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CBDC in the Market for Payments at the Point of Sale: Equilibrium Impact and Incumbent Responses

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Abstract

We investigate the introduction of a central bank digital currency (CBDC) into the market for payments. Focusing on the point of sale, we develop and estimate a structural model of consumer adoption, merchant acceptance and usage decisions. We counterfactually simulate the introduction of a CBDC, considering a version with debit-like characteristics and one encompassing the best of cash and debit, and characterize outcomes for a range of potential adoption frictions. We show that, in the absence of adoption frictions, CBDC has the potential for material consumer adoption and merchant acceptance, along with moderate usage at the point of sale. However, modest adoption frictions substantially reduce outcomes along all three dimensions. Incumbent responses required to restore pre-CBDC market shares are moderate to small and further reduce the market penetration of CBDC. Overall, this implies that an introduction of CBDC into the market for payments is by no means guaranteed to be successful.

Topics: Bank notes, Digital currencies and fintech, Econometric and statistical methods, Financial services
JEL codes: C51, D12, E42, L14, L52

Résumé

Nous étudions l’introduction d’une monnaie numérique de banque centrale (MNBC) sur le marché des paiements. Nous construisons et estimons un modèle structurel axé sur les points de vente pour simuler l’adoption de la MNBC par les consommateurs, son acceptation auprès des commerçants et les décisions autour de son usage. Nous réalisons une simulation contrefactuelle de l’introduction d’une MNBC, à partir d’une version de la MNBC dotée de caractéristiques analogues à celles de la carte de débit, et d’une autre version avec des caractéristiques alliant les atouts de l’argent comptant et de la carte de débit. Nous décrivons les résultats associés à une série de frictions autour de l’adoption de la MNBC. En l’absence de telles frictions, la MNBC pourrait être largement adoptée par les consommateurs et acceptée dans les commerces, tout en faisant l’objet d’une utilisation modérée aux points de vente. Des frictions modestes à l’adoption réduisent de façon substantielle ces résultats dans les trois dimensions à l’étude. Pour les autres modes de paiement déjà en place, un retour aux parts de marché observées avant l’entrée de la MNBC nécessite des réponses d’ampleur modérée ou limitée qui font d’ailleurs baisser davantage la progression de la MNBC sur le marché. Dans l’ensemble, le succès de l’introduction de la MNBC sur le marché des paiements est loin d’être garanti.

Sujets : Billets de banque, Monnaies numériques et technologies financières, Méthodes économétriques et statistiques, Services financiers
Codes JEL : C51, D12, E42, L14, L52

1 Introduction

Many central banks are contemplating the issuence of a central bank digital currency (CBDC), either with the intent to issue it outright or as part of contingency planning in case the use of cash declines further. In Europe, preparation for a digital euro is well underway (ECB 2024b), with application calls for components totalling 1.1 billion euros issued in January 2024 (ECB 2024a). The Bank of Canada has set out conditions that could warrant consideration of issuing a CBDC, including the emergence of a cashless economy (Lane 2021).

A sizeable literature has investigated the impact of CBDC on the market for deposits, monetary policy transmission, and financial stability considerations (see, e.g., Ahnert et al. 2022, for an overview). However, an important and less well-studied aspect of a successful introduction of CBDC is its adoption and use by market participants. Success in these dimensions is not a given. For example, Abramova et al. (2022) find that Austrian residents are satisfied with existing payment options and that no clear premise exists for the adoption of a digital euro. Similarly, Henry et al. (2023) find that most Canadian consumers do not experience gaps in their access to payment methods and so might have relatively weak incentives to adopt and use CBDC at scale. Overall, it is crucial for central banks to understand the transactional demand for the use of CBDC at the point of sale (POS), which accounts for more than 80% of consumer retail purchases in Canada.[1]

Towards this understanding, we develop a structural model of the two-sided market for payments at the POS, featuring endogenous consumer adoption, merchant acceptance, and usage decisions. We estimate the model using rich survey and diary data on Canadian consumers and merchants, and counterfactually simulate the introduction of CBDC. We show that the market penetration of CBDC depends crucially on the severity of potential frictions inhibiting consumer adoption, such as information frictions or a lack of digital literacy. While CBDC has the potential for material consumer adoption and merchant acceptance along with moderate usage at the POS, even modest adoption frictions substantially reduce outcomes along all three dimensions. Further, while adoption frictions could be offset by subsidies, the associated costs to the central bank would be large. Finally, we show that CBDC does not exert substantial competitive pressure reducing prices in the market for payments. Incumbent responses required to restore pre-CBDC market shares are moderate to small and further reduce the market penetration of CBDC.

Our structural model builds on prior work in Huynh et al. (2020) and Huynh et al. (2022). We develop an equilibrium model of interactions between consumers and merchants at a physical POS. Consumers and merchants interact in two stages. In the first stage, consumers and merchants simultaneously decide which payment methods to adopt and accept, respectively. Consumers internalize the subsequent utility from using a given payment method for transactions, which depends on transaction-payment-method-specific shocks. The model takes into account a wide range of features, including consumer perceptions of different payment methods, consumer awareness of merchant acceptance practices, population demographics, and credit card rewards. Merchants, in contrast, internalize that they may lose sales if consumers who are unable to use their preferred payment method direct their shopping elsewhere.[2] In the second stage, consumers and merchants interact at the POS, with the ultimate decision of which payment method to use resting on the consumers' shoulders.

We estimate the model using rich survey and diary data on Canadian consumers and merchants (for a detailed description of the data sources, see Kosse et al. 2017; Henry et al. 2018; Welte et al. 2024). Based on our estimation results, we proceed to counterfactually simulate the introduction of a CBDC

[1] Over the last four years, the share of retail purchases made online has levelled off at around 14% in volume terms and just over 20% in value terms according to Henry et al. (2024). The trend mirrors Statistics Canada data on e-commerce retail sales as a share of total retail sales (Tables 20-10-005-01 and 20-10-0056-03), which report an even lower share.

[2] While we do not explicitly model consumers' decision on which merchants to visit, our reduced form representation of consumer–merchant interactions captures this salient feature of merchants' incentives.

into the market for payments. In doing so, we consider two types of CBDC: a CBDC that is *debit-like* in its characteristics, and one that encompasses the *best-of-cash-and-debit.* The *best-of* CBDC in particular serves to obtain an upper bound on the potential market penetration of CBDC, as it assumes that it has the best characteristics of cash—such as anonymity and universal offline capability, which are unlikely to be fully achievable in practice—and debit on an individual consumer basis. We do not take a stance on the severity of potential frictions affecting consumer adoption (such as information frictions or limited digital literacy) and instead characterize outcomes for a range of adoption frictions.

