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Quantifying the Economic Benefits of Payment Modernization: the Case of the Large-Value Payment System*

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Abstract

In this paper, we develop a discrete choice framework to quantify economic benefits of payment modernization in Canada. Focusing on Canadian's Large-Value Transfer System (LVTS), we first estimate participants' preference on liquidity cost, payment safety as well as network effect by exploiting intra-day variations in the relative choice probabilities of the two substitutable sub-systems in LVTS (i.e., Tranche 1 and 2); then we use the estimated preference to calculate participants' welfare change when LVTS is replaced by Lynx (as an important part of the payment modernization initiative) via counterfactual simulations. The results show that 1) comparing to LVTS, Lynx's liquidity cost and safety are higher, with the former being a more important factor considered by system participants; 2) There is an overall welfare gain when over 90% of current LVTS payments migrate to an Real -Time Gross Settlement (RTGS) system like Lynx, however, it may be hard to achieve such a high migration ratio in the new market equilibrium; 3) With the equilibrium market share of Lynx, about 75% service level improvement is needed to generate

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overall net economic benefits to participants. Among other things, adopting liquidity saving mechanism and reducing risks in the new system can help achieve this improvement; 4) The welfare changes are quite heterogeneous across participants, especially between large and small ones.

Keywords: Payment Systems, Payment Modernization, Discrete Choice, Economic Benefit.

1 Introduction

Payment systems play a crucial role in an economy by providing the mechanisms for consumers, financial institutions, and governments to purchase goods and services, make financial investment, and transfer funds. Well-functioning payment systems can enhance the stability of the financial system, lower transaction costs, promote the efficient use of financial resources, and facilitate the conduct of monetary policy. Therefore, countries around the world have devoted much effort to monitoring, regulating, and upgrading their payments systems with the latest technological developments, international messaging standards, modernized regulatory and risk control framework.

In Canada, there are currently two core payment systems: the Large Value Transfer System (LVTS), and the Automated Clearing Settlement System (ACSS). Although these two payments systems are still functioning well, they were designed more than 20 years ago. As a result, the outdated technologies, limited functionality and risk control measures indicate that LVTS and ACSS are not suitable as future foundational platforms for payment clearing and settlement. Enhancements are required to establish a truly modern payments ecosystem that is fast, flexible, secure, and promotes innovation, and strengthens Canada's competitive position internationally. To achieve the enhancements, Canada is undertaking a large initiative to modernize Canadian payments ecosystem. In the modernized world, there will be three new core payment systems: a Real-Time Gross Settlement System (RTGS) for large value payments (named Lynx), a Deferred Net Settlement (DNS) system for clearing lower valued and less urgent payments (new batch retail system, formal name not yet determined), and a real time payment system for processing small value payments (named Real-Time Rail). The three payment systems will coexist and complement each other to serve their intended purposes, providing a richer set of viable payment options to meet the Canadian needs.

Although it is expected that the modernized ecosystem will bring large benefits to Canadian financial markets and overall economy, very limited work has been done for providing an economic model-based, quantitative assessment of such benefits.[1] Also, payment modernization involves substantial investment cost and the new systems might generate new types of risks. Therefore, it is crucial to provide a quantitative assessment of the potential benefits brought by the new payment systems, which in turn would provide useful information for the ongoing payment modernization initiative.

Evaluating the overall benefits of the payment modernization is an ambitious task. Given the available data, in this paper we take a first step and focus on large value payment system modernization, i.e., the replacement of LVTS with Lynx. To do this, we build an empirical model based on the discrete choice approach for consumer welfare evaluation developed by McFadden (1981), Small and Rosen (1981), Trajtenberg (1989), Petrin (2002), among others. Exploiting the intra-day variations in participants' system choice behavior recorded in the historical LVTS and ACSS data, we estimate the payoff function (preference) of each participant when sending an inter-bank payment. Then, using the estimated model, we conduct counterfactual experiments to calculate the welfare changes when LVTS is replaced by Lynx.

A participant (typically a financial institution)'s payoff of sending a payment via a large-value payment system depends on many factors. As a starter, we consider the two most prominent ones that govern participants' key trade-off, i.e., liquidity cost and risk of payment failure (or delay). To explicitly measure them, we construct two indicators from the characteristics of both the payment system and the payment in question. These indicators capture payment-by-payment variations in incentives that FIs face when sending payments. Besides the two indicators, the payoff of sending a payment also depends on how likely other payments also use the same system (known as "network effects"), as payment game exhibits clear strategic complementarity (see among others, Bech and Garratt (2003)). Finally, our model includes an unobserved, system specific "service quality" level in the payoff function to capture any residual factors beyond the ones mentioned above.

[1] One exception is the work by Arjani (2015) who applies discounted cash flow (DCF) analysis to study the potential economic benefits from adopting ISO 20022 payment message standard in payment modernization. However, given the limitation of DCF approach in the estimation of the future cash flows, Arjani (2015) suggests the payments research community to use an economic model-based approach to quantifying the economic ben-efits from payment modernization.

Exploiting the special feature that LVTS constitutes effectively two systems, Tranche 1 (T1) and Tranche 2 (T2), we estimate the payoff function of participants based on their realized system choices when sending different payments. The key to our estimation strategy is that the two constructed indicators and the network effect term have sufficient intra-day, payment level variations to identify their coefficients in the payoff function. With the estimated payoff function, we calculate a participant's welfare of sending each payment, and then aggregation over all payments gives us the total welfare of LVTS.

To evaluate the potential welfare gain, i.e., economic benefit, of the replacement of LVTS with Lynx, we run a counterfactual simulation by letting all the LVTS payments run through a baseline, near-RTGS Lynx system and record the output data, especially the two indicators we constructed. These indicators summarize the key differences between Lynx and LVTS along the two dimensions: liquidity cost and payment risk. Also, since the network effect in the payoff function depends on the aggregate outcome (choice probabilities of systems), we re-calculate the new equilibrium choice probability of Lynx. Finally, we can calculate the total welfare of Lynx and compare with that of LVTS under alternative assumptions on equilibrium adjustment, service quality improvement, etc.

Our results show that: 1) Comparing to LVTS, Lynx's liquidity cost is higher and payment risk is lower, with the former being a more important factor considered by system participants. 2) The choice of large-value payment systems exhibits rather strong network effects, which means it is important to take equilibrium adjustment into account when LVTS is replaced by Lynx. 3) The net economic benefit of Lynx Track changes is on over LVTS depends crucially on the payments migration from LVTS to Lynx and changes in the unobserved service quality level. In particular, we find that there is an overall welfare gain to participants if over 90% of current LVTS payments migrate to Lynx, which seems unlikely given our equilibrium adjustment calculation, or Lynx makes a 75% improvement over LVTS in terms of service quality. For example, adopting a liquidity-saving mechanism (LSM) and/or reducing credit risk (because Lynx is moving towards a RTGS system) in the system can help achieve this improvement. 4) The welfare changes are heterogeneous between large and small participants: smaller participants tend to have less welfare gain (or more welfare loss) than large ones when LVTS is replaced by Lynx.

The rest of the paper is organized as follows. Section 2 provides background information on LVTS and its modernized version, Lynx. Section 3 describes historical payment data used in this paper. Section 4 proposes two indicators to quantify the liquidity cost and perceived risk of delay that a participant faces when sending a payment. In Section 5 we present an empirical model of the participant's choice of payment systems. The estimations results of the model are presented in Section 6. The economic benefits from Lynx are computed and analyzed in Section 7. Section 8 concludes.

2 Payment Modernization: Large-Value Payment Systems

A pivotal part of the current payment modernization initiative in Canada is the replacement of the current large-value payment system, LVTS, with its modernized version Lynx. In this section, we briefly summarizes background information of the LVTS and Lynx.[2] This will help us to identify the key changes experienced by participants when moving from the LVTS to Lynx, which will be used to set up our model for quantifying the economic benefits of replacing the LVTS with Lynx.

2.1 The Legacy System: LVTS

The LVTS is Canada's core electronic payment system for processing inter-bank, large-value payments. It is the only systemically important payment system in Canada that is operated by then Payments Canada and overseen by the Bank of Canada (BoC). During the period of this study, the LVTS has 17 direct participants, including the BoC.[3] LVTS consists of two sub-

[2] In Canadian payment modernization program, the current two core payment systems (ACSS and LVTS) and future three core payment systems (RTR, new batch retail system, and LVTS) differ from each other in a variety of ways. See Kosse et al. (2020) for a detailed summary of their main attributes.

[3] The direct participants include Big 6 banks, BoC, Laurentian bank, Manulife bank, foreign banks with branches in Canada (State Street Bank, Bank of American, BNP Paribas, HSBC, ICIC), the Largest co-operative movement in Canada (Caise Desjardins) and a provincially owned deposit-taking institution (Alberta Treasury Branches) as well as a credit union consortium (Credit Union Central of Canada). Any deposit-taking institution and member

systems, Tranche 1 (T1) or Tranche 2 (T2). A participant can choose either T1 or T2 when sending a payment. The designs of T1 and T2 are rather different, especially in their distinct collateral requirements and risk control measures.

