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From LVTS to Lynx: Quantitative Assessment of Payment System Transition

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Abstract

Modernizing Canada's wholesale payments system to Lynx from the Large Value Transfer System (LVTS) brings two key changes: (1) the settlement model shifts from a hybrid system that combined components of both real-time gross settlement (RTGS) and deferred net settlement (DNS) to an RTGS system; (2) the policy regarding queue usage changes from discouraging it to encouraging the adoption of the new liquidity-saving mechanism. We utilize this unique opportunity to quantitatively assess the effects of those changes on the behaviour of participants in the high-value payments system. Our analysis reveals the following: (1) At the system level, most payments are settled in a single stream with the liquidity-savings mechanism in Lynx—facilitating liquidity pooling and leading to higher efficiency than LVTS where payments were distributed in two streams. Moreover, due to Lynx's liquidity-saving mechanism, many payments arrive earlier than those in LVTS, providing more opportunities for liquidity saving at the cost of slightly increased payment delay. (2) At the participant level, the responses are rather heterogeneous; however, our analysis suggests that liquidity efficiency is improved for several participants, and most experience slightly longer payment delays in Lynx than in LVTS.

Topics: Financial institutions; Financial services; Financial system regulation and policies; Payment clearing and settlement systems
JEL codes: E42, G28, C10

Résumé

La modernisation du système de paiement de gros du Canada, soit le passage du Système de transfert de paiements de grande valeur (STPGV) au système Lynx, amène deux changements importants : 1) le modèle de règlement repose sur un système à règlement brut en temps réel plutôt que sur un système hybride regroupant à la fois des composantes du règlement brut en temps réel et du règlement net différé, 2) la politique concernant l'utilisation de la file d'attente, qui décourageait le recours à celle-ci, favorise maintenant l'adoption du nouveau mécanisme d'économie des liquidités. Nous profitons de cette occasion unique pour évaluer de façon quantitative les effets de ces changements sur le comportement des participants au système de paiement de grande valeur. Notre analyse révèle plusieurs faits saillants. D'abord, au niveau du système, la plupart des paiements sont réglés en un seul flux grâce au mécanisme d'économie des liquidités de Lynx, ce qui facilite la mise en commun des liquidités et permet des gains d'efficience par rapport au STPGV, système dans lequel les demandes de paiement étaient réparties dans deux flux distincts. Autre avantage de ce mécanisme de Lynx, de nombreuses demandes de paiement arrivent plus rapidement que dans le cas du STPGV, ce qui offre davantage de possibilités d'économie de liquidités, au prix d'un délai de paiement un peu plus long. Ensuite, au niveau des participants, les réactions sont plutôt hétérogènes. Toutefois, selon notre analyse, plusieurs participants bénéficient

d’une efficience accrue des liquidités, et la plupart connaissent des délais de paiement légèrement supérieurs à ceux du STPGV.

Sujets : Institutions financières; Réglementation et politiques relatives au système financier; Services financiers; Systèmes de compensation et de règlement des paiements
Codes JEL : E42, G28, C10

1 Introduction

High-value payment systems (HVPSs) settle transactions between financial institutions and are part of a nation's core financial infrastructure. Additionally, they serve as a critical tool for the central banks to implement monetary policy. Lynx, Canada's new HVPS, was launched on August 30, 2021, to replace the legacy system, the large-value transfer system (LVTS), as part of the Payments Modernization Initiative.[1] The decision to develop Lynx was driven by the need to upgrade the technology and improve the risk model underpinning the HVPS in Canada (Bank of Canada and Payments Canada 2022).

Compared to LVTS, which was a hybrid system combining components of both deferred net settlement (DNS) and real-time gross settlement (RTGS), Lynx is an RTGS system that eliminates credit risk exposure among participating financial institutions (FIs).[2] Like LVTS, Lynx has two streams where payments can be settled: the liquidity-saving mechanism (LSM) and the urgent payment mechanism (UPM); in addition, Lynx has many new features and functionalities, including a queuing mechanism, a gridlock resolution mechanism, ISO 20022 messaging standard, and enhanced cyber security and resiliency.[3] To ensure a smooth transition to Lynx, the Bank of Canada and Payments Canada worked closely with system participants to help them learn and adapt to the new system.[4] After a brief transition period, the behaviour of Lynx participants stabilized, allowing us to document the payment patterns in the new system and compare them with LVTS.

Utilizing the unique opportunity provided by the transition from a hybrid to an RTGS system, we investigate the changes in FIs' payments behaviour after Canada's transition to Lynx. Using settlement data covering similar periods from each system, we compute a list of metrics to quantify the changes in payment patterns between LVTS and Lynx. This exercise is meaningful for at least two reasons. First, from a research perspective, the data generated by the new system offer us an opportunity to revisit previous studies on payment modernization. For example, Kosse et al. (2021) made some predictions about payment migration into the modernized systems, and Rivadeneyra and Zhang (2022) evaluated the potential performance of Lynx based on simulations. The conclusions from those studies can now be empirically tested, which can guide future research modelling choices. Second, from a policy perspective, the lessons from this exercise are useful for policymakers and researchers in Canada and other jurisdictions in understanding the effects of modernizing core national payment systems and designing new HVPS. This is particularly relevant given the worldwide trend to modernize payment systems.[5]

We perform a quantitative assessment using six-month settlement data in Lynx, from October 2021 to March 2022, and a comparable six-month sample period in LVTS, from October 2020 to March 2021. We choose these similar periods of the year to control for seasonality in payments. Also, both sample periods have similar underlying liquidity conditions due to historically low interest

[1] Visit the following URL for more information on the Payments Modernization Initiative: `https://payments.ca/insights/modernization`

[2] See `https://www.bis.org/cpmi/info_pfmi.htm` for details.

[3] See the document by Bank of Canada and Payments Canada (2022) for a detailed description of the Lynx system and a comparison of its attributes with the LVTS.

[4] As documented by Garratt et al. (2022), participants adapted to the new system rather quickly, and their payments behaviour stabilized after the first couple of weeks of its launch.

[5] See Bech et al. (2017) for a recent overview of the global trend of payment systems modernization.

rates. Using these transaction data samples, we compute throughput in terms of the daily cumulative value of payments submitted to the system to study changes in FIs' payment submission patterns. Next, we present system- and participant-level changes in liquidity efficiency and payment delay across the systems to understand the well-known liquidity-delay trade-off (Bech and Garratt 2003). Finally, we compute the interbank payments network statistics to investigate changes in bilateral and multilateral payment flows among participants.

In terms of aggregate daily payment value (settled in CAD) and volume (number of payments), Lynx is similar to LVTS (and slightly higher because of a natural growth trend). This indicates that there was no drastic change in overall payments flow after the migration, which alleviated the previous concern that the higher liquidity requirement of Lynx (than LVTS) would drive some payments out of HVPS and thus increase settlement risk in the broader payment ecosystem (see Kosse et al. (2021) for more details). However, note that most payments are settled in the LSM, and the UPM is rarely used in Lynx. This stands in contrast to the usage of LVTS Tranche 1 (which was analogous to Lynx's UPM), which typically settled about one-fourth of the total daily value.

In terms of system throughput, we find that payments are sent earlier and settled slightly later in Lynx than in LVTS. This change is mostly because of Lynx's newly added queuing mechanism that incentivizes FIs to send payments early to increase the chances of netting and hence liquidity savings. Thus, adopting a queuing mechanism in Lynx seems to have alleviated the common concern of strategic delays in the system.[6]

In terms of liquidity, heavy use of a single settlement mechanism (i.e., LSM in Lynx) improves the system-level liquidity efficiency over LVTS, as measured by the standard liquidity efficiency ratio (LER).[7] Though the changes in individual-level LERs are rather heterogeneous, most participants enjoy higher LERs in the new system. This suggests shifting to an RTGS system encouraged the adoption of queuing and liquidity-saving mechanisms to improve liquidity efficiency. However, more queuing generally results in longer delays in payment settlement. To examine this, we compare the lengths of payment delays in LVTS and Lynx based on various delay indicators. As expected, our results show longer delays in Lynx than LVTS; however, the differences are rather small (roughly 10 to 15 minutes in weighted settlement time).

Finally, we investigate the interbank payment network structures in both systems to observe any changes in the bilateral payments patterns and the systemic importance of FIs. Despite the high similarities between the two network structures—suggesting minor changes in bilateral flows—Lynx participants are slightly more connected (i.e., denser network), as measured by indicators like degree, reciprocity, and clustering coefficient. Furthermore, the systemically important FIs identified by the SinkRank algorithm (Soramäki and Cook 2013) remain unchanged.

The rest of this paper is organized as follows. Section 2 provides an overview of the LVTS and Lynx and their key differences. This is followed by a description of the data and summary statistics from both LVTS and Lynx samples in section 3. Next, in section 4, a quantitative comparison of various measures in the two systems is presented. After that, we discuss the network analysis and then briefly review the changes during the transition period from LVTS to Lynx in section 5. Finally, in section 6, we discuss the implications of our main findings and conclude our paper in section 7.

[6] See Garratt et al. (2022), which documents the details of how participants learned to take advantage of the queuing mechanism in Lynx to save liquidity.