Our main findings are as follows. First, we show that a debit-like *ideal-CBDC* without adoption frictions sees widespread adoption (72% of consumers) and moderate acceptance (44% of merchants) and usage (20% of transactions). However, moderate adoption frictions of CAD 3/month reduce adoption to 19% and merchant acceptance to 16%, with usage dropping to 6%. Usage shares of a debit-like CBDC are drawn predominantly from debit and credit, with a limited impact on cash. A best-of-cash-and-debit CBDC sees more widespread adoption (78%) and acceptance (90%) in the absence of adoption frictions, but retains a moderate usage for around 25% of transactions. Outcomes again are substantially reduced with even modest adoption frictions. In line with its more cash-like features, usage shares are drawn more heavily from cash in addition to debit.

Importantly, a successful CBDC in the sense of widespread adoption and usage is associated with a "disintermediation in the payments space": that is, a sizeable drop in merchant acceptance of existing digital means of payment. This is driven by the relative undesirability of credit cards for merchants due to their high cost. As a result, even moderate CBDC usage is sufficient to affect the relative profitability of payment bundles such that traditional digital means of payment are no longer accepted. However, this presumes that incumbent players in the market for payments do not respond to the introduction of a CBDC.

Analyzing such a potential response, we find that moderate responses are sufficient to restore pre-CBDC market shares. Even an *ideal-CBDC* encompassing the best features of cash and debit requires incumbent players to reduce costs for credit by less than 10% and costs for debit by less than 3%. Responses are even lower for a debit-like CBDC (less than 6% and 1%, respectively) and become negligible as adoption frictions increase. Moreover, they further inhibit the market penetration of CBDC.

Overall, we conclude that the introduction of a CBDC into the market for payments is by no means guaranteed to be successful. If it entails significant adoption frictions or does not include compelling features, it would have little effect on market outcomes. Moreover, if it were successful given present market conditions, it would invite a strategic response by incumbents that would hinder the market penetration of CBDC without substantial price reduction benefits for traditional means of payment.

Related literature We build on prior work in Huynh et al. (2020) and Huynh et al. (2022). As in Huynh et al. (2020), we are interested in the impact of CBDC on the equilibrium in the market for payments at the POS. However, we answer this question in a modified multi-sided market framework based on the model in Huynh et al. (2022), which endogenizes merchants' acceptance decisions.[3] Specifically, we substantially extend the model and analysis by incorporating additional features that are relevant in the market for payments and in particular for the introduction of a new product in the form of CBDC.[4]

Closely related is concurrent work by Nocciola and Zamora-Pérez (2024), who also estimate the transactional demand for CBDC. They estimate an explicit adoption model by consumers using data on their adoption of mobile payments. Like us, they allow for heterogeneous consumer preferences for various attributes of payment methods and consider different types of CBDC. However, in contrast to

[3]As a consequence, the description of the data (Section 2), model (Section 3), estimation procedure (Section 4), and estimation results (Section 5) share many similarities with the corresponding sections in Huynh et al. (2022).

[4]We also incorporate the relevant features from Huynh et al. (2020). We present a summary of the commonalities and differences in Appendix A.

their work, we consider a multi-sided market with endogenous merchant acceptance decisions and consider the response by incumbent players in the market for payments. Moreover, we do not aim to quantify the adoption frictions directly, but instead characterize outcomes for a range of potential frictions.

More broadly, our paper contributes to the literature on the market for payments, see Bedre-Defolie and Calvano (2013) and Edelman and Wright (2015) for seminal theoretical contributions. Early empirical work on payments includes Gowrisankaran and Stavins (2004) and Rysman (2007). More recently, Carbo-Valverde et al. (2012) and Bounie et al. (2016) estimate empirical models of payment markets using survey data on both the consumer and merchant sides of the market. Higgins (2020) and Crouzet et al. (2023) study payment technology adoption using shocks to the adoption of financial technology over time and space. In line with our findings, Camera et al. (2016) provide experimental evidence that consumers are the pivotal agents for the diffusion of technological innovations in the payments space.

Closely related to our work is the contribution by Koulayev et al. (2016). However, while the consumer side of our model is similar to theirs, we model and estimate equilibrium decisions by both sides of the market. Concurrent work by Wang (2024) considers the welfare impact of different regulatory approaches in the United States. Despite substantial differences in the underlying assumptions and modelling strategies, the findings are broadly in line with those of Huynh et al. (2022).

Several other works focus on the impact of CBDC on the market for deposits instead of the transactional demand arising from usage at the POS. Among these are Li (2023), who, like us, finds that responses by incumbents are able to substantially constrain the success of CBDC, and Gross and Letizia (2023). The potential adoption of CBDC current and savings accounts is the subject of Bijlsma et al. (2024), who identify the interest rate paid on CBDC deposits as a crucial driver.

Related to the focus on the market for deposits is a sizeable literature investigating potential bank disintermediation and financial stability considerations (for an overview, see Ahnert et al. 2022). Comparable to the mechanism identified in Chiu et al. (2023), we show that disintermediation in the market for payments at the POS needs to be considered as a potential impact of the introduction of CBDC. Finally, there is a substantial literature investigating the potential for monetary policy transmission using CBDC (see, e.g., Davoodalhosseini 2022).

Structure of the paper We proceed by first outlining the data used and presenting relevant summary statistics.[5] Second, we set up the model used to estimate consumer and merchant preferences based on the existing market for payments. Third, we present baseline results. Fourth, we discuss our counterfactual analyses regarding the introduction of a CBDC and present results. We also discuss the robustness of our findings. We conclude our analysis with an assessment of potential responses by incumbents in the market for payments and their impact.