For T1, a participant can send a payment as long as its net debit position (assuming the current payment is made), calculated as the difference between all of its T1 payments sent (including the current payment) and those received, is no greater than the collateral that the participant has pledged to the BoC for backing up its T1 payment activities. If the participant defaults on its LVTS settlement obligations, the collateral will be used to cover any net negative position in T1. For this reason, T1 payments are known as "defaulter pays".

In T2, each participant grants Bilateral Credit Limits (BCLs) to every other participant at the beginning of each day, i.e., the largest net exposure that it is willing to accept with respect to that participant. In addition, each participant is subject to a multilateral net debit cap, calculated as the sum of all BCLs extended to it and then multiplied by a specified system-wide percentage (SWP, currently set at 30%) set by BoC. The multilateral net debit cap (T2NDC) represents the maximum multilateral net debit position that the participant can incur against all other participants during the trading day. Each participant pledges collateral to the BoC equal to the largest BCL it has extended to any other participants multiplied by the SWP. If a participant defaults on its final settlement obligation, the collateral pool is used to cover the defaulter's remaining amounts.[4] For this reason, T2 payments are referred as "survivor pays".

From the above description, we can see two key differences between T1 and T2 that are generally perceived by participants: T1 is more resilient to credit risk but more costly in terms of liquidity than T2, because every payment needs to be fully collateralized in order to be processed (Kosse et al. (2021)). On the other hand, T2 uses liquidity more efficiently but it has higher credit risk because of uncollateralized BCLs in T2. As a result, participants have

of the Payments Canada can be a member of LVTS so long as they maintain an account with the BoC and have the facilities to pledge collateral in LVTS. Deposit-taking institutions that are not members of LVTS must send (or receive) their payments through one of the direct participants.

[4]In the event of a participant default, the losses of surviving participants are determined based on the BCL that have granted to the defaulter (Arjani and McVanel (2006))

to take this key trade-off of the two sub-systems into account when sending payments.

2.2 The Modernized System: Lynx

Lynx, replacing the LVTS, is the new high-value payments system for processing large value, time critical payments. One of the significant changes when moving from the LVTS to Lynx is the change in the financial risk model. The financial risk model in Lynx is intended to mitigate credit risks.[5] To achieve this objective, lynx will be a RTGS system and, as such, credit risk exposure in Lynx will be fully covered by its participants and no longer rely on either the "survivors-pay" collateral pool or the residual guarantee from the BoC.[6]

However, the reduction of credit risk in Lynx is traded off against a substantial increase in intraday liquidity requirements. As a result, to manage liquidity requirements, Lynx will offer two distinct mechanisms, liquidity savings mechanism (LSM) and urgent payment mechanism (UPM). Lynx's LSM will enable participants to delay a payment and to reduce the amount of liquidity required to settle payments because it uses a combination of queuing, intraday liquidity recycling, and payment offsetting. For payments that must be settled without delay, participants may use Lynx's UPM.

Comparing to the LVTS, since every payment sent through T1 needs to be fully collateralized, Lynx is rather similar to T1. Moreover, since most LVTS payments are sent through T2 (see Kosse et al. (2021)), the shift from the LVTS to Lynx implies an overall increase in liquidity cost and a decrease in credit risk. We shall use an economic model-based approach to conduct a quantitative analysis of how the replacement of the LVTS with Lynx will affect the overall welfare of the participants of Canadian large-value payment system.

[5] Note that the mitigation of the credit risk in Lynx does not mean that Lynx eliminates systemic risk completely. In fact, an important systemic risk concern in Lynx is the risk of a liquidity shortage, which may trigger systemic risk, e.g., gridlock of the whole system.

[6] In the exceptional event of multiple participant defaults, if the collateral provided by surviving participant to ensure settlement in the event that another participant is in default, in addition to the collateral apportioned by the defaulters, is still not sufficient to cover the value of the final net debit positions of the defaulting participants, the BoC will provide a guarantee of settlement for the remaining amount.

3 Data

3.1 Data Source

Our main data set consists of information about payments that the direct system participants processed through the LVTS in 2019. For each payment, we observe its value, exact timing (date, hour and second), sender, receiver and which tranche it is sent through: T1 or T2. Also, we observe each participant's intraday credit limits in both T1 and T2, which are determined by the amount of pledged collateral and the rules of the LVTS, at any time during each trading day. Based on the payment level transaction data and participants' credit limits in T1 and T2, we will construct intraday time-varying indicators that can capture the key incentives, i.e., liquidity cost and risk of payment failure, that participants face when sending payments.

Payments made to the BoC are mostly sent through T1 because of the small BCLs granted by the BoC. As this is limiting participants' freedom of choice (thus cannot reveal FIs's true preferences), we have excluded payments sent to the BoC from the data and analyses. We also exclude payments that are less than CAD 10 as these are mostly test payments.

We supplement the LVTS data with ACSS data, which contains daily aggregated, bilateral payment values and volumes sent through ACSS in 2019, broken down by different pairs of participants.

The ACSS data will be used to construct a proxy for the market share of the "outside option" (besides the options T1 and T2) in our estimation of the discrete choice model.

3.2 Data Description

When participants send payments through LVTS, they have to make decisions regarding to where to send their payments, T1 or T2. These realized decisions provide us information to build a measure of the relative usage of T1 versus T2, i.e., the share of the transactions in T1 relative to all transactions in LVTS. Specifically, the share can be calculated as the ratio between the total volume (value) of payments sent through T1 and the total volume (value) in LVTS.

If the share is close to zero, meaning most payments are processed in T2, it means that LVTS operates at a high level of bilateral trust that allows to overcome need for costly collateral. As the share increases, it signals that the bilateral trust decreases and counter-parties require more collateral against credit risk. In particular, an unexpected fast transition of the share from low to high warns a strong risk signal because participants might not have enough collateral to make payments.

In Figure 1, we plot the volume share of T1 in each of 100 groups of payments, where the groups are defined by the percentiles of value distribution of all the LVTS payments in 2019. Two clear facts stand out from this figure. First, the overall usage of T1 is much less frequent than T2. This indicates that the credit-based transactions (i.e., T2 transactions) relative to all transactions are quite high, implying that on average for the given sample period, the LVTS maintains an extremely high level of efficiency of liquidity usage across different percentiles of the value distribution. Second, T1 is used mostly for very high value payments. In particular, this figure shows that there is a relatively low value share of T1 for payments below 71% percentile. However, the patterns of payments above the 96% percentile shows fairly high level of usage of T1, suggesting that participants are even more concerned with the safety when processing very high value payments. Basically these observations show that given the trade-off between efficiently using liquidity and safely processing payments, participants face very different incentives when sending payments with different value sizes.[7]

Similarly, the value share of T1 for per hour varies over the course of a day in a fairly predictable pattern. The average hour-by-hour pattern of the value share of T1 in a day is reported in Figure 2, which exhibits the timing pattern of the value share of T1 in a day. This figure indicates that in general T1 is used more heavily in the afternoon than in the morning, especially in the last two hours before the system is closed. The pattern of the afternoon peak in the value share of T1 suggests that participants are more concerned with payment safety and thus switch from T2 to T1 when getting closer to the end of day, i.e., the close time

[7] This pattern of payments is also documented in Kosse et al. (2021). Using the transaction data in the LVTS from 2004 to 2018, Kosse et al. (2021) find that the large majority of payments in the small and medium value of percentile bins are sent through T2, The share of T1 payments, however, starts to increase as the transaction values get bigger.

of the system.

Besides the LVTS data, we also need information about the payment activities outside the LVTS. This helps us to measure how substitutable the LVTS is to alternative payment systems, or other payment methods more generally. Since obtaining a comprehensive data set on all payment systems/methods in Canada is virtually impossible, we focus on the most direct substitute of the LVTS, the ACSS system, for which we have rather good data. Of course, focusing on the ACSS can potentially understate the "competition" that the LVTS is facing from other systems; we shall discuss the implications to our model and results later.

Now we turn to the ACSS data. Comparing to LVTS, ACSS is designed for payments with smaller value and less urgency. Thus ACSS is more substitutable to smaller-value payments in LVTS. To capture this substitution pattern, we divide the total value of ACSS in 2019 by the mean value of LVTS payments in each percentile bin (as shown in Figure 1). This gives us a "normalized volume" of ACSS that is comparable to LVTS payments in a given percentile bin. Figure 3 shows the share of normalized volume of ACSS (relative to LVTS and ACSS combined) for each value percentile bin. Note that this construction of outside option indeed captures the substitution pattern that ACSS is more substitutable to LVTS for smaller payments.

4 Liquidity Efficiency and Payment Safety

Credit risk mitigation in T1 is at the cost of high liquidity usage, while a high efficiency of liquidity usage in T2 is at the expense of a high credit risk. Moreover, the high cost of accessing to liquidity in T1 can increase its exposure to liquidity risks.[8] Hence, the liquidity cost and risk (liquidity and/or credit) are the two key factors that a decision maker has to take into account when sending a payment. In this section, we will propose two indicators that will be used as proxy variables for the liquidity cost and risk of processing a payment in our empirical model.

[8] Since access to liquidity is costly for settling payments in T1, there is potential (driven by the incentive of participants) underprovision of intraday liquidity, and as result, delays or rejections in the settlement of transactions **?**.

