The results support the hypothesis that the exceptional liquidity initiatives introduced in October 2008 and the large increase in the settlement balances in the LVTS seem to have effectively changed intraday liquidity conditions and hence improved payment timing and settlement efficiency, which may be referred to as a *liquidity effect*.

Table 4: Percentage of Payment Value Sent by All Direct Participants in the LVTS by 16:30 (Actual and Hypothetical)

$\sum\left(S_i^t\right)^{2006}$	$\sum\left(S_i^t\right)^{ELB}$	$\sum\left(S_i^t\right)^{NMLP}$	$\sum\left(S_i^t\right)^{a}$	$\sum\left(S_i^t\right)^{b}$	$\sum\left(S_i^t\right)^{c}$	$\sum\left(S_i^t\right)^{d}$
79.74%	84.44%	84.83%	78.26%	86.95%	76.76%	86.75%

Note: Variables are defined in *equations* (1), (2), (3), (4) *and* (5).

Given the overall positive liquidity effect of these policy changes (i.e., $\sum_{i=1}^{N}\left(S_i^t\right)^{ELB} - \sum_{i=1}^{N}\left(S_i^t\right)^{2006} > 0$ and $\sum_{i=1}^{N}\left(S_i^t\right)^{NMLP} - \sum_{i=1}^{N}\left(S_i^t\right)^{2006} > 0$), the exercise is extended to examine how much of the improvement in LVTS payment timing during both time periods is contributed by each participant. A measure in this regard can be constructed based on *equation* (1) as follows:

$$\left(C_i^t\right)^T = \frac{\left(P_i^t\right)^T \times Q_i^T - \left(P_i^t\right)^{2006} \times Q_i^{2006}}{\sum_{i=1}^{N}\left(S_i^t\right)^T - \sum_{i=1}^{N}\left(S_i^t\right)^{2006}} \times 100, \tag{6}$$

where $i = 1, 2, \ldots, N$; t is set at 16:30 and T denotes either the ELB or NMLP period. For a given T, this measure sums up to 100 over all LVTS participants, i.e. $\sum_{i=1}^{N}\left(C_i^t\right)^T = 100$.

The results suggest that during both time periods, participants' behaviours are not uniform; not every LVTS participant made a positive contribution to the overall improvement in payment timing. Two LVTS members seem to have made major contributions, while two other participants, one big and one small, actually slowed down the submission of payments quite a bit during the time when ELB and NMLP were in effect, relative to their behaviour in 2006.

5 Concluding Remarks

This paper examines payment time distribution trends in the LVTS from 2003 to 2011. A review of the data uncovers that the pattern in payment volume time distribution has been quite stable over the past nine years; however, there are notable changes in the timing of payment value transferred in the LVTS. Specifically, the peak of payment activity in the late afternoon gradually becomes more concentrated between 2003 and 2006; in 2007, there is a slight decline in the peak amount of payment value transferred between 16:30 and 17:00; from 2008 to 2011, it is no longer true that payment activity in the LVTS is mostly concentrated in the late afternoon. In addition, compared with all other years in the sample, the quickening of payment settlement in 2009 is the most significant.

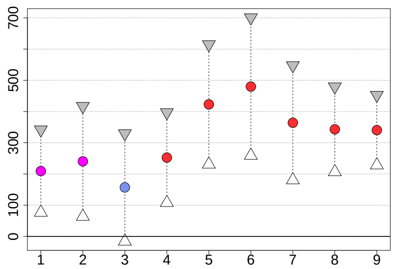
In addition to the descriptive analysis, ordinary least squares regressions are conducted to help identify various factors that might have contributed to the changes in the payment value time distribution. Results show that a larger fraction of high-value payments tends to delay the settlement, because, obviously, big individual payments require more intraday liquidity, and are more likely to be queued if they fail the risk controls. Increased values of uncollateralized interbank overnight loans also tend to slow settlement throughout the day; the effect is consistent with the fact that a larger amount of overnight loans, in general, indicates a higher demand for intraday liquidity by the LVTS participants.