[7] This was suggested by Rivadeneyra and Zhang (2022) in their simulation-based exploration before Lynx release.

2 Overview of the Canadian HVPS

This section provides a brief overview of Canada's old and new HVPS, which are owned and operated by Payments Canada. For further details, refer to Arjani and McVanel (2006) for a description of the LVTS system, and Bank of Canada and Payments Canada (2022) for a description of the Lynx system as well as a comparison of the two systems' attributes.

2.1 LVTS

LVTS was Canada's HVPS that began operating in February 1999 and ended in August 2021. During the past two decades, it has been a critical platform where major Canadian financial institutions exchanged large-value payment items, cleared end-of-day positions, and fulfilled their payment obligations.

LVTS was a hybrid system that consisted of both RTGS and DNS components. The RTGS-equivalent component, namely Tranche 1 (T1), required participants to pledge collateral dollar-to-dollar to back their T1 multilateral net debit positions at all times. The LVTS Tranche 2 (T2) was a unique deferred net settlement stream where a joint collateral pool would be sufficient to cover the losses in case of a single-participant default. In LVTS, the intraday finality and irrevocability were achieved by a joint collateral pool (computed based on bilateral credit limits (BCL) extended between pairs of direct participants) and further secured by a government guarantee. Because of the intrinsic liquidity-saving nature of DNS, the vast majority of payments in LVTS settled through T2; T1 was typically reserved for time-sensitive payments. In 2019, T2 payments accounted for 74.6% of total payment value settled and 98.9% of transaction volume.

2.2 Lynx

Lynx replaced LVTS in August 2021. It is an RTGS system that provides central queuing and a payment-offsetting algorithm (on both bilateral and multilateral levels) that helps optimize liquidity usage. Similar to LVTS, two main settlement mechanisms are used for the actual payment settlement process: the urgent payment mechanism (UPM) and the liquidity-saving mechanism (LSM). In principle, the UPM is designed for settling urgent payments; it offers an individual queue for each sending participant. However, no payment-offsetting algorithm is available.

Lynx's LSM, as indicated by its name, offers various mechanisms that allow participants to optimize liquidity usage. At the heart of its operation is a payment-offsetting algorithm named *Gridlock Buster* that runs intermittently and allows for concurrent settlement of a batch of payments in the queue at each run. As a result, when payments are netted against each other on a multilateral level, it is almost guaranteed that the resulting multilateral net debit positions of all sending participants involved in the batch are smaller than the alternative scenario where payments are settled in the original order on a gross basis; hence, less liquidity is needed to fund these debit positions. Nonetheless, in Lynx, the majority of payments sent to the LSM are settled immediately upon submission. Queued payments in the LSM are settled via a process called *impact intervention*, which releases payments whenever there is a change to the liquidity status of the sending participant (typically because of an incoming payment or intraday liquidity transfer between mechanisms).

2.3 Major Differences

There are several major differences between the two systems. First, the credit risk models implemented in the two systems are distinct. The LVTS employs a survivor-pay loss-sharing arrangement where, in the event of participant default, losses are allocated among surviving participants based on the value of bilateral credit limit extended to the defaulter by each of the survivors; specifically, a survivor's additional settlement obligation in a default event is proportional to its share of total bilateral credit limits granted to the defaulter. This model is frequently known as a "cover-1" risk-sharing model, because it is designed to guarantee that there is always sufficient collateral to cover the largest possible net debit position that a single defaulter can incur. In contrast, Lynx operates on a typical RTGS defaulter-pay "cover-all" credit risk model where credit exposures created by any number of defaulters are at all times pre-funded by their own collateral.

Second, the policy towards payment queuing has changed dramatically. In the past LVTS environment, direct participants were advised to conduct a self-check to ensure that payments passed risk controls before sending them to the system. Only a few payments were eligible for central queuing, and excessive use of queuing was discouraged by the system operator; therefore, the queue in LVTS was rarely used. We conjecture that this policy could have led participants to manage internal queues. In Lynx, however, participants are encouraged to submit those internal queued payments early to the system queue to maximize the payment-offsetting opportunities and hence liquidity savings.

Finally, one important new feature of Lynx is the greater flexibility in liquidity management. In Lynx, direct participants are able to freely transfer any amount of liquidity available from one settlement account to the other, essentially creating a common liquidity pool for all payments settling in both mechanisms. Specifically, it means that payments received in the UPM can easily be used to fund outgoing transactions in the LSM, for example. In comparison, re-allocating liquidity between LVTS T1 and LVTS T2 could not be so conveniently carried out; it required participants to log onto another platform (i.e., HABS[8]) to effect any movement of liquidity between T1 and T2, which entailed extra time and operational efforts. In addition, Lynx offers flexibility in re-prioritizing and re-sequencing queued payments at any time throughout the day, which provides the participants with an added option to settle urgent payments in time without mobilizing more liquidity. Such functionality was not available in the LVTS.

3 Data and Summary Statistics

For our main analysis, we use LVTS and Lynx data spanning six months for both systems. Each sample covers the same months to ensure consistency caused by the seasonal nature of payments data. Lynx was introduced in August 2021, and we observed that the payments patterns stabilized by September 2021; therefore, to avoid atypical participant behaviour that may have occurred during the transition, the Lynx sample we use spans October 2021 to March 2022, and hence the LVTS sample we use spans October 2020 to March 2021. Additionally, both samples occur within the

[8] HABS stands for High Availability Banking System and is mainly used for managing collateral allocations and supporting other critical banking operations by the Bank of Canada.

COVID-19 pandemic, during which the Bank of Canada implemented a monetary policy allowing historically low interest rates and switched from a corridor system to a floor system.

For both systems, we leverage payment data at the transaction level that identifies the sending participant, the receiving participant, the dollar amount, the submission and settlement times, the payment type, the payment status, the payment priority level, and the settlement mechanism. In addition, for our analysis, collateral data, which contain information on the timing and the participant's pledged amount for each system, is also leveraged. Finally, due to the greater flexibility in liquidity management between different mechanisms in Lynx, liquidity transfer data, which identify the timing, the dollar amount, the originating settlement mechanism, and the receiving settlement mechanism for each transfer a participant initiates, is also utilized in our analysis.

The following data-cleaning procedures were applied to LVTS and Lynx samples to ensure comparability. We remove the *non-normal* days from both samples to overcome the challenges caused by seasonal effects. These include Canadian provincial and U.S. national holidays. Although the payment system is active on such days, the value settled is significantly lower than an average day's value. We also filter out the day following the system's closure date, because these dates exhibit significantly higher payment activities. Payments related to settlement balances are also filtered out because they are not considered to be participant-initiated payments but rather system-initiated.[9] Figure 1 compares the normalized daily value and volume settled for each system. Both systems' daily distributions are similar, with non-normal days in the left and right tails.

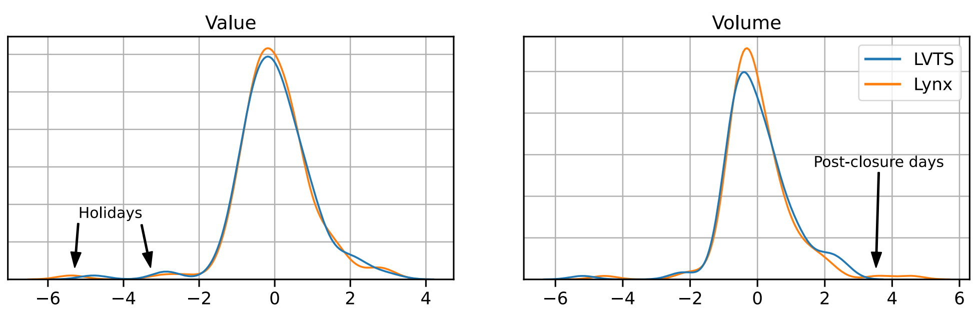


Figure 1: Normalized distribution of daily value and volume settled for each system. The non-normal days, such as Canadian provincial and U.S. national holidays and post-closure days, are in the tail distribution.

3.1 Summary Statistics

Following the data-cleaning procedures mentioned above, LVTS and Lynx samples consist of 119 and 118 unique days, respectively. The summary statistics of payment samples from each system are presented in Table 1. Minimum, maximum, mean, and median values (settled in CAD) and volume (number of payments) in Lynx are higher than LVTS, likely due to the natural growth trend.[10] The

[9] Settlement balances represent the excess of electronic funds flowing through the payment system that participants (other than the Bank of Canada) hold after all their payments have been settled.

[10] The annualized quarterly GDP growth rates and growth rates of the total value settled in HVPS during our sample periods are similar.

standard deviation is about the same, indicating similar dispersion; however, the higher value of skewness and kurtosis indicates that Lynx data have heavier but skewed tails than LVTS.

In Figure 2 we show the marginal and joint distributions of payments submission timing and amount for both samples. It can be noted that the busiest time of the day remains the morning period in both systems, as indicated by the dark contours between 6 a.m. and 8 a.m. However, the number of payments submitted remains slightly higher between 8 a.m. and 10 a.m. in Lynx than in LVTS. Nevertheless, the distribution of payments amount remains similar between the two samples. Also, in both systems, the high-value payments are submitted slightly later in the day compared to the smaller payments, which are predominantly submitted between 6 a.m. and 8 a.m. Moreover, we also observed that the daily mean and median value of payments is slightly lower in Lynx than in LVTS suggesting that, on a typical day, Lynx has a greater fraction of smaller payments.