4.1 Liquidity Cost Indicator

Given that the payment i can pass the risk-control tests in the payment system j, where $j \in \{T1, T2\}$, the liquidity cost indicator, which measures the liquidity cost of settling payment i in terms of the amount of collateral, is defined as,

$$LCI_{i,j} = \varphi_{i,j} \cdot \max\{V_i - NI_{i,j}, 0\}, \tag{1}$$

where V_i is the value of payment i, $NI_{i,j}$ is the cumulative net payment income up to payment i in the current payments cycle in system j, $\varphi_{i,j}$ is a cost factor measuring liquidity cost in terms of collateral spending. Given the design of the LVTS, if the payment i was processed in T1, $\varphi_{i,T1}$ equals to 1, i.e., \$1 collateral is required for spending \$1 credit line (Arjani and McVanel (2006)). If the payment i is processed in T2, $\varphi_{i,T2}$ is defined as $\frac{MaxASO_{i,T2}}{T2NDC_{i,T2}}$, i.e., how much collateral on average is required for spending \$1 line of credit.[9]

The intuition behind the liquidity cost indicator in (1) is straightforward. For any payment i, if $NI_{i,j}$ is greater than V_i, then sending the payment does not cost any pledged collateral, i.e., the cost is 0. When $NI_{i,j}$ is less than V_i, the balance $V_i - NI_{i,j}$ need to be paid by collateral, with different cost factors $\varphi_{i,j}$ for T1 and T2, respectively. Similar indicators are proposed and used in previous literature, see among others, the recent report of CPMI (2015).

4.2 Safety Indicator

From the sender's point of view, the main risk of sending a payment is that it may be rejected or delayed due to lack of liquidity. So each participant monitors its intra-day liquidity position closely to make sure it has sufficient payment capacity (depends on available liquidity) to stay "safe", which usually means keeping enough distance away from violating certain risk control criteria. In the following, we shall construct a payment-specific indicator that measures sender's perceived safety regarding payment capacity for the rest of the day after the

[9] $MaxASO_{i,T2}$ is the largest BCL that participant i chooses to grant to any other participant, multiplied by the SWP, which is currently set at 30%. $T2NDC_{i,T2}$ represents the maximum multilateral T2 net debit position that participant i can incur in relation to all other participants in T2 (Arjani and McVanel (2006)).

payment is made. For T1, we build on the liquidity risk indicator proposed in Arjani et al. (2020) and define the safety indicator as

$$SI_{i,T1} = \frac{NI_{i,T1} + CL_{i,T1} + RPI_{i,T1}}{RPD_{i,T1} + V_i}, \tag{2}$$

where $CL_{i,T1}$ denotes the intraday credit limits of the sender in the day of payment i, $RPI_{i,T1}$ is the sender's payment income to be received from other participants in the remainder of the day after payment i, and $RPD_{i,T1}$ is the intraday liquidity demand during the remainder of day.

Assuming the sender can perfectly predict payment income and demand for the remainder of the day,[10] a greater safety indicator means that the sender is less likely to encounter liquidity shortage after sending payment i. Hence, the indicator measures sender's expected payment capability for the remainder of the day. Note that the safety indicator resembles the notion of "clearing capacity" proposed by **?**, which measures the value of payments that a participant can send under the design of a payment system.

In T2, besides the multilateral credit limit as in T1, senders are subject to bilateral credit limits. So for any payment i, the sender's perceived safety level depends on both multilateral and bilateral liquidity positions. Hence, we extend the safety indicator for T1 to account for both credit limits, i.e., the safety indicator of payment i in T2 is defined as

$$SI_{i,T2} = \min\left\{\frac{NI_{i,T2} + CL_{i,T2} + RPI_{i,T2}}{RPD_{i,T2} + V_i}, \frac{BNI_{i,T2} + BCL_{i,T2} + BRPI_{i,T2}}{BRPD_{i,T2} + V_i}\right\}, \tag{3}$$

where the first part in the brackets is the multilateral safety indicator analogous to $SI_{i,T1}$ and the second part is the bilateral version with all the variables defined by the sender's liquidity position with respect to the receiver of payment i, i.e., $BNI_{i,T2}$, $BCL_{i,T2}$ $BRPI_{i,T2}$ and $BRPD_{i,T2}$ are the sender's bilateral net payment income from the receiver, bilateral credit limit, bilateral payment income to be received from the receiver and liquidity demand from the receiver for the remainder of the day, respectively.

[10]The extension to allow forecasting errors in the indicator is left for future research.

Comparing with $SI_{i,T1}$, $SI_{i,T2}$ is smaller given the same multilateral liquidity safety indicator in T1 and T2, because of the additional bilateral constraints. Also, $SI_{i,T2}$ has richer variations as it depends on the receiver of the payment in question. Moreover, given that the different designs (i.e., risk controls) of T1 and T2 are targeting at liquidity and credit risks respectively, $SI_{i,T1}$ mostly captures liquidity risk while $SI_{i,T2}$ largely reflects credit risk associated with payments.

5 Model

For a given intended payment i between two participants, deciding which payment system for settling the payment is a discrete choice problem. Based on the standard demand estimation framework developed by Berry et al. (1995) (hereafter BLP), we propose a discrete choice demand model for the participants' decisions on which payment system to use for a payment. The estimated model will be informative about participants' preferences and thus can be used to assess the economic benefits from the replacement of LVTS with Lynx.

To begin with, let $\mathcal{J} = \{T1, T2, 0\}$ denote the choice set of payment systems that the decision maker of each payment i [11] can choose from for settlement, where the alternative 0 represents the "outside option", i.e., the option of not choosing either T1 or T2, which includes using alternative systems, e.g., ACSS, for the settlement, delaying or canceling the current payment for the next cycle, etc.

To map the discrete choice framework to the LVTS payments data, we group similar payments together by defining a series of markets, where a market m is defined as a combination of "hour-sender-receiver-value percentile." Given the definition of market, we can aggregate all the payments in a market (these payments are "similar" in terms of timing/sender/receiver/size) to obtain the total volume of T1 and T2 in the market. The volume of outside option is con-

[11] In fact, the decision on which system to use is jointly made by the sender and receiver of the payment. For simplicity, we do not model the details of the joint decision process, but regard the sender and receiver collectively as one single entity and focus on their final joint decision on which payment system to be used. This single entity is defined as the decision maker. For payments processed in LVTS, the decision mostly dominated by the sender but we do not want to restrict the interpretation of our model to the sender's choice problem.

structed as in Section 3.2 based on ACSS data. The volume shares of T1, T2 and the outside option correspond to the market shares implied by our discrete choice model, which measure choice probabilities of payment systems in the market m, and are the main outcome variables of our discrete choice model.

Note that with the above specification, we abstract away from the timing decision of sending a payment, which rules out the possibility of strategic delay. The disadvantage of this approach is that in a counterfactual scenario where the environment changes, our model cannot predict how timing decisions change. Incorporating these more complicated decisions into the model seems challenging and is beyond the focus of this paper and thus left for future investigations.

Given the choice set of payment systems, $\mathcal{J} = \{T1, T2, 0\}$, a decision maker's optimal choice is determined by its preference, which is represented by a random payoff function. Specifically, for each payment i in market m, the random payoff to the decision maker (i.e., referring to sender and receiver collectively) of sending it through system $j \in \{T1, T2, 0\}$ is specified to follow a nested-logit structure:

$$\pi_{i,j,m} = \alpha LCI_{j,m} + \beta SI_{j,m} + \gamma \bar{s}_{j,m} + X_m \rho + \xi_{j,m} + \zeta_{i,g,m} + (1-\lambda)\varepsilon_{i,j,m}, \quad (4)$$

where

- $LCI_{j,m}$ is the log of value-weighted average of liquidity costs of all the payments in m and $SI_{j,m}$ is log of value-weighted average of safety indicator in m.
- $\bar{s}_{j,m}$ is the total market share of system j in the "neighboring markets of m", defined as markets with the same sender as m but with different "receiver-hour-value percentile". This variable captures the sender's overall preference for a particular payment system. The preference could be driven by the economy of scale of using one payment system, or the expected benefits from payments coordination in one payment system, i.e., other participants also use the same payment system. The later is due to the well-known strategic complementarity in payment games, see, among others, Bech and Garratt

(2003)), which is called "network effect" or "social interaction" effect in newtork and social interaction literature (see, among others, Brock and Durlauf (2001)).

- X_m is a vector of observed market specific characteristics, including the dummy variables for each sending participant, receiving participant, value percentile, and hour (in a day).

- $\xi_{j,m}$ represents an unobserved characteristic of the payment system j in market m. It is important to include this system- and market-level demand shock in the model because it is impossible to include all the factors affecting the demand for option j in market m, see, among others, Berry et al. (1995) for detailed justifications for the importance of this term. In our context, ξ may include factors that are not captured by $LCI_{j,m}$, $SI_{j,m}$,$\bar{s}_{j,m}$, and X_m, e.g., service level of a payment system, operational and legal risks that participants face in a payment system, etc.