2 Consumer and Merchant Payment Data

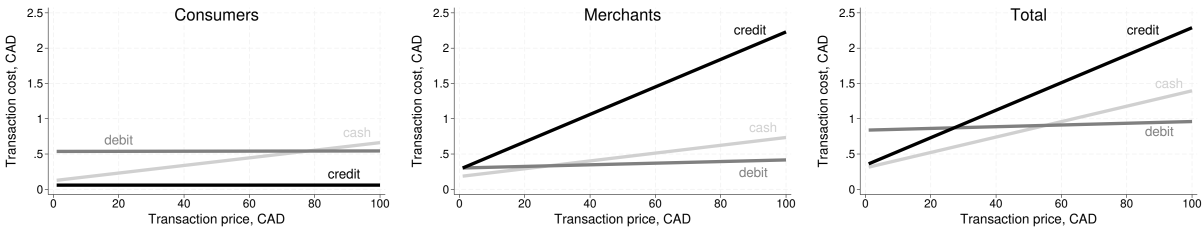
We use data from both consumer- and merchant-side surveys developed by the Bank of Canada. The consumer survey is the 2017 Methods-of-Payment (MOP) Survey (see Henry et al. 2018, for details), which comprises two components. The first is a survey questionnaire, which contains information on individuals' demographics and payment card ownership. The second component is a diary, in which respondents report all of the transactions they make over a three-day period. The diary also asks questions about several key characteristics of these transactions, including the type of store at which they were made, the payment method used to complete them, and their value. The merchant-side survey used is the Bank of Canada's 2015 Retailer Survey on the Cost of Payment Methods (RSCPM; for details see

[5]This essentially replicates the corresponding section in Huynh et al. (2022) but reflects the more recent data used on the consumer side (directly) and the merchant side (indirectly via calibration).

Kosse et al. 2017), which includes questions about perceptions of payment method costs and benefits, payment method acceptance, and revenue and fees broken down by payment method. To account for technological advances, we also leverage insights about merchant acceptance practices from the 2023 Merchant Acceptance Survey (MAS; see Welte et al. 2024, for details).

Usage cost functions. Our data analysis suggests that consumers and merchants view payment methods very differently in terms of their usage costs. Figure 1, which is based on results from Kosse et al. (2017), can be used to rank consumers' and merchants' average usage costs for a given transaction size.[6] Most noteworthy, for all price points, consumers find credit cards the least costly, while merchants find them the most costly. Further, both consumers and merchants find cash cheaper than debit cards for smaller transactions but more costly for larger transactions. The total cost for both sides of the market is

Figure 1: Transaction costs: Consumers (left), merchants (middle), and total (right), 2014



Notes: Average transaction costs are defined as linear functions of prices, with the intercepts and slopes for each payment instrument estimated in Kosse et al. (2017) (Figure 13 on p. 38).

obtained by adding the consumer and merchant cost functions for each price. The right-hand panel of Figure 1 shows that in 2014, credit cards were never the cheapest payment option. For relatively low transaction values, cash was the cheapest choice; and for prices above 60 dollars, debit cards had the lowest total cost.

Adoption and acceptance decisions. For profit-maximizing merchants, accepting payment instruments that are more expensive clearly reduces their per-transaction profits. However, the acceptance may also trigger extra sales to new consumers who are attracted by such an acceptance choice, and thus it may generate additional profits.[7] With this in mind, we proceed to the discussion of consumer adoption and merchant acceptance choices. Summary statistics for various combinations of payment instruments for each side of the market are shown in Table 1. Note that the table also shows the acceptance frequencies derived from the 2023 MAS. This is because they contain moments we target to capture technological advances between 2014 and 2023 as outlined when presenting estimation results in Section 5. In 2017, consumers almost always (98% of consumers) had a payment card of some kind, with 83% owning both a debit card and a credit card. On the merchant side, about one-fifth of merchants accepted only cash, while 70% accepted both types of cards. This suggests that while merchants could often expect consumers to carry a payment card, a consumer would not always have been able to use their preferred card. This pattern is attenuated somewhat in 2023, where merchant acceptance practices reflect an increased acceptance of debit and credit cards. Nonetheless, close to 8% of merchants remain "cash only" and do not accept any digital means of payment.

Consumer demographics and perceptions. In the data, we observe consumers' demographic variables, their banking information, and a set of transactions they completed over a three-day period.

[6]In our model, consumers have the same usage cost functions up to a random innovation at the POS, while the expected usage cost functions for merchants also vary by province.

[7]The trade-off between these opposing effects is also a recurrent narrative in the in-depth interviews conducted with merchants as part of the Merchant Acceptance Surveys.

Table 1: Summary of consumer adoption and merchant acceptance decisions

Variable	Consumers (2017)		Merchants (2014)		Merchants (2023)	
	Frequency	Percent	Frequency	Percent	Frequency	Percent
Cash only	16	0.78	162	22.10	66	7.85
Cash and debit	178	8.64	31	4.23	17	2.02
Cash and credit	68	3.30	24	3.27	8	0.95
All methods	1,798	87.28	516	70.40	750	89.18
Total	2,060	100.00	733	100.00	841	100.00

Notes: In estimation, we do not allow for the cash-and-credit-only combination, and we re-code this combination as if consumers (merchants) adopt (accept) all instruments. This is motivated by the fact that in practical terms "cash-and-credit-only" is unlikely to be a sensible answer on either the consumer side—consumers who have a credit card also have a bank account and thus access to a debit card—or the merchant side—a terminal capable of handling credit transactions can also handle debit transactions.

The consumer-level data are summarized in Table 2. In the empirical model, we use the demographic variables to control for heterogeneity in consumer preferences for the adoption and usage of various payment instruments at the POS. Notably, we also account for whether credit cards yield rewards and whether consumers are revolvers—that is, maintain a positive balance on their credit card instead of fully paying it off every month. The latter is true for about one-quarter of the consumers in our sample. Both variables are statistically significant in explaining consumer usages at the POS.[8]

Table 2: Summary statistics for consumer-level variables

Variable	Mean	Median	Minimum	Maximum	SD
Age in years	48.45	49.00	18.00	99.00	17.29
Income in CAD	73,930	55,000	12,500	202,500	53,822
Education (1 = some university)	0.50	1.00	0.00	1.00	0.50
Credit score	746.44	790.33	419.83	881.67	128.67
Urban	0.86	1.00	0.00	1.00	0.34
Female	0.50	0.00	0.00	1.00	0.50
Married	0.51	1.00	0.00	1.00	0.50
Credit card rewards	0.76	1.00	0.00	1.00	0.43
Credit card revolver	0.23	0.00	0.00	1.00	0.42
Number of transactions	4.66	4.00	1.00	19.00	2.76
Transaction price	33.68	20.00	0.10	300.00	41.73

Notes: SD stands for "standard deviation." Credit scores are imputed by using a nearest neighbour estimator (based on the reported banking information and demographics) and the TransUnion credit registry; there are six levels for education, ranging from some public school (level 1) to a completed graduate degree (level 6), which we re-code into a binary variable taking the value of 1 if some university education has been obtained. Transactions are measured by number within a three-day diary period.