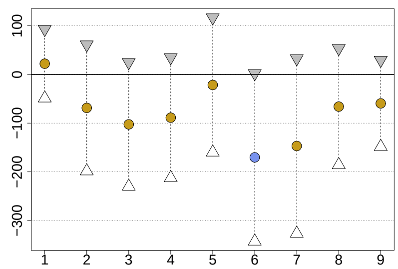
Several factors are found to have helped speed up settlement of LVTS payments. As a critical source of intraday liquidity for LVTS activity at the end of the day, CDSX final payouts tend to quicken LVTS payments significantly. Increased frequency of the LVTS Jumbo algorithm and the queue-expiry algorithm, which improves efficiency of payment netting and liquidity recycling, accelerates the submission of LVTS payments. And, interestingly, a higher degree of payment concentration seems to accelerate the timing of LVTS payments throughout the day. The quickening effect can be explained by the conjecture that, as increasing payment shares move to the participants who are more collaborative in submitting payments, greater economization of liquidity would result in earlier settlement.

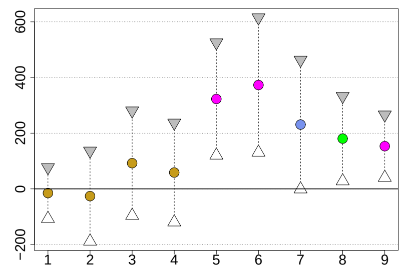
Furthermore, temporary full acceptance of the non-mortgage loan portfolio as LVTS collateral from October 2008 to February 2010 provided greater flexibility in managing collateral and reduced funding costs for participants, which therefore resulted in earlier payments for most of the day. Results also suggest that changes to the operating framework for the implementation of monetary policy between April 2009 and June 2010 quickened the settlement of LVTS payments throughout the day. It confirms the expectation that increased settlement balances reduce the LVTS participants' need to economize on liquidity costs in submitting payments, and hence tend to expedite settlement. Through a mechanical exercise (comparing payment timing in the LVTS between the year 2006 and these two time periods), changes in LVTS participants' behaviours, i.e. submitting payments earlier due to reduced liquidity cost, were found at the aggregate level to account for a large share of earlier settlement of payments over both periods. However, the results also reveal that the behavioural changes at the participant level are not uniform: some participants made considerable contributions toward earlier settlement, while others showed relatively more delays in the timing of payments.

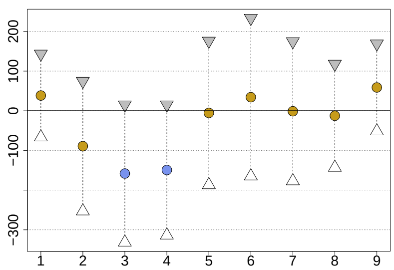
Future research on payment timing in the LVTS could explore various factors that would help explain why participants respond differently to the enhanced liquidity conditions provided by monetary policy changes. It would also be interesting to take the analysis further by disaggregating LVTS payments into two payment types: client-initiated payments versus interbank transfers. Changes in the pattern of value and/or volume of each payment type could potentially be another factor contributing to the changes in LVTS payment timing. Furthermore, the regressions of the deciles on explanatory variables in this paper contain additional non-sample information, i.e. $E[d_t^1] < E[d_t^2] < \cdots < E[d_t^9]$, which could be imposed on the regressions to enhance their efficiency. To implement this, the analysis could be converted to a Bayesian regression approach.

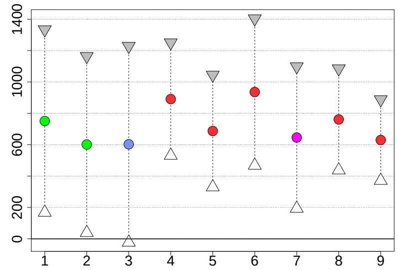
Figure 10: Regressions of the LVTS Value Time Deciles: Calendar Effects