Table 1: Summary statistics of daily payment data for Lynx from Oct 2021 to Mar 2022 and LVTS from Oct 2020 to Mar 2021.

	LVTS		**Lynx**	
	Value	**Volume**	**Value**	**Volume**
Minimum	139.2 ($Bn)	35,854	163.2 ($Bn)	39,111
Maximum	312.5 ($Bn)	61,368	332.3 ($Bn)	79,123
Mean	200.0 ($Bn)	44,402	220.7 ($Bn)	49,200
Median	194.5 ($Bn)	43,020	215.2 ($Bn)	47,640
Standard Deviation	31.73	5,558	31.61	6,213
Skewness	0.98	1.99	1.16	1.67
Kurtosis	1.28	1.15	1.94	4.45

Next, in Table 2 we present the daily average value and volume made by all participants at the system level in different settlement mechanisms. After the transition to Lynx, most payments are settled in a single mechanism—the LSM. On average, Lynx only settled about 1% value and 0.02% volume of payments in the UPM. If we compare this with LVTS Tranche 1 (which was analogous to Lynx's UPM), it settled about 34% value and 1% volume of payments.

In Figure 3 we compare the daily average (over each week) value and volume settled in both systems. Throughout the period in our sample, Lynx settled a higher value and volume of payments than LVTS. However, the variation in value and volume settled across days remains about the same, as shown by the confidence intervals. Furthermore, the seasonal pattern in the daily value of volume also remains similar; this justifies our choice of comparing the two systems during similar periods.

The migration of payments to the single mechanism in Lynx, however, could provide benefits of liquidity pooling and hence would help in improving the liquidity efficiency of the system.[11] This behaviour change is motivated by the policy differences between LVTS and Lynx, specifically

[11] We observed that the liquidity efficiency of Lynx is higher than LVTS in our sample. See Figure 8 in Section 4.2.

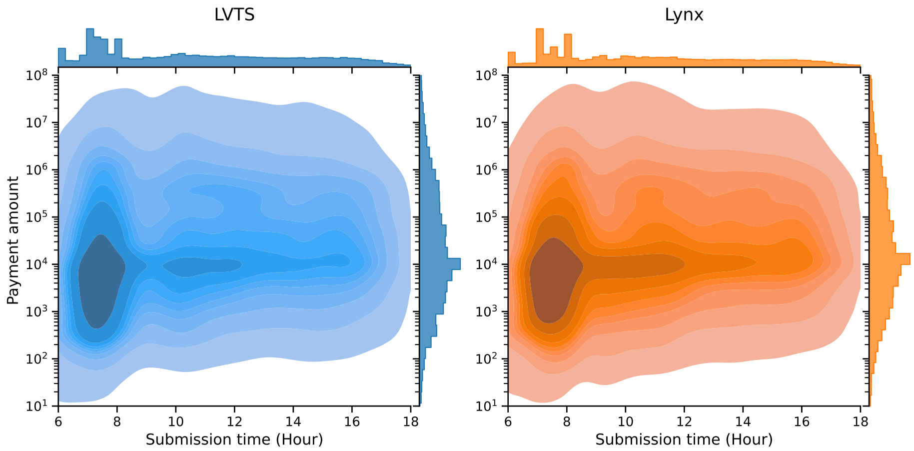


Figure 2: The marginal and joint distribution of payments amount and submission timing. Darker areas in the joint distribution indicate a higher density at that given payment amount and submission time. Note that the payment amount uses a log scale.

Table 2: Average value and volume of payments settled in LVTS and Lynx

System[a]	Settlement mechanism[b]	Number of payments	Value in billion CAD
LVTS	Tranche 1	435	51
	Tranche 2	43,967	149
Lynx	UPM	10	2
	LSM	49,190	219

[a] We use settlement data for Lynx from Oct 2021 to Mar 2022 and LVTS from Oct 2020 to Mar 2021.
[b] Settlement mechanisms for LVTS are Tranche 1, which primarily settled urgent payments, and Tranche 2, which settled all other types of payments. Similarly in Lynx, the UPM is used to facilitate urgent payments, and the LSM is used for other payments.

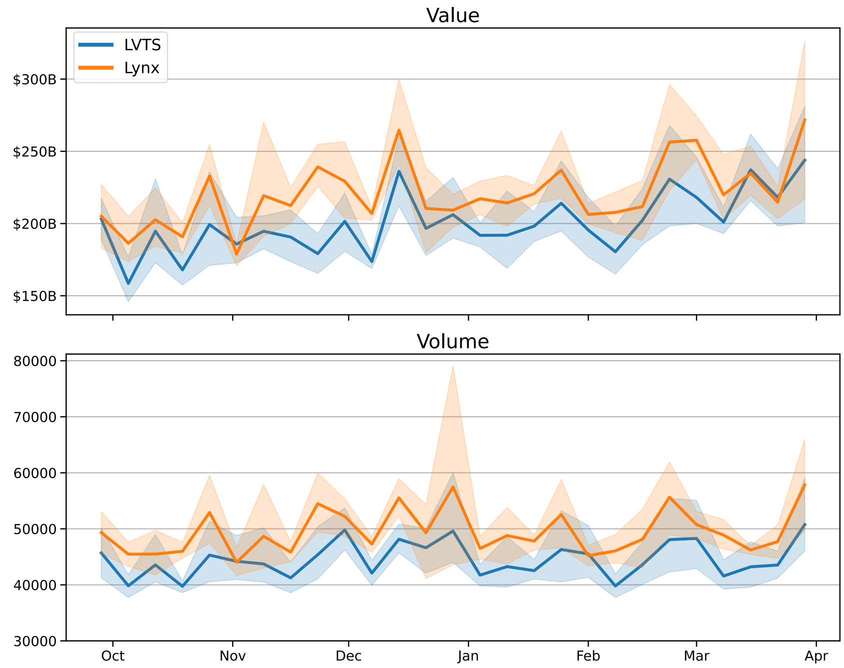


Figure 3: System-level daily average (over a week) value and volume of payments settled in LVTS and Lynx in our sample for LVTS from Oct 2020 to Mar 2021 and Lynx from Oct 2021 to Mar 2022. Note that the shaded area represents a 95% confidence interval.

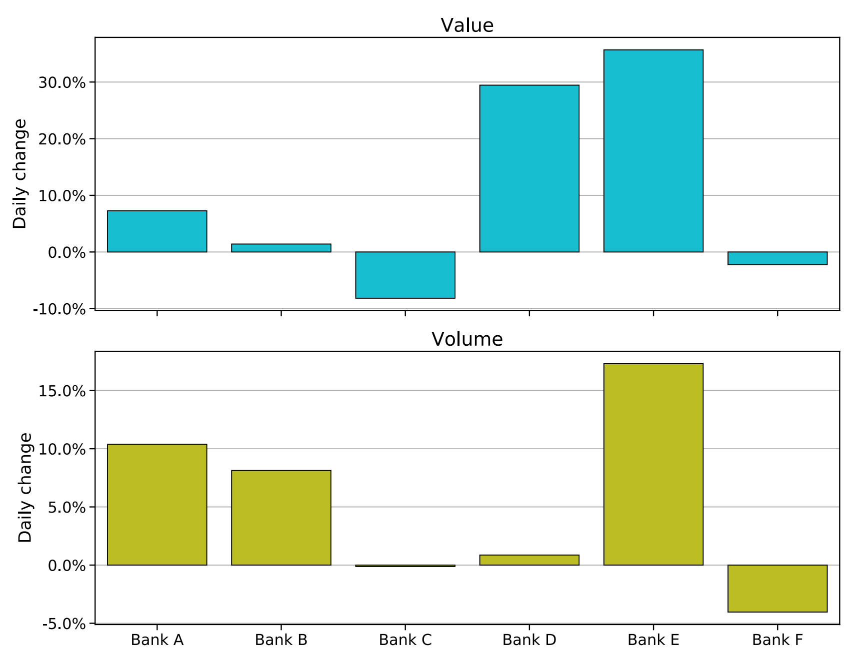


Figure 4: Participant-level percentage change in average value and volume of payments settled in Lynx from LVTS for a few selected participants in our sample.

related to the payments to and from the Bank of Canada. In LVTS, the Bank's payments were settled only in Tranche 1; however, this policy is now relaxed, and participants can choose any settlement mechanism in Lynx. Moreover, having the option to easily manage intraday liquidity between settlement mechanisms in Lynx could have also motivated the migration of the time-critical payments, which otherwise could experience a delay.

In Figure 4, for a few selected FIs (representing a mix of big and small participants), we report participant-level percentage change in daily average value (top) and volume (bottom) of payments settled in Lynx and LVTS. The total value and volume settled in Lynx are higher for many participants than in LVTS. However, for a few participants the value and volume are about the same or slightly smaller than those in LVTS. This indicates that the changes are rather heterogeneous across participants after the transition to Lynx. However, although the plot is not shown here, at the participant level the average ratio between the total sent and received in a given day remains similar in both systems.