- $\zeta_{i,g,m} + (1-\lambda)\varepsilon_{i,j,m}$ is the preference shock following the nested-logit structure with $\lambda \in [0, 1)$ being the nesting parameter to be estimated. In particular $\zeta_{i,g,m}$ is an extreme value random variable to capture the interaction between the decision maker of sending payment i and the nested group of payment systems, $\{0\}$ and $\{T1, T2\}$, which are labeled by $g = 0$ and $g = 1$, respectively. And $\varepsilon_{i,j,m}$ is an extreme value variable and is identically and independently distributed.[12]

The nested-logit structure is important for modeling the substitution patterns between the three options in the choice set. The nesting parameter λ in this model can be interpreted as a measure of substitutability of alternative payment systems across groups.[13] As the parameter λ approaches one, the within-group correlation of payoff levels goes to one. On the other hand, as λ approaches zero, the within group correlation goes zero, and thereby the nested logit model is reduced to the logit model. In our case, the substitution between T1 and

[12]In the nested-logit specification, the variable $\zeta_{i,g,m}$ is a common variable to all systems in g. **?** shows that the distribution of $\zeta_{i,g,m}$ is the unique distribution with the property that, if $\varepsilon_{i,j,m}$ is an extreme value random variable, then $\zeta_{i,g,m} + (1-\lambda)\varepsilon_{i,j,m}$ is also an extreme value random variable.

[13]See, among others, Trajtenberg (1989) for details.

T2 is naturally stronger than that between T1 (or T2) and the outside option . Therefore, the nested logit model specified above allows us to model a more realistic substitution pattern among the three options in the choice set than the simple logit model, which suffers from the well-known drawback of the independence of irrelevant alternatives property.

Given the random payoff in (4), we denote the mean utility level of payment system j in market m as,

$$\delta_{j,m} = \alpha LCI_{j,m} + \beta SI_{j,m} + \gamma \bar{s}_{j,m} + X_m \rho + \xi_{j,m}, \tag{5}$$

which will play an important role to derive the market shares of payment system j. Note that it is also in a regression form and will be convenient for estimation. Aggregating individual choices for each system j in group g, we obtain the within-group share of g in market m,

$$s_{j|g,m} = \frac{e^{\delta_{j,m}/(1-\lambda)}}{D_g}, \tag{6}$$

where $D_g = \sum_{j \in G_g} e^{\delta_{j,m}/(1-\lambda)}$ and G_g includes options in group g.

Similarly, we can obtain the market share of each payment system j in the choice set $\{T1, T2, 0\}$:

$$s_{j,m} = \frac{e^{\delta_{j,m}/(1-\lambda)}}{D_g^{\lambda}[\sum_g D_g^{(1-\lambda)}]}. \tag{7}$$

Based on (5), (6), and (7), with $\delta_{0,m}$ being normalized to zero, we apply the well-known choice probability inversion formula of the nested logit model (see Berry (1994)) to obtain the following regression equation:

$$\log\left(\frac{\hat{s}_{j,m}}{\hat{s}_{0,m}}\right) = \alpha LCI_{j,m} + \beta SI_{j,m} + \gamma \bar{s}_{j,m} + \lambda \log\left(\hat{s}_{j|g,m}\right) + X_m \rho + \xi_{j,m}, \tag{8}$$

where $\hat{s}_{j,m}$ is the observed market share of j in market m and $\hat{s}_{j|g,m}$ is the observed within-group market share of j in market m. Equation (8) forms the basis of estimating the parameters in the model.

To estimate (8), we need to impose statistical assumptions on the demand shock $\xi_{j,m}$. Following Berry (1994) and Berry et al. (1995), we assume that the following mean independence condition holds:

$$E[\xi_{j,m}|Z_{j,m}] = 0, \tag{9}$$

where $Z_{j,m}$ is a set of exogenous variables that it do not depend on $\xi_{j,m}$.

The two market share variables on the RHS, $\bar{s}_{j,m}$ and $\log\left(\hat{s}_{j|g,m}\right)$, in (8) are clearly endogenous because they depends on the market shares on the LHS. Thus we will construct instrumental variables for them below. Regarding to other RHS variables, X_m is determined by exogenous payment demand from the outside the system and thus unlikely to be correlated with $\xi_{j,t}$; both $LCI_{j,m}$ and $SI_{j,m}$ can depends on the market shares in market m as well as its neighbors (and thus ξ's), however, we think such dependence is weak after controlling for $\bar{s}_{j,m}$ directly (assuming the dependence of $LCI_{j,m}$ and $SI_{j,m}$ on market shares mostly go through $\bar{s}_{j,m}$). In this sense, from the pure econometric point of view, the inclusion of $\bar{s}_{j,m}$ in our model can be regarded as a way to control the endogeneity of $LCI_{j,m}$ and $SI_{j,m}$. Hence, we treat $LCI_{j,m}$ and $SI_{j,m}$ as exogenous variables and only handle the endogeneity problem in market share variables.

Specifically, for the two endogenous variables $\bar{s}_{j,B_m}, \log\left(\hat{s}_{j|g,m}\right)$, we construct the following instrumental variables:

$$\left[\bar{s}_{j,B'_m \setminus B_m}, \ \frac{1}{|\mathcal{M}_m|}\sum_{l \in \mathcal{M}_m} \log\left(\hat{s}_{j|g,l}\right)\right], \tag{10}$$

where B'_m is a superset of B_m (a bigger neighbor of market m), $\mathcal{M}_m$ is a set of markets "adjacent" to market m (excluding m itself), i.e., those having the same sender, submission hour, and value percentile, but different receiver. The construction of these instrumental variables is based on the following two ideas. First, the market shares of T1 and T2 in neighboring markets are informative about those in the market considered (i.e., relevance). Second, the demand shocks in neighboring markets have limited correlation with that in the market in question (i.e., exogeneity). With the constructed instrument variables in (10) (along with other exogenous variables), we can estimate (8) using the standard two stage least-squares method.

6 Estimation Results

Table 1 reports the estimation results of the discrete choice model introduced in the previous section, with four alternative specifications. These specifications are a simple logit specification, a simple logit specification with fixed effects, a nested logit specification, and a nested logit specification with instrumental variables. For convenience, we refer to the first as Logit, the second as FE Logit, the third as Nested Logit, and the fourth as IV Nested logit. The advantage of presenting the logit results is that we can explore the effects of controlling for the fixed effects. We present the Nested Logit results to examine the effectiveness of the instrumental variables for the log of within-group share $(s_{j|g,m})$ in the nested logit specification.

In the first column of Table 1, we report the estimation results of the simple logit model. Although the coefficients of safety indicator and network effect are of the expected sign, the positive coefficient on liquidity cost is anomaly, as we would expect liquidity cost to yield negative marginal payoff. Additionally, the logit model gives an adjusted R^2 of 0.712, which implies that about 29 percent of the variance in mean utility levels is due to the unobserved characteristics. In the second column of Table 1, we report the estimation results of the FE Logit model. All the coefficients are significantly different from zero, and have the expected sign. Also R^2 from the FE Logit model is fairly high at 0.903, a significant improvement from the Logit model. All of these suggest that controlling for fixed effects is critical to obtain reasonable estimations of the coefficients.

In Table 1, the third column reports the estimation results of the Nested Logit specificiation using the OLS, while the fourth column reports the results of IV Nested Logit, using the instrument variables in (10). Comparing the estimation results in the third column with that in the fourth column, we find that the coefficients between two columns differ noticeably, especially the coefficient on the network effect in the fourth column decreases substantially. This indicates the importance of correcting the endogeneity problem.

Focusing on IV Nested Logit model, our favored specification, we can see that the coefficients on liquidity cost, safety indicator, network effect, and log of the within-group market share all have expected signs and are statistically significant. Also, the nesting parameter, i.e., the coefficient of the log of the within-group market share, is greater than .7, indicating a strong within-group correlation between the preferences for *T1* and *T2* relative to the cross-group correlation between *T1* (or *T2*) and outside option 0. Also, the statistically significant coefficient of the log of the within-group market share suggests that the extension from the FE logit to the IV Nested Logit seems necessary. Finally, the large value of the first-stage F test statistic supports the relevance of the constructed instruments.

7 Quantifying the Economic Benefits of Lynx

In this section, we use the estimated discrete choice model in previous section to calculate the economic benefits of Lynx, which is replacing LVTS as part of the payment modernization initiative.

7.1 Welfare Calculation

The discrete choice model allows us to calculate the welfare, or economic benefits, to participants from sending payments. Given our IV nested logit specification, using similar approach as in Trajtenberg (1989) who suggested the use of discrete choice models to measure the benefits of product innovations, the expected maximum payoff of sending a payment in market m under the current LVTS regime is calculated as follows:

$$EV_{\text{LVTS,m}} = \log\left[1 + \left(\exp\left(\frac{\hat{\delta}_{\text{T1},m}}{1-\hat{\lambda}}\right) + \exp\left(\frac{\hat{\delta}_{\text{T2},m}}{1-\hat{\lambda}}\right)\right)^{1-\hat{\lambda}}\right], \tag{11}$$

where $\hat{\delta}_{\text{T1},m}$ and $\hat{\delta}_{\text{T2},m}$ are the fitted value of mean utilities defined as

$$\hat{\delta}_{j,m} = \hat{\alpha} LCI_{j,m} + \hat{\beta} SI_{j,m} + \hat{\gamma}\bar{s}_{j,B_m} + X_m\hat{\rho} + \hat{\xi}_{j,m}, j \in \{T1, T2\}. \tag{12}$$

Note that these estimated parameters in (11) and (12), $\hat{\lambda}$, $\hat{\alpha}$, $\hat{\beta}$, $\hat{\gamma}$, $\hat{\rho}$, and $\hat{\xi}_{j,m}$ are obtained from the estimation results in Section 6.