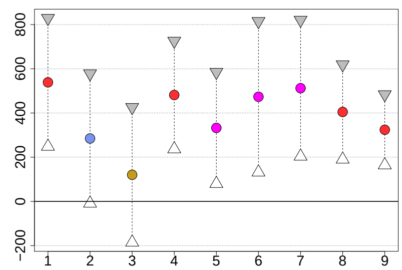

(a) Monday

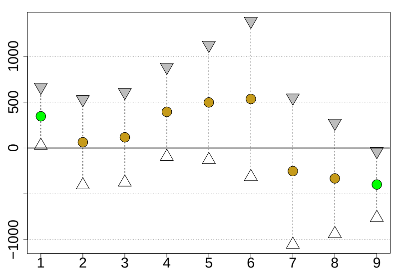

(b) Wednesday

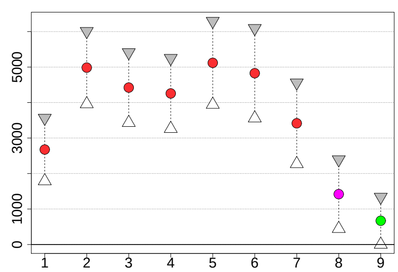

(c) Settlement Day for T-Bills

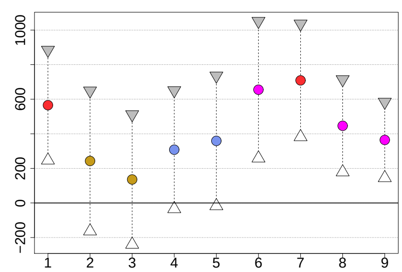

(d) Friday

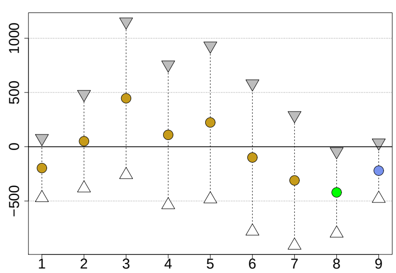

(e) Beginning of Month

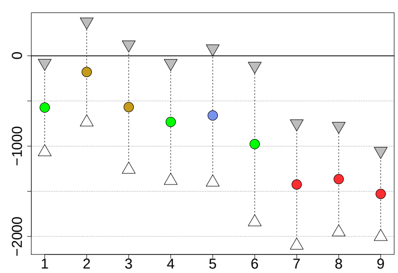

(f) End of Month


(g) 2007−08 Financial Crisis


(h) U.S. Holiday


(i) Day after a Holiday


(j) Financial Year-End


(k) Corporate Year-End

Notes: Nine ordinary least squares regressions are conducted independently, and there are 2,162 observations for each regression. Each panel illustrates the regression result for an explanatory variable. The horizontal axis represents the deciles of daily payment value, or the corresponding regression number. The vertical axis shows the scale for the point estimates of the coefficients. The two triangles around each coefficient estimate indicate the 95 percent confidence intervals. Estimated standard errors are corrected by the Newey-West method. The color of the circle denotes the significance of the coefficient in each regression: red <= 0.1 percent, magenta = 1 percent, green = 5 percent, blue = 10 percent, brown > 10 percent = insignificant.

Appendix: Variables

Number of Payments is the daily total number of payments transferred in the LVTS, including uncollateralized interbank overnight loans, but excluding all transactions related to the settlement of CDSX and the CLS Bank.

LVTS Payment Value is the sum of payment value of all LVTS funds transfered during a day, excluding settlement payments related to the settlement of the CLS Bank and CDSX, uncollateralized overnight interbank loans, and the repayments of these loans. The definition contains both interbank and customer payments.

Interbank Overnight Loans is the total value of the uncollateralized interbank overnight loans during a day. These loans are identified by a customized version of the Furfine algorithm as used in the study by Hendry and Kamhi (2007).

Share of High-value Payments is the fraction of the daily total payment value (excluding transactions related to the settlement of CDSX and the CLS Bank) that is greater than or equal to $10 million. The threshold is chosen because throughout the sample period, the payment value at the daily 90th percentile is less than $10 million.

CDSX Final Payout Value is the value of the end-of-day payouts sent by CDSX over the LVTS to LVTS direct participants with a net credit position.

the CLS Bank Canadian-Dollar Value is the daily total of payments transfered over the LVTS for the purpose of settlement of the CLS Bank. It is equivalent to the value of all Canadian-dollar legs settled by the CLS Bank.

Increase in Jumbo Algorithm Frequency is a binary variable equal to 1 on and after 5 December 2005, when the frequency of executing the LVTS Jumbo algorithm was increased from every 20 to every 15 minutes.

Increase in Queue Expiry Frequency is a binary variable equal to 1 on and after 28 May 2007, when the maximum amount of time for any Jumbo payment to stay in the queue was shortened from 65 to 35 minutes. And on the same day, the frequency of the queue-expiry algorithm was increased from every hour to every half-hour.