4 Key Metrics

In this section we first present throughput in terms of the daily cumulative value of payments sent and settled in the system to investigate changes in FIs' payments submission patterns. Next, to understand the liquidity-delay trade-off among these two systems, we present changes in liquidity patterns involving collateral apportionment, intraday liquidity transfers, and liquidity efficiency ratio. This is followed by changes in the delay of payments submissions and settlements across the systems using the queued payments, payment re-prioritization, and value-weighted settlement time.

4.1 Throughput

The throughput in terms of the daily average value of payments sent and settled over time of day in both systems is presented in Figure 5.[12] Here the sent time is the participant's choice and captures the changes in their behaviour; however, the settled time depends on the system's characteristics.[13] It can be observed that at the system level, the payments are sent early and settled slightly late in Lynx compared to the LVTS, i.e., many payments were queued in Lynx. Such throughput differences are slightly higher for the small payments with a value smaller than CAD$10,000. This change in behaviour in submission timing is consistent with the availability of an effective queuing mechanism in Lynx, encouraging FIs to send their payments early to the system.

In Figure 6 we compare the value sent throughput for a few chosen FIs in our systems. For the banks A to F, representing a mix of big and small FIs, the payments sent throughput slightly varies between LVTS and Lynx. However, although results are not shown here, for a few FIs the payments sent throughput varies comparatively more. In our sample, for most banks, the payments are sent earlier to the system in Lynx; however, for a few banks payments are sent slightly later in

[12] Though we focus on the 8 a.m. to 6 p.m. period in showing the throughput, there is a non-negligible amount of payment activity happening before 8 a.m., particularly between 6 a.m. and 8 a.m. For example, from October 2021 to March 2022, about 30% of total volume was settled by 8 a.m., accounting for over 10% of total value (excluding payments from the Bank of Canada).

[13] We use submission time for sent throughput and settled time for settled throughput analysis. We do not observe significant changes in volume throughout; therefore, these metrics are not presented in this paper.

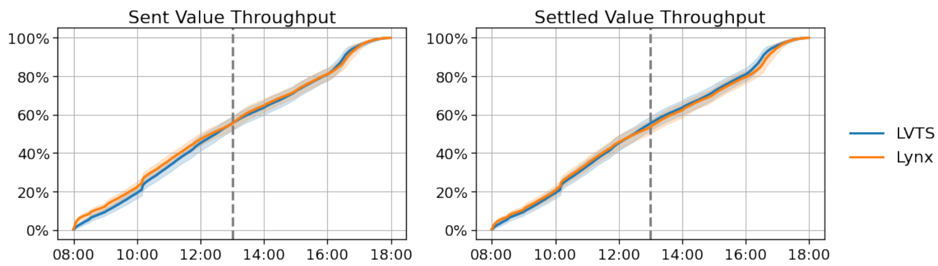


Figure 5: System-level average daily value of payments sent and settled in the LVTS and Lynx over regular business hours of the day. The shaded area represents the standard deviation across days in our sample. Note that we focus on the hours between 8 a.m. and 6 p.m. because participants are required to log in to the system by 8 a.m., and after 6 p.m. both systems only process special payments. The vertical dotted line represents the mid-point of the system's day.

Lynx. Also, for a few participants there are no significant changes in throughput between LVTS and Lynx (e.g., see bank B). Such heterogeneous responses suggest that the influence of incorporating an effective queuing mechanism in Lynx varies across the participants. However, at the system level, value throughput in Lynx is better than LVTS.

4.2 Liquidity

Our comparison of liquidity across the two systems focuses on three main aspects: settlement balances, collateral, and intraday liquidity efficiency.

Settlement balances represent the excess of electronic funds flowing through the payment system that participants (other than the Bank of Canada) hold after all their payments have been settled.[14] In both sample periods, levels of settlement balances are historically high due to the implementation of a floor system in March 2020. The excess settlement balances circulate throughout the payment system during the day, and participants can use them to fund payments until they are redeposited back at the Bank of Canada at the end of each day after the payment system closes. Thus, during the sample period, settlement balances comprise a significant portion of liquidity for participants. The first row of Table 3 shows the daily average of system-level settlement balances in LVTS and Lynx. Aggregate settlement balances in LVTS and Lynx are of similar magnitude. On the participant level, 10 of the 15 participants experienced an increase in settlement balances (in the range of 5 to 60%) in Lynx compared to LVTS (see Figure 7, bottom, for a few selected participants).

Another important source of intraday liquidity comes from intraday lines of credit, which are subject to collateral requirements in both LVTS and Lynx. Participants typically pledge collateral to the Bank of Canada using CDSX.[15] The pledged collateral can be allocated for several purposes, including the HVPS. Each day before the payment processing cycle begins, participants must de-

[14] The settlement balances are interest-bearing deposits held overnight at the Bank of Canada after the close of the payment cycle each day.

[15] CDSX is the clearing and settlement system for securities denominated in Canadian dollars, which is operated by the Canadian Depository for Securities. Upon receipt of the pledged collateral, the Bank determines its value, including any adjustments for margin requirements.

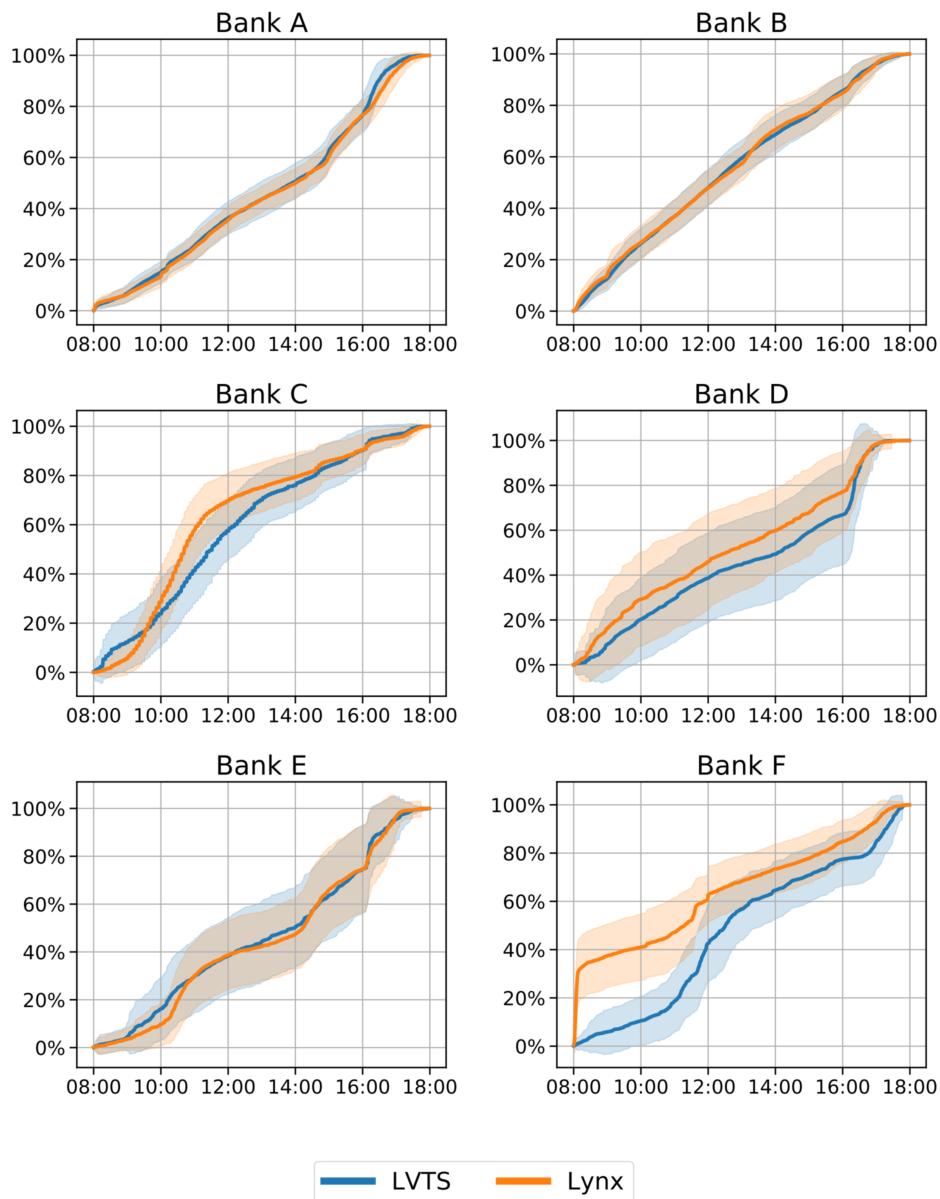


Figure 6: The participant-level daily value sent throughput in LVTS and Lynx for a few selected participants. The shaded area represents the standard deviation across days in our sample. Note that we exclude the time before 8 a.m. and after 6 p.m. because most of the standard daily payments activity starts after 8 a.m., and after 6 p.m. both systems settle only special payments.