In addition to their demographics, survey participants also report their perceptions of merchant acceptance at the POS as well as the perceived ease of use, security, and affordability (expected cost of use) for each payment instrument. These variables are measured on either a four- or five-point Likert scale and are reported in Table 3, with higher values associated with higher or better characteristics. Electronic payment methods—debit and credit cards—are typically ranked lower than cash, along any dimension. When comparing debit and credit cards, we find that on average consumers rate debit cards slightly higher than credit cards, with a notable difference in the affordability dimension. Consumers perceive cash to be the most widely accepted payment method—in line with the empirical evidence—and to be associated with the lowest setup cost.

Transaction-level data. Consumers recorded all of their transactions for a three-day period, providing information on the price, transaction type (e.g., groceries, gasoline), and payment method choice at

[8] Both variables are newly included relative to Huynh et al. (2022). They have been shown to be important in explaining consumer behaviour in prior work focusing only on the consumer side, see Huynh et al. (2020).

Table 3: Summary statistics for perception variables

Characteristic	Method	Mean	Median	Minimum	Maximum	SD
Ease of use	Cash	4.57	5.00	1.00	5.00	0.80
	Debit	4.33	5.00	1.00	5.00	0.85
	Credit	4.35	5.00	1.00	5.00	0.82
Affordability	Cash	4.53	5.00	1.00	5.00	0.84
	Debit	3.93	4.00	1.00	5.00	1.00
	Credit	3.50	4.00	1.00	5.00	1.24
Security	Cash	4.17	4.00	1.00	5.00	1.01
	Debit	3.97	4.00	1.00	5.00	0.85
	Credit	3.95	4.00	1.00	5.00	0.87
Acceptance	Cash	3.93	4.00	1.00	4.00	0.36
	Debit	3.81	4.00	1.00	4.00	0.51
	Credit	3.71	4.00	1.00	4.00	0.63
Setup cost	Cash	4.57	5.00	1.00	5.00	0.80
	Debit	4.33	5.00	1.00	5.00	0.85
	Credit	4.28	5.00	1.00	5.00	0.92

Notes: SD stands for "standard deviation." In estimation, we normalize all perception variables using the formula $X_m = \hat{X}_m / \left(\hat{X}_{ca} + \hat{X}_{dc} + \hat{X}_{cc}\right)$*, where* $\hat{X}_m$ *denotes the consumer rating on a four- or five-point Likert scale (with larger values denoting higher characteristics).*

the POS (e.g., cash, debit, or credit). Table 4 shows the frequency of use for each payment instrument by transaction type. On average, credit cards were the most common method of payment (41% of transactions), followed by cash (34%) and debit cards (25%). Credit cards are even more heavily used for gasoline, personal attire, and durable goods, while cash is disproportionately used to pay for professional services, travel/parking, and entertainment and meals.

Table 4: Summary statistics for the transaction types and prices at point of sale

Transaction type	Frequency of use			Prices		
	Cash	Debit	Credit	Mean	Median	SD
Groceries/drugs	0.30	0.28	0.42	36.29	20.96	43.50
Gasoline	0.13	0.27	0.60	42.54	40.00	24.29
Personal attire	0.20	0.23	0.58	54.01	39.70	49.00
Health care	0.25	0.24	0.51	50.63	34.45	55.53
Hobby/sporting goods	0.37	0.21	0.42	36.52	21.37	45.10
Professional/personal services	0.45	0.13	0.42	55.03	33.90	53.84
Travel/parking	0.47	0.10	0.42	23.92	10.00	40.73
Entertainment/meals	0.43	0.24	0.33	19.64	10.57	27.81
Durable goods	0.22	0.20	0.58	54.95	33.98	58.69
Other	0.47	0.21	0.32	30.85	15.00	42.76
Average	0.34	0.25	0.41	33.68	20.00	41.62

Notes: SD stands for "standard deviation." The number of observations is 12,029. Our sample includes transactions completed at the point of sale only and, hence, may represent the lower tail of the distribution of consumer expenditures.

Consumer awareness. An important feature of our framework is that we allow for consumer uncertainty regarding whether a merchant will accept their card payment or not. Towards this, we leverage information on whether consumers have visited a store before (i.e., whether a given purchase is a "repeat visit"), which we associate with knowledge of the given merchant's acceptance practices. Thus, the relative proportion of repeat customers versus consumers making one-time purchases ("tourists" in the terminology of Rochet and Tirole (2003)), in the overall population of consumers, affects merchants' incentives to accept alternative combinations of payment instruments. We observe whether a given purchase is a repeat visit in the diary data and summarize it by transaction type in Table 5.

Table 5: Consumer awareness, probability of repeat visits, 2017

	Age, years		Income, '000		Gender		University		Price, CAD	
Transaction type	≤ 25	> 25	< 65	≥ 65	Male	Female	No	Yes	< 100	≥ 100
Groceries/drugs	0.96	0.98	0.98	0.97	0.98	0.97	0.98	0.97	0.98	0.97
Gasoline	0.96	0.96	0.96	0.96	0.96	0.96	0.96	0.95	0.96	0.95
Personal attire	0.93	0.92	0.92	0.92	0.92	0.92	0.93	0.92	0.92	0.92
Health care	0.86	0.92	0.92	0.91	0.91	0.92	0.93	0.90	0.93	0.85
Hobby/sporting goods	0.90	0.91	0.92	0.91	0.91	0.91	0.92	0.90	0.91	0.91
Professional/personal services	0.85	0.86	0.87	0.85	0.86	0.86	0.88	0.84	0.87	0.83
Travel/parking	0.90	0.90	0.91	0.89	0.89	0.91	0.91	0.89	0.91	0.86
Entertainment/meals	0.91	0.93	0.93	0.92	0.93	0.92	0.94	0.91	0.92	0.90
Durable goods	0.92	0.93	0.93	0.93	0.94	0.93	0.94	0.93	0.93	0.93
Other	0.94	0.94	0.94	0.93	0.94	0.93	0.95	0.93	0.94	0.93

Notes: The values represent frequencies of consumers' reported return visits to stores by transaction type, age, income, gender, education level, and transaction price.