Increase in System-wide Percentage is a binary variable equal to 1 on and after 1 May 2008, when the system-wide percentage was increased from 24% to 30%. The system-wide percentage is used in determining the maximum multilateral net debit position that an LVTS participant can incur in Tranche 2; specifically, an increase in the system-wide percentage leads to a higher net debit cap for all participants.

State Street Joined the LVTS is a binary variable equal to 1 on and after 18 October 2004, when the State Street Bank and Trust Company joined the LVTS as a new direct participant.

ING Joined the LVTS is a binary variable equal to 1 on and after 4 October 2010, when ING Bank of Canada joined the LVTS as a new direct participant.

Liquidity Measures in 2008−10 is a binary variable equal to 1 between 20 October 2008 and 2 February 2010 (inclusive), when the Bank of Canada introduced a number of new measures to provide exceptional liquidity to the Canadian financial system. These measures were to help resume the flow of credit and to enhance the functioning of money markets. One of the initiatives was to temporarily accept non-mortgage loan portfolios as LVTS collateral. This temporary change to the collateral policy allowed LVTS participants to use marketable securities that have collateral value outside the LVTS for other purposes, and thus provided participants with greater flexibility in managing collateral.

Monetary Policy Implemented at ELB is a binary variable equal to 1 between 21 April 2009 and 30 June 2010 (inclusive), when Canadian monetary policy was conducted at the effective lower bound (ELB). As part of the key changes of setting a lower bound on the overnight interest rate, the Bank of Canada also targeted the daily supply of settlement balances at $3 billion, expanded from a small quantity of $25-$50 million supplied under normal circumstances, to create incentives for the overnight rate to trade at the bottom of the operating band.

Bank of Canada Target Rate is the Bank of Canada's target for the overnight interest rate.

Deviation of CORRA from the Target Rate is the difference between the Bank of Canada target rate and CORRA. A positive deviation implies a higher-than-expected demand for intraday liquidity by LVTS participants.

HHI of LVTS Value is the Herfindahl-Hirschman index of the value of LVTS payments sent by all direct participants, excluding the Bank of Canada.

Settlement Day for T-Bills is a binary variable equal to 1 on every second Thursday starting on 5 June 2003. It is the settlement date for auctions of Government of Canada treasury bills (T-Bills), and on such days, payment flows from LVTS direct participants to the Bank of Canada tend to increase.

Beginning of Month is a binary variable equal to 1 on the first two business days of each month. The LVTS typically experiences higher-than-normal transaction volume at the beginning of each month, due to the carryover from the previous month end. In addition, payment flows usually increase in the LVTS on the first business day of March, June, September and December, which are the maturity dates for the Government of Canada marketable bonds.

End of Month is a binary variable equal to 1 on the last two business days of each month. LVTS transaction volume usually increases at month end, because many bill payments become due at the end of each month, e.g. payments for mortgages, rent and government taxes on income and sales.

2007−08 Financial crisis is a binary variable equal to 1 between 9 August 2007 and 31 December 2008 (inclusive), when pressures in global financial markets heightened.

U.S. Holiday is a binary variable equal to 1 on the following U.S. national holidays: Martin Luther King, Jr. Day, President's Day, Memorial Day, Independence Day, Columbus Day, Veteran's Day and Thanksgiving Day.

Day after a Holiday is a binary variable equal to 1 on the business day following a Canadian federal statutory holiday. This analysis takes into account the following Canadian statutory holidays: New Year's Day, Family Day, Good Friday, Victoria Day, Canada Day, Civic Holiday, Labour Day, Thanksgiving Day, Remembrance Day and Boxing Day.

Financial Year-End is a binary variable equal to 1 on the following four days each year: 29, 30 and 31 October and 1 November. 31 October is the fiscal year-end for Canadian financial institutions; however, during the period surrounding this book-closing date, the intense year-end accounting activities tend to increase payment flows in the LVTS.

Corporate Year-End is a binary variable equal to 1 on the four business days surrounding the end of each calendar year, i.e. the last two business days in December and the first two business days in January of the following year. 31 December is the fiscal year-end for the majority of Canadian corporations.

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