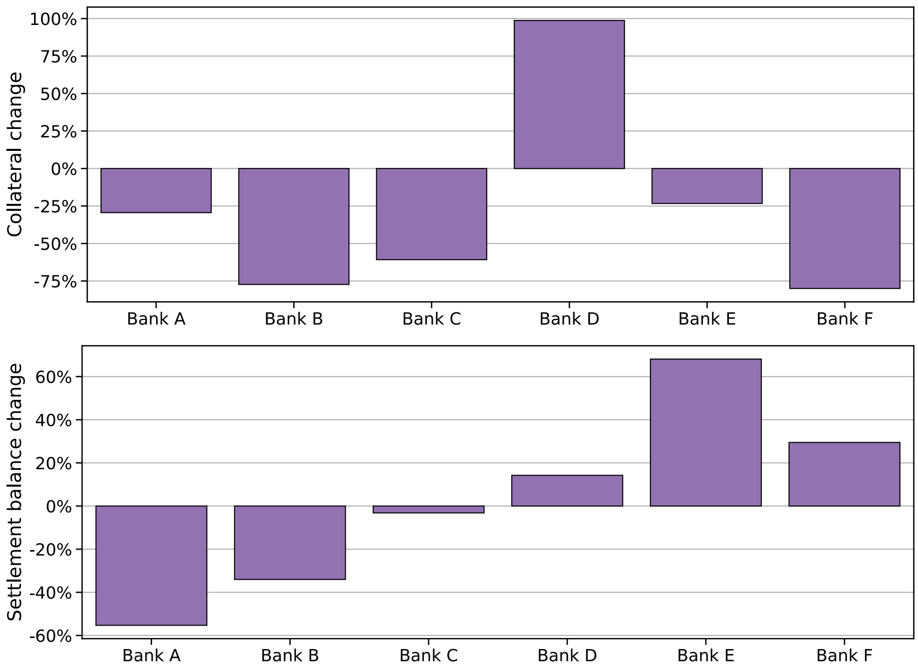


Figure 7: Participant-level percentage changes in daily collateral allocated to Lynx compared to LVTS (top) and daily settlement balances in Lynx compared to LVTS for a few participants (bottom).

termine how much of the pledged collateral to allocate to the HVPS (either LVTS or Lynx).[16] A comparison of the value of collateral allocated to LVTS and Lynx is shown in the second row of Table 3. The aggregated value of pledged collateral that is allocated to Lynx is on average CAD$20.9 billion, which is lower than collateral allocated to LVTS by almost a third. We further look at the changes in collateral allocated to Lynx compared to LVTS on the participant level, which is shown in Figure 7 (top). Only two participants increased the value of pledged collateral allocated to HVPS, while the majority of participants reduced the value of collateral allocated to Lynx compared to LVTS.

In terms of how the value of collateral allocated to the payment system establishes the intraday credit limit, Lynx and LVTS have different rules. In LVTS, the two payment streams, T1 and T2, have separate credit limits and collateral requirements, and participants need to allocate collateral for each of the two streams.[17] In Lynx, there is no separate credit limit for the LSM and UPM; instead, there is only one total credit limit for the overall Lynx payment activities during the day. Specifically, the allocated collateral to Lynx establishes the *ceiling* for the amount the participants can borrow from the Bank of Canada for the day. The *actual* amount a participant chooses to borrow (in the form of an intraday loan), however, can be lower than the credit limit.

Participants can freely transfer the borrowed intraday funds (i.e., intraday loan) among their

[16] Participants are subject to a minimum level of collateral allocated to the HVPS.

[17] T1 requires its intraday credit limit to be fully collateralized. T2, on the other hand, uses a survivors-pay collateral pool, where collateral apportioned to T2 should equal the largest bilateral credit limit that a participant chooses to grant to any other participant, multiplied by a system-wide percentage.

Table 3: Liquidity comparison in LVTS and Lynx

Daily average (billion CAD)	LVTS	Lynx
Settlement balances	246	264
Total collateral allocated to the system	32.9[b]	20.9
Intraday liquidity transfers[a]	2.16	89.34

[a] Number of times the liquidity is transferred between mechanisms.
[b] LVTS allocated collateral include an additional buffer over the required amount, which is computed using bilateral and multilateral credit limits.

LSM and UPM accounts. To see how participants take advantage of this flexibility to transfer liquidity among accounts, we calculated the average daily count of occurrences of intraday liquidity transfers among all participants, shown in the last row of Table 3. On average, Lynx participants transfer funds internally almost 90 times in total during the day, suggesting active management of intraday liquidity. LVTS does not offer such a direct way to transfer liquidity internally, so instead we count the number of times participants change the value of collateral apportioned to any of the streams. The average number is around two times across all participants, implying that such changes are infrequent and liquidity management is more rigid in LVTS.

Besides comparing sources of intraday liquidity, we also measure how efficiently the intraday liquidity is used in LVTS and Lynx. Following Alexandrova-Kabadjova et al. (2022), we define the system-wide liquidity efficiency ratio (LER) to be the ratio of aggregated payment values settled over aggregated intraday liquidity needed, where the liquidity used is defined as the minimum amount of liquidity needed to support the observed flow of payments throughout a day.[18] Specifically, for a participant, the amount of intraday liquidity needed is the maximum cumulative net debit position during the day. To fix ideas, we denote $p^{i,j}(t)$ as the amount of payment that bank i sends to bank j in discrete time interval $t = 0, 1, 2, ..., T$, which we choose to be each second in our calculation. Then bank i's cumulative net debit position at time t during a day is given by:

$$n_i(t) = \sum_{s=1}^{t} \sum_{i \neq j} \left[p^{i,j}(s) - p^{j,i}(s) \right] \tag{1}$$

$n_i(t)$ is the difference between the cumulative incoming payment value minus the cumulative outgoing payment value up to time t. Then the maximum cumulative net debit position that bank i attains during the day is given by:

$$N_i \equiv \max_t \{n_i(t), 0\} \tag{2}$$

Summing over all participants, we can then find the amount of intraday liquidity needed to process payments in the order of their submission to the system. Finally, to compute the value of payments

[18] Note that this measure of liquidity usage is in the *ex-post* sense. We prefer this measure because the *ex-ante* measure of liquidity (i.e., the liquidity deposited in the system) is excessive due to the extraordinary measures of liquidity injection by the central bank, and it does not reflect the actual liquidity usage by the payment system.

settled for each dollar of liquidity used, we take the ratio of total payment value settled over total liquidity used:

$$\text{LER} = \frac{\sum_{i,j,t} p^{i,j}(t)}{\sum_i N_i} \tag{3}$$

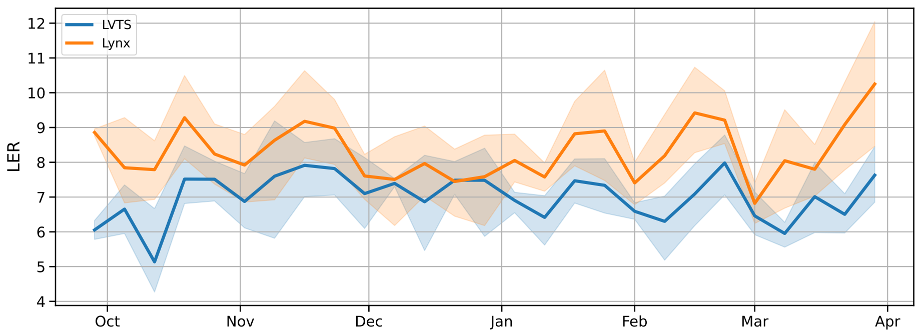


Figure 8: System-level daily average (over a week) LER in LVTS and Lynx. The shaded area represents a 95% confidence interval.

Our calculation shows that the average LER in LVTS during the sample period is 7.0, and it is 8.4 in Lynx. Lines in Figure 8 show the weekly average of LER in LVTS and Lynx from October to March, and the shaded area shows 95% confidence intervals. The LER in Lynx is higher than in LVTS given the same month and day.[19] Similarly, in Figure 9 we compare the participant-level LER for both systems, and 12 of the 15 participants have higher LER in Lynx than in LVTS. However, in both Lynx and LVTS, participant-level LER has large variations among different participants, as shown by the error bars in Figure 9.

One potential concern about our definition of system-level LER is that it is mathematically equivalent to the participant-level LER weighted by the liquidity used and therefore over-weights those participants with higher liquidity needs. To address this concern, we also calculated the simple average of LER across participants per day for both systems. The median of this alternative LER measure is 18.1 in Lynx, which is higher than LVTS, for which it is 14.2.

In summary, we find that participants have higher settlement balances in Lynx than in LVTS and allocate a lower amount of collateral to Lynx. Lynx has higher system-level liquidity efficiency in the sense that there is more payment settled per dollar of liquidity used in the system, although individual-level changes in liquidity efficiency display large variations.

4.3 Delay

In this section, we examine delays of submitted payment requests observed in the payment system. Specifically, we focus on *queued* payments in LVTS and Lynx.[20] We start our analysis by providing a brief background on the queuing mechanisms in LVTS and Lynx.

Although LVTS had a built-in queuing mechanism, the excessive usage of queuing was explicitly

[19] Note that we do not check if these differences are statistically significant.

[20] Here we look at "external" queues, i.e., queues in the payment system. There can be "internal" queues that participants privately manage on their own notes, which is not within the scope of this paper.