After LVTS is replaced by Lynx, the choice set of payment systems that participants are facing becomes $\{0, \text{Lynx}\}$. And the expected maximum payoff of sending a payment in market m boils down to:

$$EV_{\text{Lynx},m} = \log\left[1 + \exp\left(\hat{\delta}_{\text{Lynx},m}\right)\right], \tag{13}$$

where $\hat{\delta}_{\text{Lynx},m}$ is the mean payoff of sending a payment through Lynx and can be decomposed as

$$\hat{\delta}_{\text{Lynx},m} = \hat{\alpha} LCI_{\text{Lynx},m} + \hat{\beta} SI_{\text{Lynx},m} + \hat{\gamma}\bar{s}_{\text{Lynx},B_m} + X_m\hat{\rho} + \hat{\xi}_{\text{Lynx},m}. \tag{14}$$

Note that $\hat{\alpha}$, $\hat{\beta}$, $\hat{\gamma}$ and $X_m\hat{\rho}$ in (14) are the same as in (12), however, other variables in (14) are unknown and we will discuss how we assign their values in the next subsection.

Given the expected maximum payoffs of both LVTS and Lynx in market m, we can measure the welfare change from replacing LVTS with Lynx by the required amount of collateral (in Canadian dollars), i.e.,

$$\Delta EB = \sum_m \text{W}_m \cdot \text{Vol}_m \cdot \left(EV_{\text{Lynx},m} - EV_{\text{LVTS},m}\right), \tag{15}$$

where Vol_m is the total payment volume in market m, and W_m is a factor that translates the payoff level of each payment for a payment system into "willingness-to-pay" measured in terms of collateral (in Canadian dollars). Since the liquidity cost enters the payoff function in log form, we can define the factor as

$$\text{W}_m = \frac{\exp\left(LCI_{T1,m}\right) + \exp\left(LCI_{T2,m}\right)}{|\hat{\alpha}|}. \tag{16}$$

It is possible to further translate the collateral amount into actual financial cost (e.g., using appropriate interest rates), however, this is not straightforward because it can be tricky to measure collateral cost that varies by participants, timing, etc., and less relevant to our current analysis so we leave it for future investigation.[14]

7.2 Payoff Function of Lynx

Since Lynx is not launched by the time of this analysis, we do not have realized data from the new system. Hence, we have to construct synthetic data of Lynx using simulation. Simulating a full-scale Lynx with all its design features is challenging, we focus on a simplified version of Lynx with only its core characteristics, i.e., it is a real-time settlement system, and each payment needs to be fully collateralized in order to be processed.

In particular, we let all the payment instructions from the 2019 LVTS data including both T1 and T2 run through the simplified Lynx and record the outcome, e.g., we evaluate the cost and safety indicators in this new system. In this process, we maintain the following assumptions: (1) all the LVTS payments migrate to the Lynx system; (2) the timing and order of all the payments for each day are kept unchanged; (3) participants pledge sufficient collateral to Lynx so that they can make all the payments in a fully collateralized manner; (4) the risk control test for each payment in Lynx is the same as in T1.

Figure 4 shows the comparison between LVTS and Lynx in terms of liquidity cost, for different hours in a day and different sending participants. As expected, the liquidity cost of Lynx is higher than that of LVTS. Also, the difference is rather heterogeneous across participants and different hours. For example, participants with higher overall liquidity cost, mostly driven by their larger volume of payments, have to bear greater increase in liquidity cost when Lynx replaces LVTS.

Figure 5 plots the safety indicators for Lynx and LVTS, respectively, across different participants and hours in a day. It is clear that the safety indicator of Lynx is higher than LVTS, mostly due to the pooled credit limits (T1 and T2) and the removal of bilateral risk control test of T2 (reflecting the reduction in credit risk). Comparing with the liquidity cost, the safety indicator is much smaller in scale and thus its difference between Lynx and LVTS will have less effect on the participants' welfare changes.

[14] See McPhail and Vakos (2003) for some high-level estimates of the collateral costs in LVTS.

With the above simulation, we obtain values of liquidity and safety indicators, $LCI_{\text{Lynx},m}$ and $SI_{\text{Lynx},m}$, in the mean payoff function of Lynx (14). Regarding to the unobserved characteristic of Lynx, $\hat{\xi}_{\text{Lynx}}$, which captures the relative payoff (e.g., service quality level) comparing to the outside option, we assume it is proportional to the average of its counterparts of T1 and T2, i.e.,

$$\hat{\xi}_{\text{Lynx}} = \frac{\theta_1}{2}\left(\hat{\xi}_{\text{T1}} + \hat{\xi}_{\text{T2}}\right),$$

where θ_1 is a tuning parameter capturing the unobserved service quality level of Lynx (comparing to the LVTS).

Finally, the model includes a network effect captured by $\bar{s}_{j,m}$ in (4) that needs to be determined for Lynx. We consider two ways of assigning the value. First, we simply assume that it is proportional to the total market share of LVTS, i.e.,

$$\bar{s}_{\text{Lynx},m} = \theta_2\left(\bar{s}_{\text{T1},m} + \bar{s}_{\text{T2},m}\right),$$

where θ_2 represents the fraction of LVTS payments migrating to LVTS. Second, $\bar{s}_{\text{Lynx},m}$ can be endogenously determined the equilibrium adjustment of market shares. Specifically, with the new system Lynx replacing LVTS, the model implies market shares of Lynx that differ from those of LVTS. Then the network effect term, which depends on the market shares in neighboring markets, needs to be updated. This change in turn implies a vector of new market shares of Lynx. This heuristic adjustment process can be formalized as a iterative approach to compute the new equilibrium market shares of Lynx. Formally, the equilibrium market shares of Lynx can be computed iteratively as follows:

$$s^{r+1}_{\text{Lynx},m} = \frac{\exp\left(\hat{\alpha}LCI_{\text{Lynx},m} + \hat{\beta}SI_{\text{Lynx},m} + \hat{\gamma}\bar{s}_{\text{Lynx},m}\left(\mathbf{s}^r_{\text{Lynx}}\right) + X_m\hat{\rho} + \xi_{\text{Lynx},m}\right)}{1+\exp\left(\hat{\alpha}LCI_{\text{Lynx},m} + \hat{\beta}SI_{\text{Lynx},m} + \hat{\gamma}\bar{s}_{\text{Lynx},m}\left(\mathbf{s}^r_{\text{Lynx}}\right) + X_m\hat{\rho} + \xi_{\text{Lynx},m}\right)}, \tag{17}$$

where $\mathbf{s}^r_{\text{Lynx}}$ is the vector of market shares in the r-th iteration (with some starting value $\mathbf{s}^0_{\text{Lynx}}$). This iteration process is in fact a contraction mapping given the value of our estimated parameter $\hat{\gamma} = 1.549$, see Brock and Durlauf (2001) for details.

PAYMENTS CANADA

7.3 Results

We first consider the simple case where $\theta_1 = 1$ and there is no equilibrium adjustment, i.e., treating the network effect term as exogenous and examining how the network effect contributes to the welfare measure. Figure 6 shows the total welfare change against θ_2, the fraction of payments in LVTS migrating to Lynx. There are three lines in the graph: "Baseline" refers to the simple Lynx described above; "20% Cost Reduction" is the case where we assume Lynx adopts certain liquidity saving mechanism such that its liquidity cost is overall 20% lower than the baseline simple Lynx; "100% Safety Increase" refers to the case where Lynx improves the safety indicator by 100%.

We can see that as θ_2 increases, the net economic benefits of Lynx also increases and exceeds 0 when θ reaches around .9, which means that there is a welfare gain when over 90% of current LVTS payments migrate to Lynx. Also, lowering liquidity cost by 20% has a non-negligible effect on welfare, but increasing payment safety indicator can do very little.

Next, we consider the case with equilibrium adjustment. It turns out the new equilibrium implies a lower migration ratio, which is around 55%,[15] than 90%. Under this lower migration ratio, the baseline Lynx is likely to cause a welfare loss to participants, however, a quality improvement (e.g., an increase in $\hat{\xi}_{\text{Lynx}}$) can mitigate the loss and even generate welfare gains. Then a natural question is how much quality improvement is needed? Figure 7 illustrates the overall welfare changes against θ_1, the percentage of quality improvement. We can see that Lynx needs an almost 75% improvement in service level over LVTS to achieve an overall welfare gain to the participants. Again, lowering liquidity cost (e.g., through liquidity saving mechanisms) has much larger effects than improving payment safety indicator.