To operationalize the data, we estimate a probit model of the likelihood of a purchase being a repeat visit on a vector of demographics variables, transaction values, debit card ownership, number of registers at the POS, time of day, and transaction type. We then use the estimated model to predict the probability of a visit being a repeat visit and use these probabilities as the likelihood that a given transaction is a repeat visit.[9]

Merchant-side data. On the merchant side, we observe revenue, acceptance, and cost information for 733 merchants. The majority of these businesses are small enterprises with fewer than 50 employees. In general, our analysis focuses on small and medium-sized enterprises (SMEs). Aside from data availability considerations, the lack of market power of SMEs validates the price-taking assumption (see Section 3)—that is, that merchants do not adjust transaction prices in response to their payment choice. In other words, transaction prices are exogenously given for the purpose of our analysis. This is in line with evidence found by Higgins (2020) in Mexico. The distribution of merchants by size is summarized in Table 6.

Table 6: Distribution of merchant by revenue

	Revenue, thousands of CAD							Total
	50	175	375	625	875	3,000	7,500	
Number	149	114	124	72	58	182	34	733
Percent	20.33	15.55	16.92	9.82	7.91	24.83	4.64	100
Cumulative	20.33	35.88	52.8	62.62	70.53	95.36	100	

Notes: The data description can be found in Kosse et al. (2017)

Usage cost data for merchants is obtained from Kosse et al. (2017). Average costs are reported in Figure 1. In the estimation, we allow merchant usage costs to vary by province. Hence, the merchants in our model differ with respect to their size and usage costs. This two-dimensional heterogeneity enables us to identify the distribution of merchant acceptance costs and profit margin parameters.

3 Model

We develop an equilibrium model of interactions between consumers and merchants at a physical POS. The model aims to capture the following key features. First, both consumers and merchants make optimal adoption decisions conditional on their expectations about future transactions at the POS. Second, and towards this, consumers internalize that their utility from using a given payment method for a given transaction depends on the realization of transaction-payment-method-specific shocks. Third, merchants

[9] For details, see Appendix B.

internalize that they may lose sales when consumers who are unable to use their preferred payment method direct their shopping elsewhere. Finally, consumers often know ex ante about which payment methods merchants accept because they have visited the merchant before. While this accounts for the bulk of transactions—see Table 5—there are also transactions for which consumers are uninformed.

In our model, consumers and merchants interact in two stages. In the first stage, they simultaneously decide which payment methods to adopt (consumers) and accept (merchants). In the second stage, consumers and merchants interact at the POS. In what follows, we first describe the set of available payment methods, followed by the players'—consumers and merchants—utility functions. We then describe how they interact. Note that we do not explicitly model consumers' decisions about which merchants to visit. Nonetheless, our reduced-form way of representing these interactions aims to capture the features described above. Our approach allows us to capture the key features of the interaction between the decisions consumers and merchants make about adoption and acceptance, respectively, as well as consumers' decisions about usage at the POS. We conclude the model setup by deriving the implications for the maximization problems of consumers and merchants and defining the equilibrium.

3.1 Available Payment Methods

Merchants and consumers interact for day-to-day transactions. These transactions can be made using one of three means of payment: (1) cash, ca; (2) a debit card, dc; or (3) a credit card, cc.

Let $\mathcal{M} = \big(\{ca\}, \{ca, dc\}, \{ca, dc, cc\}\big)$ denote the set of possible adoption or acceptance decisions available to consumers and merchants, where cash is always included. Cash therefore plays the role of the default payment method in which any transaction can always be conducted, irrespective of consumers' adoption decisions and merchants' acceptance decisions. This default is required by the model, and the choice of cash is motivated by its status as the most widely accepted payment method (see Welte et al. 2024).[10] We exclude the combination $\{ca, cc\}$ from the choice set; while our model could easily incorporate this option, this restriction is motivated by the observation that consumers who have a credit card also have a debit card.[11]

3.2 Consumers

Consumers are indexed by $b = 1, \ldots, N_b$. We assume that they have inelastic demand for an exogenously given set of transactions, denoted $\mathcal{J}_b$.

Assumption 1: *Every consumer, b, is endowed with a set of transactions, $\mathcal{J}_b$ with cardinality J_b, all of which must be completed. The number of transactions J_b is exogenously given, and consumers have an inelastic demand for each transaction/good.*

Given that our focus is on the choice of payment methods at the POS, Assumption 1 reflects that the utility from the choice of payment method does not meaningfully alter the choice of which goods to consume in the first place. Treating the consumption pattern as exogenous allows us to focus on the adoption and choice of payment methods. Consumers in our sample conduct between 1 and 19 transactions over the three-day period covered by the diary data, with an average of 4.66 transactions.

[10] In 2023, only 4% of merchants did not accept cash and were therefore excluded from our sample.

[11] For consumers, credit card balances must be paid, and the routine use of cash for this purpose is cumbersome. On the merchant side, given that the cost of processing credit card transactions is strictly higher than the cost for debit cards, it seems unreasonable to combine cash with a more expensive payment instrument such as a credit card while not accepting a debit card. In the data, only 5% of consumers and 3% of merchants report cash and credit combination. We reclassify consumers and merchants who report the $\{ca, cc\}$ combination as those adopting/accepting all means of payment: that is, $\{ca, dc, cc\}$.

We allow for consumers to be differentiated according to their demographic characteristics, denoted D_b, which encompass income, age, gender, education level, marital status, urbanization status, and credit score.

First-stage decision. In the first stage, each consumer b simultaneously and independently chooses a bundle of payment instruments, $\mathcal{M}_b \in \mathcal{M}$. The decision of which payment methods to adopt depends on consumers' expectations about the future utility derived from using these payment methods at the POS in the second stage.

Second-stage utility. For each transaction j, consumer b derives utility U_{bjm} from completing it using payment method $m \in \mathcal{M}_b$. We assume that this usage utility depends on the consumer's demographics, D_b, the transaction type T_{bj}, the consumer's perception of the payment method characteristics denoted X_{bm}, transactions costs $C_{bm}(p_{bj})$, which depend on the transaction price p_{bj}, and a random usage innovation denoted ϵ_{bjm}. For credit cards, the usage utility additionally depends on whether consumer b is a revolver, and whether consumer b receives rewards when using a credit card. Specifically, we assume

$$U_{bjm} = X_{bm}\beta + \alpha\, C_{bm}(p_{bj}) + \xi_m(D_b, T_{bj}) + \epsilon_{bjm}, \tag{1}$$

where β is a vector of the marginal utilities (and where $(\mathbb{1}_{m=cc}Rev_b, \mathbb{1}_{m=cc}Rew_b) \in X_{bm}$ allows us to account for revolver status and credit card rewards), α is the marginal (dis)utility from the transaction costs, and $\xi_m(D_b, T_{bj})$ is a method-specific fixed effect that is related to the demographics and the transaction type. We discuss each element of the utility function (1) below.