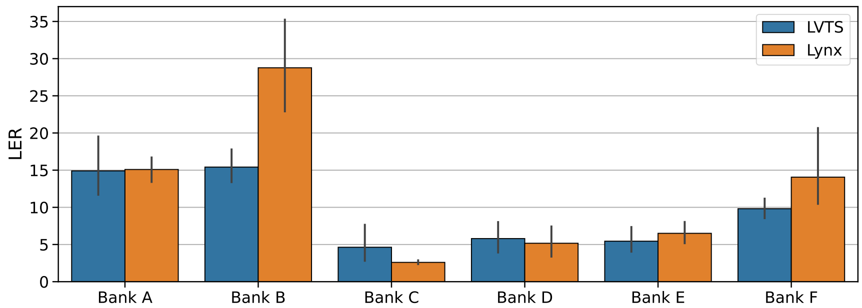


Figure 9: Participant-level LER for a few selected participants.

discouraged by Payments Canada, who owns and operates the system (Arjani and McVanel, 2006). The queuing mechanism employed by LVTS was only applied to Jumbo payments, i.e., payments with values larger than a certain threshold.[21] When a Jumbo payment fails the initial risk-control test (i.e., it violates net credit limits established by the collateral apportioned to the payment stream), it will become queued. A payment is released from the queue whenever it is able to pass the applicable risk-control test as a result of either receipt of incoming payments or increased collateral apportioned to the payment stream. Queued payments are ordered on a first-in-first-out (FIFO) basis, which means the first payment needs to be released before other payments down the queue. A payment-offsetting algorithm attempts to search for offset batches of queued payments every 15 minutes, and payments that have been queued for 65 minutes or more will then expire.

Lynx, on the other hand, highlights its queuing functionality as the main tool to save liquidity. In the early days of Lynx's launch, Payments Canada strongly encouraged participants to explore and utilize Lynx's queuing mechanism. In the LSM, if a participant does not have sufficient liquidity to settle a payment immediately, the payment is queued until sufficient liquidity becomes available, either through incoming payments (also known as liquidity recycling) or through transfers of additional funds into the LSM. Importantly, the LSM offers FIFO by-pass, which means that payments with the same priority sequenced lower in the queue can by-pass larger payments ahead of it and get settled whenever sufficient liquidity exists. The use of FIFO by-pass enables Lynx to settle as many payments as possible with the available liquidity in the order of priority assigned to them.[22] Participants can re-prioritize payments in the queue at any time to change the sequencing. In addition, Lynx also employs a payment-offsetting algorithm—the *Gridlock Buster*—that runs every five minutes on all queued payments in the LSM stream, attempting to identify queued payments that can be offset simultaneously.

The first straight-forward measure of queuing utilization is the number of payments queued. In LVTS, participants barely used the queuing function. Table 4 shows that there are only 22 queued payments in the whole system of LVTS for the entire six-month sample period. In Lynx, the total

[21] The threshold of a Jumbo payment was set by each bank at the beginning of the cycle. There were three options in setting the Jumbo threshold: 1) set it at the Payments Canada-established limit of $100 million; 2) set it above $100 million; or 3) set it at zero, which means that all payments submitted by a participant that fail the initial risk-control test will be rejected by the system. The Jumbo-threshold value set by a participant is applied to both its T1 and T2 payments.

[22] In other words, no queued payments in lower priority classes are settled before higher-priority payments.

Table 4: Comparison of delay measures in LVTS and Lynx

Measure	LVTS	Lynx
Number of payments queued (≥CAD$100 million)	22	15388
Number of payments re-prioritized	—	1258
Average queuing duration (min)	15	2
Value-weighted queuing duration (min)	20	34
Value-weighted settlement time (HH:MM)	11:49	12:00

number of all queued payments is over 1 million—around 19% of all settled payments. If we only focus on queued payments that are over $100 million in value, which is comparable to the Jumbo payments in LVTS, the total number is 15,388. Re-prioritization of queued payments does not play an important role: Only 0.1% of queued payments were re-prioritized. The vast majority of queued payments are assigned the lowest level of priority (99), which is also the default value.

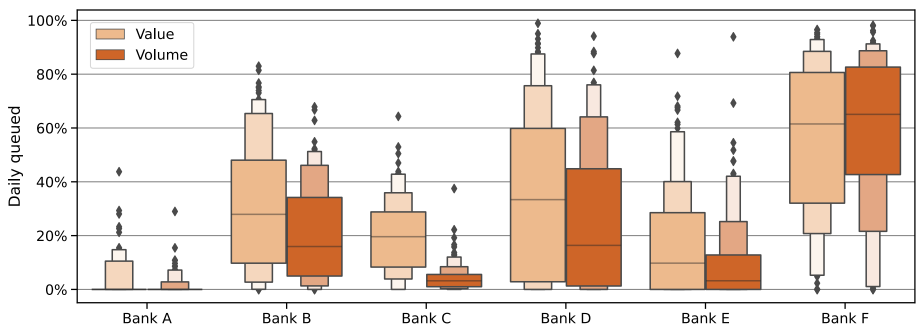


Figure 10: Proportion of value and volume queued in Lynx for a few participants

Figure 10 shows the proportion of queued payments in all outgoing payments for a few chosen Lynx participants in terms of value and volume, respectively. The proportions of queued value and volume are measured at daily frequency, and we summarize the distribution of the daily-level data in the following way: The horizontal line in the middle of the widest box shows the median of the distribution (i.e., 50th percentile), with the top and bottom edges of this box showing the 75th percentile and the 25th percentile, respectively. The edges of the second widest boxes show the 87.5th and 12.5th percentile, respectively. And the edges of the thinnest boxes show the 93.75th and 6.25th percentile, respectively. The plots suggest three features about participants' queued payments. First, there is large heterogeneity across participants in terms of daily queued value and volume of payments. Second, even within one bank, the proportion of queued payments can vary significantly from day to day. Finally, the queued volume displays larger variations both across banks and across time.

How long do queued payments stay in the queue before settlement? To answer that, we first look at the average queuing duration for each queued payment. Table 4 shows that the average queuing duration in Lynx is 2 minutes, and in LVTS it is 15 minutes. In fact, in Lynx 80.7% of queued payments get resolved within 10 seconds, as shown in Figure 11.[23] Such a brief queuing duration of these payments is due to a combination of FIFO by-pass and liquidity recycling, which enables smaller payments to by-pass larger payments in front of them in the queue and get settled whenever liquidity levels are sufficient. Other payments, typically larger in size, wait significantly longer in the queue before settlement, because they need to wait for payment-offsetting opportunities from other participants to arise and to get identified by the Gridlock Buster algorithm, which runs on a five-minute interval, or wait for the accumulation of incoming payments received from others until enough liquidity has been raised. The fact that LVTS does not allow FIFO by-pass and only applies the queuing function to Jumbo payments explains the longer queuing duration in LVTS.

Given this correlation between payment value and queuing time, if we want to reflect the average queuing duration *per dollar of value queued* in the system, we need to take the value-weighted average of queuing duration. Specifically, suppose we index all payments settled in the system in a day using $k = 1, 2, ..., K$, with p_k denoting the amount of the kth payment and q_k denoting the queuing duration of the kth payment. Note that $q_k = 0$ for payments that are not queued, and $q_k > 0$ for queued payments. Then the value-weighted average queuing duration is expressed as

$$\tilde{Q} = \frac{\sum_k q_k p_k}{\sum_k p_k \cdot \mathbf{1}\{q_k > 0\}} \tag{4}$$

Table 4 shows that the value-weighted average queuing duration in Lynx is 34 minutes, which is substantially higher than the average queuing duration per queued payment. In addition to the aforementioned correlation between payment size and queuing duration, another contributing factor to the difference is the periodic feature of the Gridlock Buster algorithm, an algorithm that identifies and resolves payment-offsetting opportunities but runs every five minutes, and some high-value payments can wait for several rounds of Gridlock Buster to run before they are settled. In LVTS, the difference between average queuing duration and value-weighted queuing duration is not as large, since queued payments in LVTS are already Jumbo payments with large values.[24]

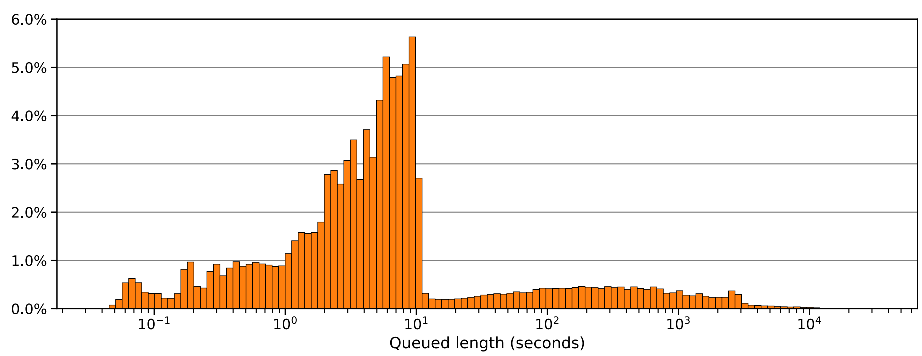


Figure 11: Distribution of queuing duration in Lynx (in logarithmic scale)

[23] Note that we use a logarithm scale along the x-axis; therefore, the drop around 10 seconds seems sharp.

[24] Although there is a periodic payment-offsetting algorithm in LVTS, it is virtually unutilized because there are too few queued payments to generate bilateral/multilateral payment-offsetting opportunities.