Besides the overall welfare change, we show the heterogeneous effects across participants in Figure 8 for the special case where $\theta_1 = 1.75$ (with equilibrium adjustment), i.e., overall welfare change is 0. We can see that the welfare changes are rather heterogeneous across

[15] This result is in the same ballpark the payment modernization patterns predicted by Kosse et al. (2021). However, recall that this result is obtained under the assumption that Lynx is pure RTGS system, which is not exactly the case because of the adoption of liquidity saving mechanisms in Lynx. Hence, we expect that this predicted migration ratio might be a reasonable "lower bound" for the actual migration ratio that will be realized in the near future.

participants, e.g., Bank 1 (a big participant) enjoys a quite large welfare gain while small participants as a whole (labeled as “Others”) suffers from a welfare loss. The differences are mainly driven by the heterogeneous effects of replacing LVTS with Lynx on the random payoff functions across different participants. This heterogeneous effect raises some interesting policy questions, e.g., the central bank and payment system operator may consider providing certain incentives for some participants, which suffers from welfare losses, to participate in the new system, given that after all participation is vital for the new system to achieve its public objectives.

8 Concluding Remarks

In this paper, we propose a discrete choice demand framework to model the participants' decisions on which payment system to use for sending payments and apply it to measure benefits of payment modernization in Canada. Focusing on the large-value payment system modernization, we first use historical data of LVTS to estimate participants' preference on liquidity cost, payment safety as well as network effect; then we use the estimated preference to calculate participants' welfare change when LVTS is replaced by Lynx based on simulation. Our results suggest that a high migration ratio and/or service quality improvements (e.g., new liquidity saving/safety features) are crucial to generate overall net economic benefits to participants.

Our study is the first step to quantify the economic benefits of payment modernization. There are several caveats in our current results:

- We construct and include only two indicators describing the incentives that participants are facing when making a payment. Although they capture two important factors, the two indicators clearly cannot exhaust all the important considerations that participants have when making payments. Including more variables capturing the incentives participants face can improve our results, although this is not an easy task.
- Our measure of the “outside option” (relative to LVTS) is based on ACSS data. This as-

sumption may underestimate the share of actual outside option, especially for small-value payments, because there are other payment systems/networks available for financial institutions to process payments. Whether this would change our conclusion is not clear. For example, if Lynx has certain new features that can “steal” market shares from other payment systems, then we would underestimate the welfare gain of the new system.

- Our evaluation focuses on the large-value payment system modernization and thus only covers part of the payment ecosystem. Hence, the welfare results should be interpreted with caution. For example, even if Lynx cannot generate a welfare gain when replacing LVTS, other modernized payment systems, e.g., the new retail payments may produce sufficiently high surplus to make the overall benefits of payment modernization positive.
- We only measure the economic benefits to participants in the system and do not consider the overall potential benefit or loss to the whole society. Given that payment systems have clear externalities in terms of systemic risk, it is important to extend the current analysis along this line.

Despite the above mentioned caveats, which are mostly driven by the data limitations, our proposed framework for evaluating the economic benefits of payment systems is rather general and flexible. With more and richer data in the future, especially data generated by Lynx, the framework can be extended and enriched to provide a more comprehensive assessments of the welfare implications of payment modernization.

References

Arjani, Neville, “The economic benefit of adopting the ISO 20022 payment message standard in Canada,” Technical Report, Canadian Payments Association 2015.

__ **and Darcey McVanel**, “A primer on Canada’s large value transfer system,” Technical Report, Bank of Canada 2006.

__ **, Fuchun Li, and Leonard Sabetti**, “Monitoring Intraday Liquidity Risks in a Real Time Gross Settlement System,” Technical Report, Payments Canada Discussion Paper 2020.

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

Berry, S., J. Levinsohn, and A. Pakes, “Automobile prices in market equilibrium,” *Econometrica: Journal of the Econometric Society*, 1995, pp. 841–890.

Berry, S.T., “Estimating discrete-choice models of product differentiation,” *The RAND Journal of Economics*, 1994, pp. 242–262.

Brock, William A and Steven N Durlauf, “Discrete choice with social interactions,” *The Review of Economic Studies*, 2001, *68* (2), 235–260.

CPMI, “Liquidity efficiency of the large value payment systems around the world,” Technical Report 2015.

Kosse, Anneke, Zhentong Lu, and Gabriel Xerri, “An economic perspective on payments migration,” Technical Report, Bank of Canada 2020.

__ **, __ , and __** , “An economic perspective on payments migration,” *Journal of Financial Market Infrastructure*, 2021.

McFadden, D., “Econometric Models of Probabilistic Choice,” in C. Manski and D. McFadden, eds., *Structural Analysis of Discrete Data with Econometric Applications*, Cambridge: MIT Press, 1981, chapter 5, pp. 198–272.

McPhail, Kim and Anastasia Vakos, "Excess Collateral in the LVTS: How Much is Too Much?," Technical Report, Bank of Canada 2003.

Petrin, Amil, "Quantifying the benefits of new products: The case of the minivan," *Journal of political Economy*, 2002, *110* (4), 705–729.

Small, Kenneth A and Harvey S Rosen, "Applied welfare economics with discrete choice models," *Econometrica: Journal of the Econometric Society*, 1981, pp. 105–130.

Trajtenberg, Manuel, "The welfare analysis of product innovations, with an application to computed tomography scanners," *Journal of Political Economy*, 1989, *97* (2), 444–479.

Tables

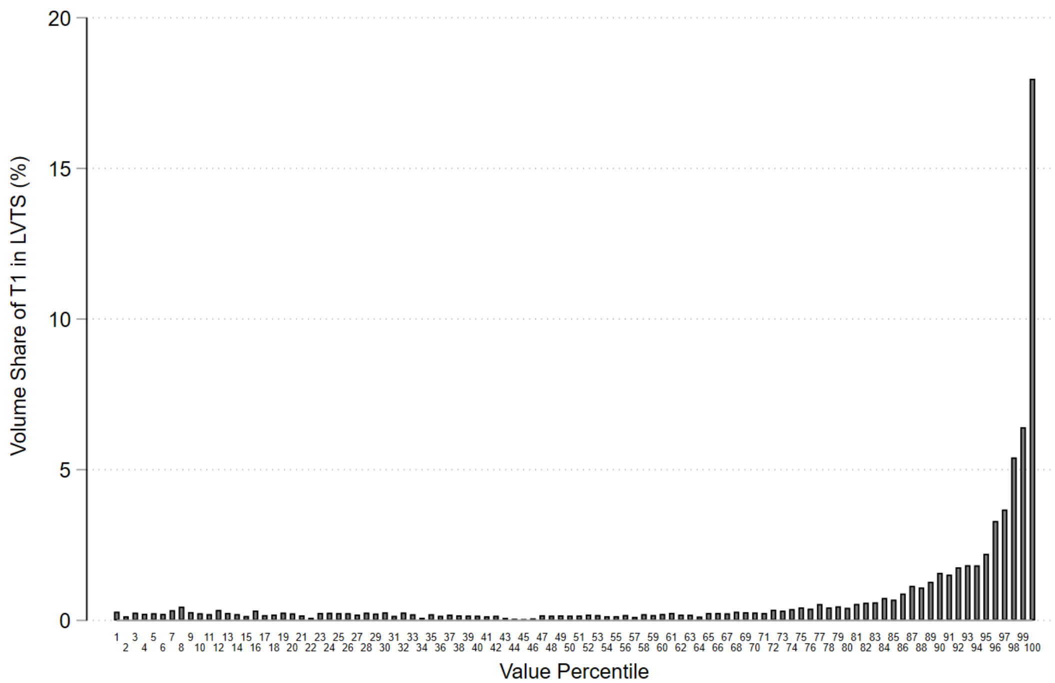
Table 1: Demand Estimation Results

	Simple Logit		Nested Logit	
	Without FE	With FE	Without IV	With IV
Liquidity Cost	0.564	-0.0443	-0.0220	-0.0299
	(0.00250)	(0.00467)	(0.00440)	(0.00438)
Safety Indicator	0.0154	0.0246	0.0264	0.0202
	(0.00248)	(0.00187)	(0.00181)	(0.00180)
Network Effect	6.191	9.788	6.001	1.549
	(0.0175)	(0.260)	(0.223)	(0.117)
Nesting Parameter			0.515	0.724
			(0.00775)	(0.0218)
Constant	-8.140	-7.082	-5.262	-4.522
	(0.0335)	(0.130)	(0.123)	(0.157)
Sender FE				
Receiver FE				
Hour FE				
Value Pctile FE				
Cragg-Donald Wald F				7869.96
# Obs.	104,707	104,707	104,707	100,350
Adj. R^2	0.712	0.903	0.909	0.913

Note: Table 1 reports the estimation results of the discrete choice model, with four alternative specifications. These specifications are a simple logit specification without fixed effect, a simple logit specification with fixed effects, a nested-logit specification without IV, and a nested-logit specification with IVs. The standard errors of the estimated parameters are reported in parentheses. All the estimates shown in the table are statistically significant at 1% significant level.