The perception variables, X_{bm}, refer to the consumer's rating of the ease of use, security, and affordability of each method of payment, m. These variables—see Table 3 for an overview—vary across consumers and payment instruments but are constant across the transactions of the same consumer.

When completing their transactions at the POS, consumers incur transaction costs. These costs depend on both the number of transactions and their prices. In particular, we assume that the cost of conducting transaction j by consumer b using method m is

$$C_{bm}(p_{bj}) = c_{0bm} + c_{1bm}p_{bj}, \tag{2}$$

where c_{0bm} and c_{1bm} are, respectively, the per-transaction and per-value costs estimated from Kosse et al. (2017); see Figure 1. The price variable has subscripts b and j because different consumers can purchase different quantities and qualities of the same good.

It is conceivable that in addition to the observed consumer perceptions and transaction costs, other factors determine consumer usage of payment instruments at the POS. For example, a debit account with a limited number of free transactions can reduce consumer incentives to use their debit card for daily purchases. To account for these factors, we include a set of method-specific fixed effects as a function of consumer demographics and transaction type, $\xi_m(D_b, T_{bj})$. These method-specific fixed effects can be interpreted as a "match value" between a consumer, payment method, and transaction type, which increases or decreases consumer utility and, hence, the incentives to use alternative payment instruments. These unobserved match values are important because they generate correlation in decisions of the same consumer as well as in decisions of similar consumers.

3.3 Merchants

Merchants are indexed by $s = 1, \ldots, N_s$. They sell a variety of products to consumers. Note that the merchants we observe in our sample are small and medium-sized and compete only in their local markets.

We therefore do not explicitly model large merchants (e.g., Costco, Loblaws, Sobeys, Walmart), which compete across multiple markets.

To facilitate the empirical implementation, we assume that all merchants sell all products recorded by consumers in our sample and that they are price-takers in the real product markets. Moreover, we assume that all merchants earn a constant profit margin, γ, on any transaction j with any consumer b. This pins down the relationship between the transaction price p_{bj} and the marginal cost of production mc_{sbj}.

Assumption 2: *Every merchant s sells all products recorded by consumers in our sample, behaves as a price-taker in the output market, and earns a constant profit margin, $\gamma = \gamma_{sbj} \equiv \dfrac{p_{bj} - mc_{sbj}}{p_{bj}}$, for all s, b, j.*

The price-taking assumption is motivated by the presence of (unmodelled) large retailers, which render the small- and medium-sized merchants' local markets contestable. It implies that any change in the merchants' cost structure vis-à-vis payment instruments will not be passed through to product prices facing consumers and instead will be absorbed by merchants' profit margins. Together with the inelastic consumption demand by consumers (see Assumption 1), Assumption 2 implies that we can treat the transaction prices observed in the data as exogenously given for the purpose of our analysis.

The assumption that merchants sell all products recorded by consumers in our sample may at first glance appear less innocuous. It is highly likely that some merchants in our sample do not offer the full variety of products, and instead even sell products that are not reported by consumers in our sample. We nonetheless make this assumption because it allows us to treat local markets as identical up to their size, as we describe in detail in Section 3.4, which improves computational tractability. It can be replaced by a weaker assumption that requires that any errors are non-systematic: that is, that our sample of consumers is representative of any given merchant's market.

First-stage decision and second-stage payoffs. In the first stage, each merchant s chooses a bundle of payment instruments, $\mathcal{M}_s \in \mathcal{M}$, to accept. If a transaction j at price p_{bj} is completed in the second stage using payment method m, the merchant earns utility

$$U_{sjm} = \gamma p_{bj} - C_{sm}(p_{bj}), \tag{3}$$

where γp_{bj} reflects the constant profit margin earned (see Assumption 2) and

$$C_{sm}(p_{bj}) = c_{0sm} + c_{1sm} p_{bj} \tag{4}$$

is the cost of payment method m to complete transaction (b, j). Similar to consumers, costs for merchants are decomposed into a per-transaction cost, c_{0sm}, and a per-value cost, c_{1sm}.[12]

3.4 Consumer Awareness and Matching

Our model abstracts from explicitly modelling consumers' decisions of which merchants to visit and which goods to purchase. Instead, we employ a reduced-form way of capturing the key features of the payment method adoption and usage choices described previously.

[12] A mean-zero random innovation (realized at the POS) can be added to Equation (4) such that it would not affect merchants' acceptance choice. This is because the linear merchant usage cost function, $C_{sm}(p_{bj})$, enters the profit function determining the first-stage decision in expectation only.

Awareness and second-stage choice. We decompose consumers' transactions into *informed* and *uninformed* transactions.

Assumption 3: *For each consumer b and each transaction $j \in \mathcal{J}_b$, the consumer is exogenously aware, $I_{bj} = 1$, or unaware, $I_{bj} = 0$. Consumers have a weak preference to complete transactions in their local market.*

In our empirical implementation, we treat each transaction in which a consumer and merchant have transacted previously as an informed transaction so that consumers are aware. In terms of interpretation, informed transactions could be considered planned or repeat trips, while uninformed transactions could be considered random or one-time purchases.

For informed transactions (i.e., whenever $I_{bj} = 1$), we assume that the consumer is able to complete the transaction at a merchant that accepts their preferred means of payment.[13] Given that consumers, all else equal, prefer to shop locally, this implies that any informed transaction will be conducted at a local merchant only if that merchant accepts the consumer's preferred payment method.[14] In contrast, for uninformed transactions (i.e., whenever $I_{bj} = 0$), we assume that the consumer is randomly matched with a merchant and has to complete the transaction using the subset of payment methods that they adopted *and* that is accepted by the merchant.