The observed queuing duration only shows the "external" delays, i.e., delays between payment submission and settlement in the system. There can also be "internal" delays, i.e., the time difference between the arrival of payment requests in the hands of the cash manager and the submission of payment requests in the system. Since internal delays are not observed, it is insufficient to only look at the observed queuing duration to draw a fair comparison on total delays. Thus we also calculate the value-weighted average settlement time in the two systems, which is defined as

$$\tilde{T} = \frac{\sum_{t=0}^{T} t \cdot P(t)}{\sum_{t=0}^{T} P(t)} \tag{5}$$

where $t = 0, 1, 2, ..., T$ is a discrete time interval, and $P(t)$ is the total value of payments settled in time interval t. To facilitate the interpretation of the value-weighted average settlement time, consider the simplest case of perfectly even payment flows throughout the payment processing cycle day: In each time interval t, the total value of payment settled in t is a constant (i.e., $P(t) = \bar{P}$). By Equation (5), $\tilde{T} = \frac{\sum_{t=0}^{T} t}{T} = \frac{T}{2}$, meaning that the value-weighted settlement time is the exact middle point of the payment processing cycle. On the other hand, if the payment flow is heavier in the afternoon than in the morning, then $\tilde{T} > \frac{T}{2}$, i.e., the value-weighted settlement time is later than the middle point, and vice versa.[25] Thus, value-weighted settlement time measures the centre point of the flow of settled values, with smaller values indicating earlier settlement for an average unit of value. Table 4 shows that the value-weighted settlement time is generally around noon for both Lynx and LVTS. To put it in perspective, the payment processing cycle in both LVTS and Lynx starts at 12:30 a.m. and ends at 6:30 p.m. each day, but payment activities mostly take place after 08:30. So the value-weighted settlement time around noon suggests that there is more payment flows in the morning session than in the afternoon, which confirms our finding in throughput measures. Moreover, the value-weighted settlement time in Lynx is about 11 minutes later than in LTVS, which is consistent with the so-called liquidity-delay trade-off previously identified in the literature (see, for example, Bech and Garratt 2003): Higher liquidity efficiency is often associated with later settlement time.

5 Additional Results

5.1 Network Analysis

Finally, we compare the interbank payment networks in LVTS and Lynx to observe any changes in the bilateral payment patterns and the systemic importance of participants. For both networks, we aim to compare (i) a statistical characterization of the network topology and (ii) a measure of systemic risk to identify systemically important institutions. The results of various network measures computed on both systems are summarized in Table 5.

In our networks, the nodes represent the number of FIs, and the edges represent the direct links between these FIs. The average (and maximum) number of nodes and edges is higher in Lynx, mainly because of an additional participant in the new system. The degree is a count of a node's

[25] Note that value-weighted settlement time has no implications for the dispersion of payment flows. In other words, a perfectly even payment flow throughout the day has the same value-weighted settlement time as if all values are settled at the middle point of the payment cycle. It is a measure for average settlement time per unit of value. For dispersion of payment timing, refer to Section 4.1.

direct relationships with other nodes (also known as its neighbours). On average, each node has a higher degree in Lynx than in LVTS. This could also be due to an additional FI in Lynx. However, the maximum degree is slightly higher in Lynx, suggesting an increased direct relationship among participants.

Table 5: Network measures for LVTS and Lynx

Measure	Average		Maximum	
	LVTS	Lynx	LVTS	Lynx
Number of nodes	16	17	16	17
Number of edges	211	241	218	272
Degree	13.2	14.2	13.6	16
Reciprocity	0.95	0.96	0.97	1.00
Clustering coefficient	0.92	0.92	0.94	1.00

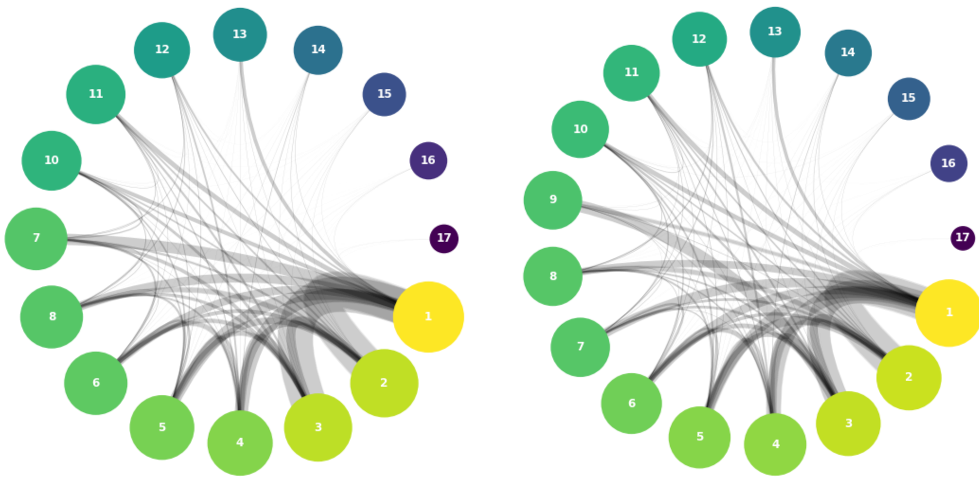
[a] We use six months of settlement data for both systems. For Lynx: Oct 2021 to Mar 2022, and for LVTS: Oct 2020 to Mar 2021.

Reciprocity measures the percentage of forward links (payment sent by bank A to bank B) that also have a link travelling in the opposite direction (payment received by bank A from bank B). The average reciprocity in Lynx is almost similar to the LVTS; however, the maximum reciprocity is slightly higher. This suggests that total values sent and received are similar in Lynx and LVTS. Finally, we compute the clustering coefficients, which measure the proportion of a node's neighbours that are also neighbours to one another. The average clustering coefficient of the Lynx network is about the same as the LVTS network; however, the maximum clustering is slightly higher in Lynx. This suggests that on some days, the Lynx network is more connected and has payment exchanges among all banks in the system.

Figure 12 shows a visual comparison of the Lynx network and the LVTS. The node sizes represent the total value of payments sent by the FI multilaterally, and the edges are the bilateral value sent. Although the overall network structures of Lynx and LVTS look similar, the addition of a new FI in Lynx influences the network. For instance, the edge size between nodes 1 to 3 and 1 to 7 is smaller in Lynx than in LVTS. Also, node 7 is bigger than node 8 in Lynx than in LVTS.

Next, we compute the SinkRank for FIs in both systems using the algorithm developed in Soramäki and Cook (2013). The SinkRank identifies systemically important banks in payment systems; specifically, it helps detect the FIs with greater power to absorb liquidity from the system in the case of their failures.[26] In Figure 13, we present the SinkRank of a few chosen participants. We observe that the overall ranking regarding systemic importance has not changed after migration to Lynx. The bank colour-coded purple has the highest SinkRank in both systems, followed by the green- and brown-coloured banks. However, the purple bank's systemic importance is slightly lowered in Lynx.

[26] Refer to Soramäki and Cook (2013) for further details on the SinkRank algorithm.



(a) LVTS (b) Lynx

Figure 12: Interbank payment networks showing nodes proportional to the daily average multilateral value of payment sent by each FI. The edges are the daily average bilateral value sent by the FI to other FIs. Note that LVTS has 16 nodes and Lynx has 17.

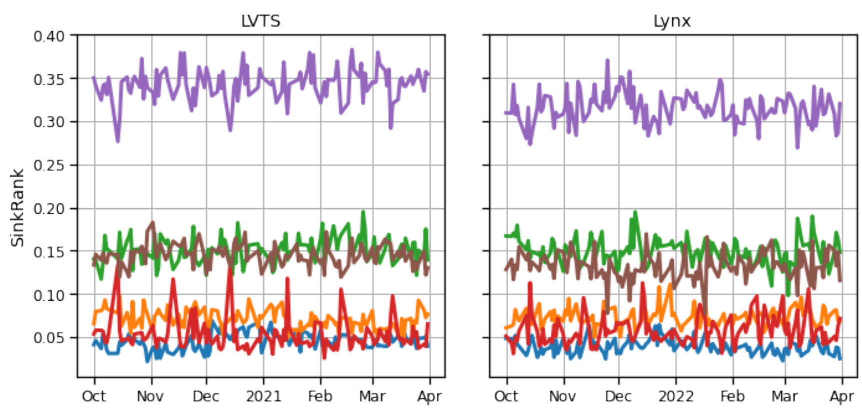


Figure 13: SinkRank of a few selected participants in LVTS and Lynx

5.2 Transition Sample

This subsection looks at the transition period from LVTS to Lynx. During this period, Payments Canada and the Bank of Canada worked closely with system participants in the process of learning and adaptation. Here we only show a few key statistics; a detailed analysis of banks' learning and strategic behaviour can be found in Garratt et al. (2022).