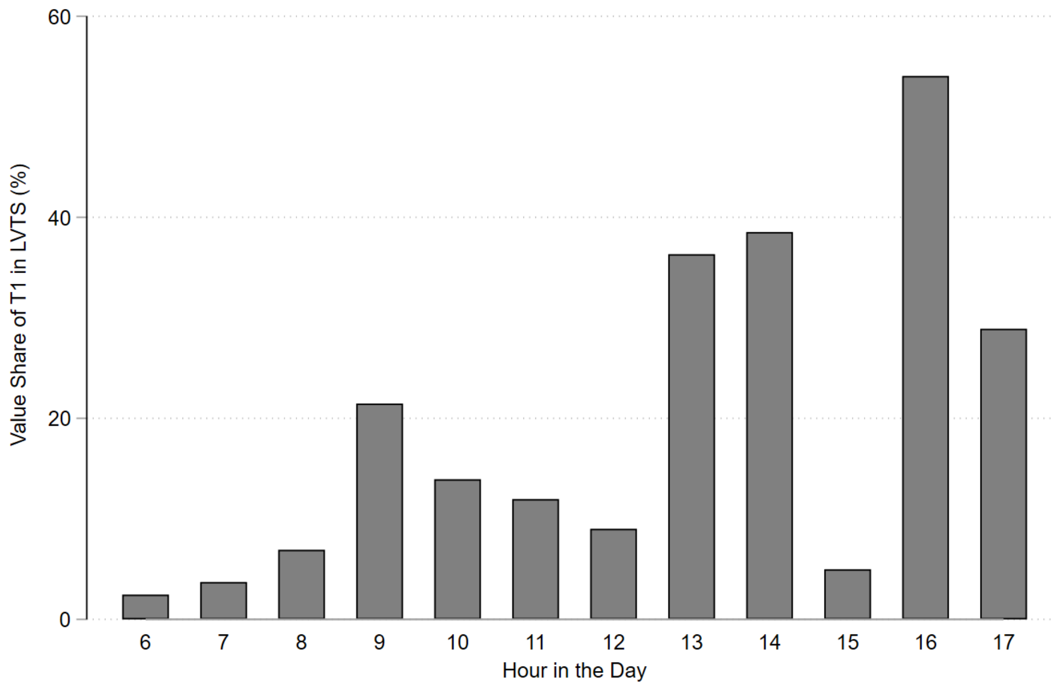
Figures

Figure 1: Volume Share of T1 for Different Payment Sizes



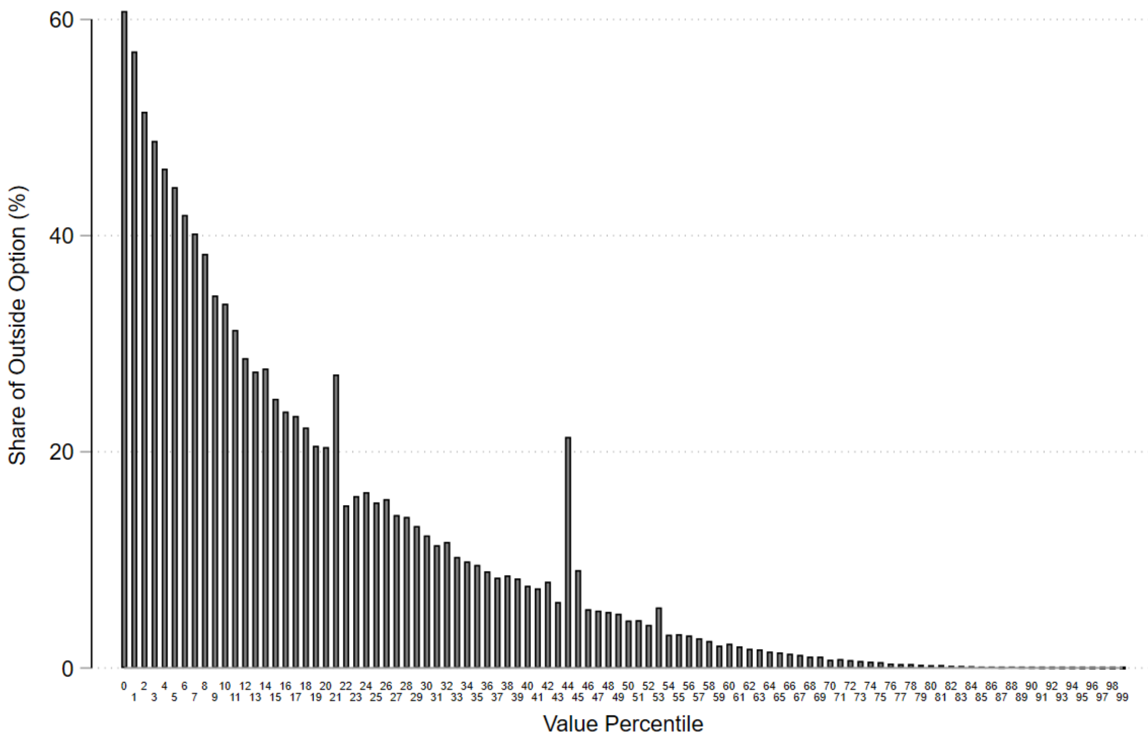
Note: Figure 1 plots the volume share of T1 in each of 100 groups of payments, where the groups are defined by the percentiles of value distribution of all the LVTS payments in 2019. In each group, the volume share is calculated as the ratio between the total volume of payments sent through T1 and the total volume through LVTS.

Figure 2: Value Share of T1 for Different Hours



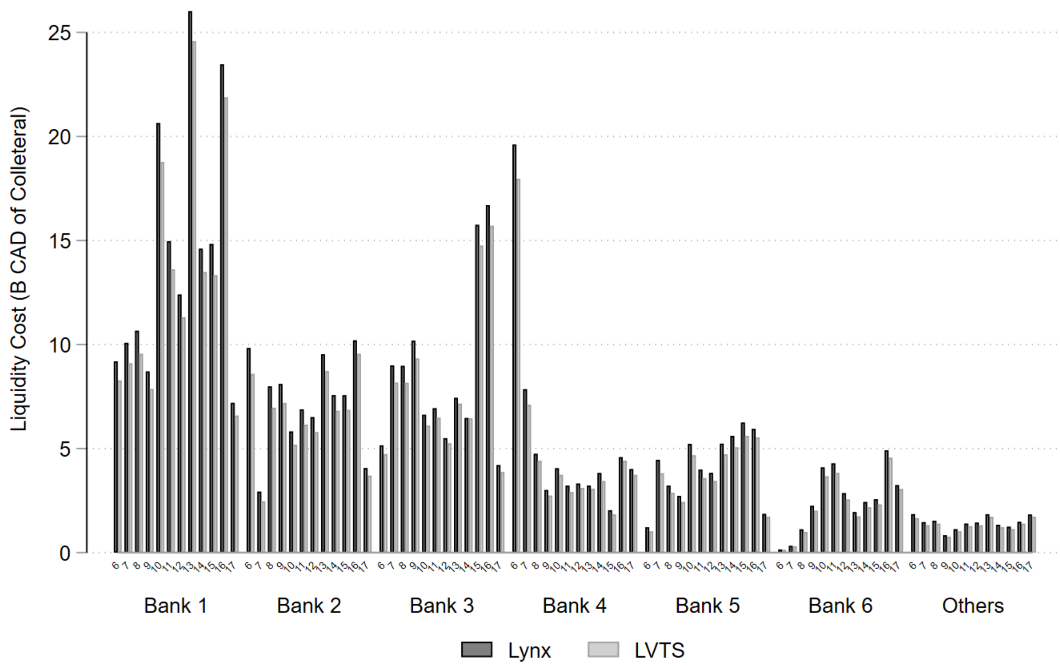
Note: Figure 2 plots the average hour-by-hour pattern of the value share of T1 in a day. In each hour, the value share is calculated as the ratio between the total value of payments sent through T1 and the total value of payments through LVTS.

Figure 3: Volume Share of Outside Option



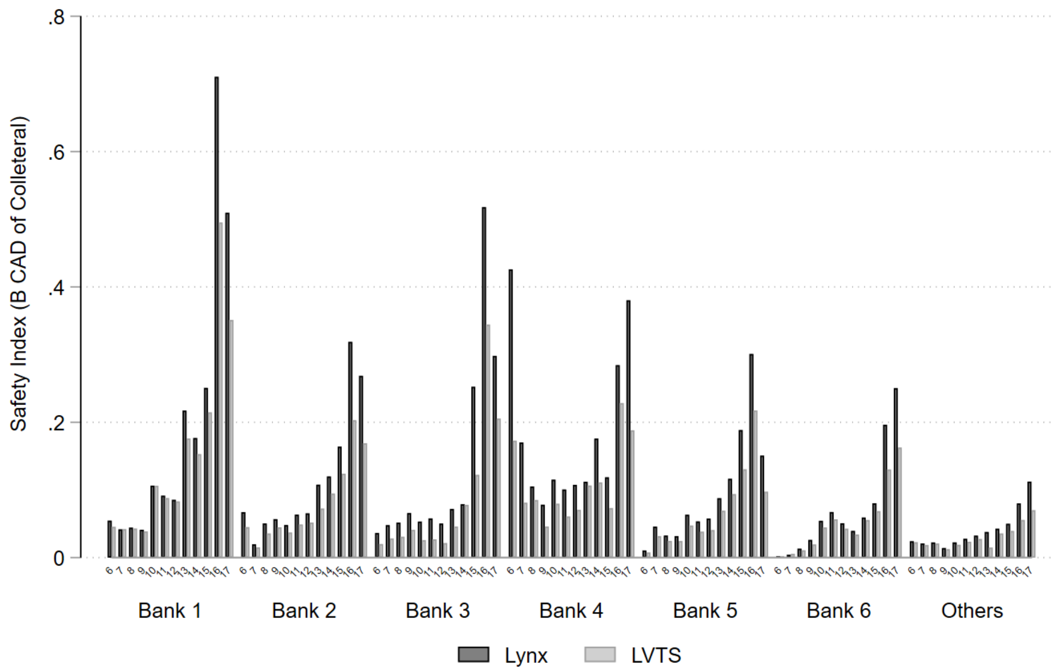
Note: Figure 3 shows the share of normalized volume of ACSS in 2019 (relative to LVTS and ACSS combined) for each value percentile bin.