Formally, we denote the probability that consumer b chooses payment method m for transaction j when the choice set of available payment methods is $\tilde{\mathcal{M}}$ by

$$\mathcal{P}^*_{bjm}(\tilde{\mathcal{M}}) = \Pr\left(m = \arg\max_{m' \in \tilde{\mathcal{M}}} U_{bjm'}\right). \tag{5}$$

Given our awareness assumption, any aware transaction can always be completed with the consumer's preferred payment instrument: that is, the consumer's set of available payment methods is $\tilde{\mathcal{M}} = \mathcal{M}_b$. In contrast, for unaware transactions, consumers are randomly matched with a merchant s and need to choose a payment method that they have adopted and that is accepted by the merchant, $\tilde{\mathcal{M}} = \mathcal{M}_b \cap \mathcal{M}_s$. To account for this in their adoption decision, they rationally anticipate the average probability that a merchant will accept $\mathcal{M}_s$, denoted by $\bar{P}_{\mathcal{M}_s}$.

Overall, the probability that a consumer uses method m, given that their adopted set of payment methods is $\mathcal{M}_b$, is given by

$$P_{bjm}(\mathcal{M}_b) = I_{bj}\mathcal{P}^*_{bjm}(\mathcal{M}_b) + (1 - I_{bj}) \sum_{\mathcal{M}_s \in \mathcal{M}} \bar{P}_{\mathcal{M}_s} \times \mathcal{P}^*_{bjm}(\mathcal{M}_b \cap \mathcal{M}_s). \tag{6}$$

Note that we explore modifications to the above characterization of the consumer–merchant interactions in Section 6.5. We are motivated by the introduction of a new payment method that may disrupt the market for payments and reduce equilibrium acceptance of individual payment methods below the observed widespread acceptance. Specifically, we consider an extension in which consumers can no longer costlessly find a merchant that accepts their preferred payment method, but instead incur a cost inversely related to the equilibrium acceptance. While we are unable to identify this transport cost using our available data—due to the high acceptance levels for each payment option—we are able to assess the differences for given levels of a transport cost friction and show the implications when merchant acceptance is less

[13]Strictly speaking, our interpretation of a repeat visit implies that a consumer re-visits a store only if it has both their desired product and their preferred payment method.

[14]The preference itself can, for example, be rationalized by consumers incurring vanishingly small travel costs whenever they visit a large retailer. In terms of timing, the notion that informed transactions are conducted using the consumers' preferred payment method strictly speaking implies that consumers look at their wallet *prior* to deciding where to shop. Specifically, they observe the realizations of their transaction-specific utility innovations to identify their preferred payment method and make the decision about which store to visit based on this knowledge.

widespread.

Consumers' first-stage choice. In the first stage, consumers do not yet know their stage-two usage innovations, ϵ_{bjm}. They form expectations of their utility from each transaction, which depends on their adoption choice, $\mathcal{M}_b$. It follows that the total utility a consumer expects in the second stage, given adoption choice $\mathcal{M}_b$, is the sum of the per-transaction expected utilities over all the transactions in the set, $\mathcal{J}_b$: that is,

$$EU_b(\mathcal{M}_b) = \sum_{j \in \mathcal{J}_b} \mathbb{E}_\epsilon \left[I_{bj} \max_{m \in \mathcal{M}_b} U_{bjm} + (1 - I_{bj}) \sum_{\mathcal{M}_s \in \mathcal{M}} \bar{P}_{\mathcal{M}_s} \max_{m \in \mathcal{M}_b \cap \mathcal{M}_s} U_{bjm} \right]. \tag{7}$$

Let $F_{b,\mathcal{M}_b}$ denote the fixed cost of adopting payment combination $\mathcal{M}_b$.[15] We specify the fixed costs to have the form $F_{b,\mathcal{M}_b} = Z_b \; f^b_{\mathcal{M}_b} + \varepsilon_{b,\mathcal{M}_b}$, where Z_b is a vector of explanatory variables; $\varepsilon_{b,\mathcal{M}_b}$ is a cost innovation that is realized at the time of adoption; and $f^b_{\mathcal{M}_b}$ is a parameter. Consumers choose the bundle $\mathcal{M}_b$ such that the total utility minus the fixed cost is maximized. The probability that bundle $\mathcal{M}_b$ is adopted is

$$P_{b,\mathcal{M}_b} = \Pr\left(\mathcal{M}_b = \operatorname*{arg\,max}_{\mathcal{M}'_b \in \mathcal{M}} \left\{ EU_b(\mathcal{M}'_b) - F_{b,\mathcal{M}'_b} \right\} \right). \tag{8}$$

Merchants' second-stage payoffs. Given the representativeness of our consumer sample for each merchant (see Assumption 2), we first derive the expected utility for a merchant that encounters a market size exactly equal to our consumer sample. We then show how we account for variation in merchant market size (i.e., revenues).

Given Assumption 3 and our representation of how awareness impacts consumers, a merchant will be able to transact with an *informed* consumer for a given transaction, (b, j), only if the merchant accepts the consumer's preferred payment method. Denote by

$$\pi_{sbjm} = \gamma p_{bj} - C_{bm}(p_{pj}) \tag{9}$$

the potential profits from a transction j with consumer b using payment method m. By not adopting a given payment method, the merchant loses sales and thus potential profits, π_{sbjm}, whenever the consumer's preferred payment method m is not contained in the merchant's acceptance set (i.e., whenever $m \notin \mathcal{M}_s$). In contrast, they will always earn $\pi_{sbjm'}$ when the transaction is uninformed as consumers complete it with the merchant by choosing a payment method m' from $\mathcal{M}_b \cap \mathcal{M}_s$.

Taking as given the adoption probabilities by consumers, $P_{b,\mathcal{M}_b}$, this implies that the expected profit $E\pi^i_{sbj}(\mathcal{M}_s)$ from an informed transaction is

$$E\pi^i_{sbj}(\mathcal{M}_s) = \sum_{\mathcal{M}_b \in \mathcal{M}} P_{b,\mathcal{M}_b} \times \sum_{m \in \mathcal{M}_s} \mathcal{P}^*_{bjm}(\mathcal{M}_b) \big[\gamma p_{bj} - C_{bm}(p_{bj}) \big], \tag{10}$$

whereas the expected profit $E\pi^u_{sbj}(\mathcal{M}_s)$ from an uninformed transaction is[16]

$$E\pi^u_{sbj}(\mathcal{M}_s) = \sum_{\mathcal{M}_b \in \mathcal{M}} P_{b,\mathcal{M}_b} \times \sum_{m \in \mathcal{M}_s} \mathcal{P}^*_{bjm}(\mathcal{M}_b \cap \mathcal{M}_s) \big[\gamma p_{bj} - C_{bm}(p_{bj}) \big]. \tag{11}$$

Given Equations (10) and (11), and the awareness status I_{bj}, the merchant's expected aggregate profits

[15]While we refer to $F_{b,\mathcal{M}_b}$ as a "cost," we do not impose any non-negativity constraint and thus allow for potential benefits from adoption.