Table 6: Summary statistics and liquidity and delay measures of daily payment data during the month of Sept 2021 for Lynx and Sept 2020 for LVTS

Measure	LVTS	Lynx
Value ($Bn)	190	202
Volume (thousand)	43	47
Liquidity efficiency ratio (LER)	7.4	7.5
Value-weighed settlement time (VWST)	11:36	11:56

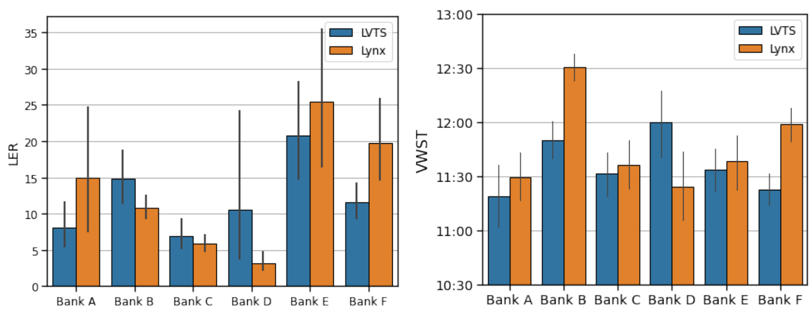


Figure 14: Participant-level liquidity efficiency ratio (LER) and value-weighed settlement time (VWST) for for a few selected participants in Canada's old and new payment system

We compute a few key measures discussed earlier for September 2021 settlement data from Lynx and compare them with the September 2020 settlement data from LVTS. The results are summarized in Table 6. During the first full month of Lynx after its launch, the system-level daily average value and volume of payments remained similar to that of the main sample discussed earlier.

It is important to note that the system-level liquidity efficiency—measured using LER—during the transition sample is about the same as LVTS but smaller than the LER of Lynx during the main sample. However, the value-weighted settlement time of Lynx is much higher than LVTS during the same period. These results indicate that during the transition period, participants were cautious and pledged more liquidity but did not manage it efficiently—incurring higher delays and lower liquidity efficiency. The participant-level LER and value-weighted settlement time for the six chosen FIs in Lynx and LVTS are shown in Figure 14. It shows that only three out of six FIs have higher LERs in Lynx; however, most participants have higher value-weighted settlement times in Lynx than LVTS.

6 Discussion

One of our most notable results is the minimal usage of the Lynx's UPM. Although the LVTS and Lynx systems appear structurally similar—two tranches versus two settlement mechanisms (one for time-sensitive payments and the other for non-urgent transactions)—the data show that the UPM in Lynx is less utilized compared to T1 in LVTS.

There are several reasons why Lynx operations are more concentrated in the LSM. First and foremost is that the Bank of Canada payments are settled in the Lynx LSM, whereas historically all outgoing transactions made by the Bank of Canada occurred in LVTS T1. Data show that the Lynx direct participants echo this major switch in order to reap the most benefit from the liquidity that the Bank of Canada injects into the system. Although liquidity can be transferred between all settlement mechanisms at virtually no cost, our results show that there are still advantages of receiving liquidity in real time and instantaneously recycling any incoming payments through the automated process of impact intervention. More precisely, there is no motivation to not do so.

Second, the differences between the UPM and LSM in Lynx are much smaller that those between LVTS T1 and T2, due to the RTGS nature of Lynx's two mechanisms. Specifically, LVTS T1 played an indispensable role in settling high-value and/or time-sensitive transactions. In Lynx, the motivation to use the UPM for its intended objective of handling urgent payments is to a large extent dampened by the many liquidity-saving measures provided in the LSM. For example, in LVTS, a participant's bilateral net debit position (vis-a-via another LVTS participant) is capped by its BCL that is granted by the payment-receiving participant. Hence, in the critical moment of lacking sufficient liquidity to send through an urgent payment, the sending participant usually needs to contact the payment-receiving institution to ask for a temporary increase in its BCL. If such communication cannot be established on short notice, then the only other option is to send this payment through T1. However, this is no longer the case in Lynx. In the LSM, participants can still process time-sensitive transactions without the need for switching settlement mechanisms by re-prioritizing and/or re-sequencing the queued payments. Urgent payments can be marked as higher priority and be moved ahead of others payments, regardless of the original time order when they entered the system. Lynx always makes sure higher-priority payments are settled first. In addition, liquidity can be freely transferred between the UPM and LSM to assist in any urgent situations.

Our analysis also indicates significant collateral savings in Lynx compared to the value of collateral pledged in LVTS. This can also be attributed to the greater flexibility and enhanced convenience in transferring liquidity between settlement mechanisms. The data show a sharp increase in the number of instances where Lynx participants actively transfer liquidity between settlement mechanisms and/or re-order payments in the queue. Such means and opportunities did not exist in LVTS. Previously, the standing BCLs between pairs of LVTS participants typically stayed constant over a long time horizon; we saw only infrequent changes to cyclical BCLs. The same is true of LVTS T1: Seldom did the participants adjust their collateral allocations in T1 to allow unusually-high-value (or time-sensitive) payments to pass through the risk control.

It is also worth noting that the liquidity efficiency has improved for the majority of FIs in Lynx, to which the potential contributors are (1) significant increases in the usage of central queuing and (2) the liquidity pooling effect achieved by unhindered mobility of excess liquidity within the system. Moreover, the central queuing mechanism offers remarkable advantages of automated payment coordination over manual collaboration outside the system. It also encourages participants to send their payments immediately from their internal queue to the queue in Lynx. More payments waiting in the central queue can trigger more frequent impact intervention and, hence, can enhance payment offsetting and liquidity recycling in the system overall.

Mathematically, in order for the LERs to be high given the total value settled, the denominator should inevitably be smaller. In Lynx, liquidity pooling allows participants to reduce their collateral pledge, which fundamentally serves as a cap on the multilateral net debit position in RTGS. In comparison, LVTS was in principle a two-pool system where payments sent through T1 and T2 each have to satisfy their own risk controls. Without logging into HABS and re-allocating liquidity between T1 and T2, the participants cannot directly use incoming payments received in T1 for funding outgoing payments in T2, for example, which in general yields higher values of net debit positions in both tranches.

Notably, we observe higher payment delays in Lynx than in LVTS. By design in Lynx, not all payments are settled immediately upon submission, *even when* the sending participant has sufficient liquidity at the time. Instead, payment will be unconditionally sent to the queue if the sending participant's queue is not empty. Most of the time, the majority of Lynx participants do, in fact, have payments waiting in the queue. The design is intended to encourage payment queuing and increase the likelihood and the frequency of payment offsetting and possible concurrent settlement; however, it also introduces delay in settlement. Nonetheless, most payments (especially small-value) were queued for less than 10 seconds.

7 Conclusions

Utilizing the opportunity presented by the modernization of the HVPS in Canada, this paper investigates the changes in FIs' payments behaviours after the transition from LVTS to Lynx. Using six months of settlement data covering similar periods from each system, we compute the list of metrics, such as throughput, liquidity efficiency, delay, and network statistics, to quantify the changes in payment patterns between LVTS and Lynx. Our exploration reveals the following: (1) In Lynx, most payments are settled in a single mechanism, allowing liquidity pooling; (2) in Lynx, many payments arrive early and settle late compared to LVTS; (3) many participants carry more settlement balances and allocate less liquidity in Lynx than LVTS; and (4) most participants settle payments with higher delay, and liquidity efficiency is improved for many participants.

We believe this exercise is useful for policymakers and researchers alike in Canada and elsewhere for the following reasons: (1) it provides a framework for a comprehensive quantitative assessment of the new system against the old system; (2) it offers an opportunity to review and revise the models used and assumptions made to predict changes in FIs' payments behaviour before the launch of Lynx (these models and assumptions can be adjusted accordingly for future research); and (3) the lessons from this exercise are useful for understanding the effects of the modernization of core national payment systems. Also, these insights could be handy while designing new HVPSs in other jurisdictions, which is valuable given the worldwide trend towards modernizing payment systems. In summary, this paper provides a general framework for the quantitative assessment of HVPSs.

References

Alexandrova-Kabadjova, B., A. Badev, S. B. Bastoso, E. Benos, F. Cepeda-López, J. Chapman, M. Diehl, I. Duca-Radu, R. Garratt, R. Heijmans, A. Kosse, A. Martin, T. Nellen, T. Nilsson, J. Paulick, A. Pustelnikov, F. Rivadeneyra, M. R. do Coutto Bastoso, and S. Testi (2022). Intraday liquidity around the world. *Mimeo*.

Arjani, N. and D. McVanel (2006). A primer on Canada's large value transfer system.

Bank of Canada and Payments Canada (2022). An overview of Lynx, Canada's high-value payment system. Technical report.

Bech, M. L. and R. Garratt (2003, April). The intraday liquidity management game. *Journal of Economic Theory 109*(2), 198–219.

Bech, M. L., Y. Shimizu, and P. Wong (2017). The quest for speed in payments. *BIS Quarterly Review (March)*.

Garratt, R., Z. Lu, and P. Tian (2022). How banks create gridlock to save liquidity in Canada's new wholesale payment system. Technical report, Bank of Canada.

Kosse, A., Z. Lu, and G. Xerri (2021). Predicting payment migration in Canada. *Journal of Financial Market Infrastructure*.

Rivadeneyra, F. and N. Zhang (2022). Payment coordination and liquidity efficiency in the new Canadian wholesale payments system. Technical report, Bank of Canada Staff Discussion Paper.

Soramäki, K. and S. Cook (2013). Sinkrank: An algorithm for identifying systemically important banks in payment systems. *Economics 7*(1).