Figure 4: Liquidity Cost: LVTS vs Lynx



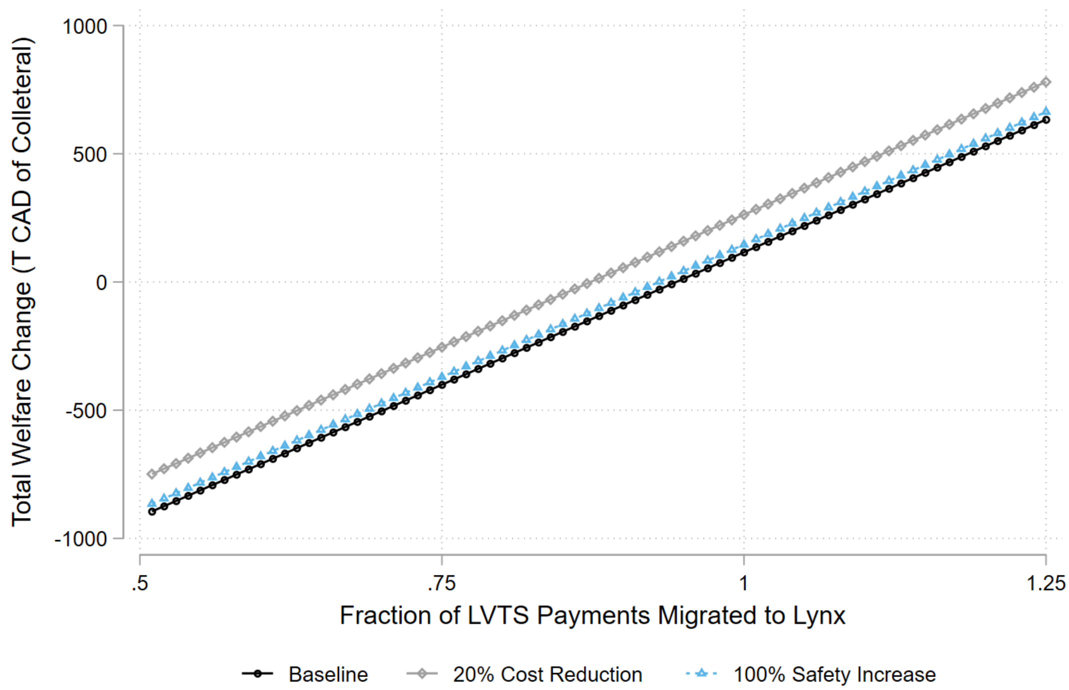
Note: Figure 4 shows the comparison of liquidity cost between LVTS and Lynx in 2019, for different hours in a day and different sending participants.

Figure 5: Safety Indicator: LVTS vs Lynx



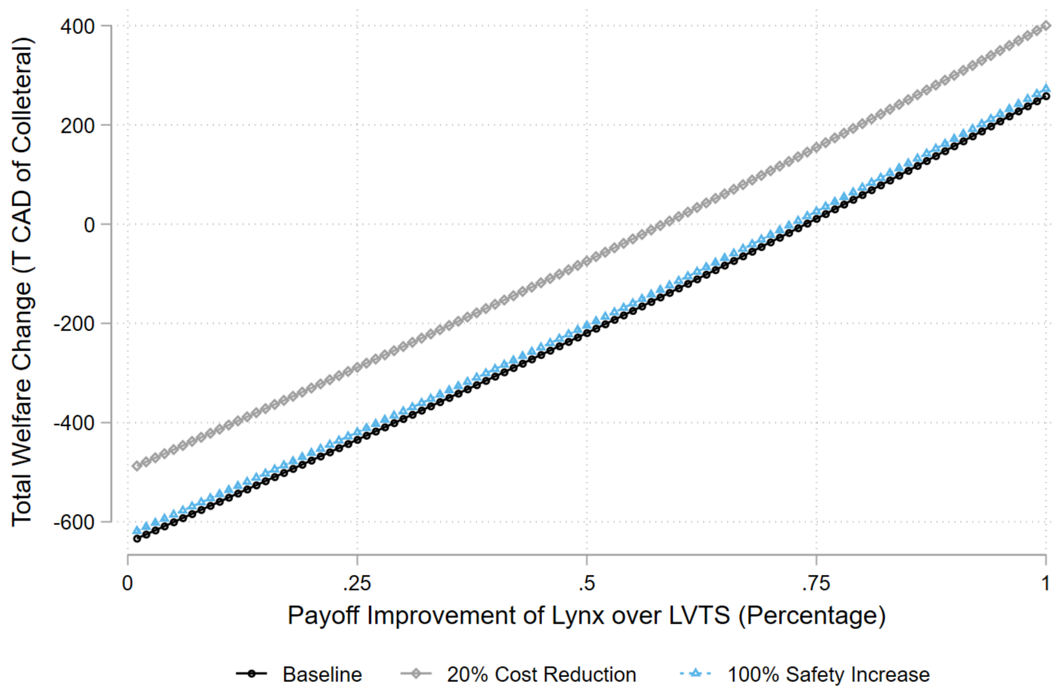
Note: Figure 5 plots the safety indicator for Lynx and LVTS, respectively, across different participants and hours in a day.

Figure 6: Total Welfare Change: No Equilibrium Adjustment



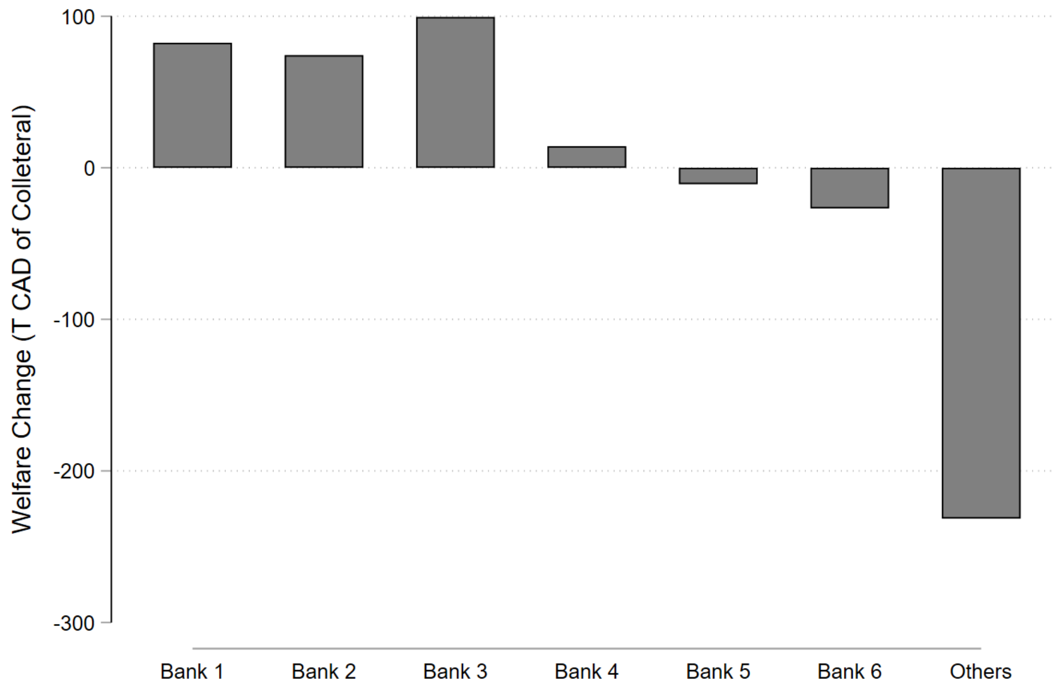
Note: Figure 6 shows the total welfare change against θ_2, the fraction of payments in LVTS migrating to Lynx. There are three lines in the graph: "Baseline" refers to the simple Lynx described in the main text; "20% Cost Reduction" is the case where we assume Lynx adopts certain liquidity saving mechanism such that its liquidity cost is overall 20% lower than the baseline simple Lynx; "100% Safety Increase" refers to the case where Lynx improves the safety indicator by 100%.

Figure 7: Total Welfare Change: With Equilibrium Adjustment



Note: Figure 7 illustrates the overall welfare changes against θ_1, which is a tuning parameter capturing the service level improvement of Lynx.

Figure 8: Welfare Change: Heterogeneity Across Banks



Note: Figure 8 shows the heterogeneous welfare changes across participants for a given level of the tuning parameter capturing the service quality of Lynx, i.e., $\theta_1 = 1.75$, at which the overall welfare change is 0.