[16]Note that this does not simplify to $\gamma p_{bj} - C_{bm}(p_{bj})$ because the costs to the merchant C_{bm} depend on the payment method so that the probability with which consumers adopt and choose from a given bundle $\mathcal{M}_b$ matters for the overall profit of the merchant, even if the weights sum up to 1.

$E\Pi_s$ from accepting payment methods $\mathcal{M}_s \in \mathcal{M}$ can be expressed as

$$\text{E}\Pi_s(\mathcal{M}_s) = S_s \times \sum_{b=1}^{N_b} \sum_{j \in \mathcal{J}_b} I_{bj} E\pi^i_{sbj}(\mathcal{M}_s) + (1 - I_{bj}) E\pi^u_{sbj}(\mathcal{M}_s), \tag{12}$$

where S_s is the market size available to a merchant.

Market size. In the data, merchants are heterogeneous with respect to the acceptance combination they choose, revenue, and location, where the latter determines usage costs for each payment instrument at the province level. We define a market facing a merchant in terms of our consumer sample size. To do this, we calculate the total revenue that can be generated by our sample of consumers in terms of total prices paid given the observed merchant acceptance decision and compare this value with the one reported by the merchant.

Formally, let $\hat{R}_{s,\mathcal{M}_s}$ denote the revenue of the merchant with acceptance combination $\mathcal{M}_s$, who has a market size that is exactly equal to our consumer sample and let $m^*_{bj} \in \{ca, dc, cc\}$ denote the (observed) realizations of consumer usage decisions at the POS. Then,

$$\hat{R}_{s,\mathcal{M}_s} = \sum_{b=1}^{N_b} \sum_{j \in \mathcal{J}_b} \left[(1 - I_{bj}) + I_{bj} \times \sum_{m \in \mathcal{M}_s} \mathbb{1}\{m^*_{bj} = m\} \right] \times p_{bj}, \tag{13}$$

which predicts the revenues generated by all the consumers in our sample as a function of the acceptance combination $\mathcal{M}_s$. We observe merchants' revenues and acceptance decisions from the data. Let $R_{s,\mathcal{M}_s}$ denote merchant s's revenues for a combination $\mathcal{M}_s$ observed in the data, and define the market size available to a merchant as

$$S_s = \frac{R_{s,\mathcal{M}_s}}{\hat{R}_{s,\mathcal{M}_s}}. \tag{14}$$

Equation (14) relates the sum of the prices paid by the consumers in our sample to the merchants' revenue and acceptance decisions. For example, a merchant whose revenues are twice as large as the revenue generated by our sample of consumers (i.e., $R_{s,\mathcal{M}_s} = 2 \times \hat{R}_{s,\mathcal{M}_s}$) would sell to a market of size $S_s = 2$.

Note that while the market size is defined at the realized acceptance choice, Equation (13) can be used to predict the counterfactual merchant revenues for all feasible choices of $\mathcal{M}_s \in \mathcal{M}$. In other words, we define S_s according to the factual and use this estimate in the calculation of the counterfactual merchant choices in the same market: that is, $R_{s,\tilde{\mathcal{M}}_s} = S_s \times \hat{R}_{s,\tilde{\mathcal{M}}_s}$ for any $\tilde{\mathcal{M}}_s \in \mathcal{M}$.

Merchants' first-stage choice. Analogous to the consumers, the acceptance of $\mathcal{M}_s$ comes with fixed cost $F_{s,\mathcal{M}_s} = Z_s f^s_{\mathcal{M}_s} + \omega_{s,\mathcal{M}_s}$, where Z_s is a vector of the explanatory variables, $\omega_{s,\mathcal{M}_s}$ is a cost innovation that is realized at the time of acceptance, and $f^s_{\mathcal{M}_s}$ is a parameter vector. Merchants choose the bundle $\mathcal{M}_s$, which maximizes profits. The probability that a given $\mathcal{M}_s$ is optimal is given by

$$P_{s,\mathcal{M}_s} = \Pr\left(\mathcal{M}_s = \underset{\mathcal{M}'_s \in \mathcal{M}}{\arg\max} \left\{ \text{E}\Pi_s(\mathcal{M}'_s) - F_{s,\mathcal{M}'_s} \right\} \right). \tag{15}$$

The key determinant of a merchant's decision about which payment methods to accept is the potential for lost sales as a result of not being able to sell to informed consumers whose preferred payment method they do not accept.

3.5 Equilibrium

Illustration. Figure 2 provides a graphical illustration of the two-stage game played in each period. At the beginning of each period, consumers and merchants simultaneously and independently make adoption and acceptance decisions. After all decisions are made, the usage stage begins and consumers are matched with merchants for every transaction until all transactions of all consumers are completed. The matching process depends on consumer awareness being exogenously attached to every transaction. In particular, consumers who are conducting informed transactions visit only those merchants who accept the payment instruments these consumers prefer. Conversely, this implies that merchants lose out on potential profits from selling to informed consumers whose preferred payment method they do not accept.

Figure 2: Two-stage model of interactions between merchants and consumers

Consumer adoption		Merchant acceptance: **ca-only**	**ca, dc**	**ca, dc, cc**
ca-only	Informed	{ca}	{ca}	{ca}
	Uninformed	{ca}	{ca}	{ca}
ca, dc	Informed	{ca, **dc**}	{ca, dc}	{ca, dc}
	Uninformed	{ca}	{ca, dc}	{ca, dc}
ca, dc, cc	Informed	{ca, **dc, cc**}	{ca, dc, **cc**}	{ca, dc, cc}
	Uninformed	{ca}	{ca, dc}	{ca, dc, cc}

Notes: The table lists consumer choice sets for any merchant acceptance and consumer adoption pair, distinguished by whether the consumer is informed or uninformed. ca, dc and cc stand for cash, debit card, and credit card, respectively; red font indicates missing sales for a merchant with a given acceptance choice.

For uninformed transactions, consumers are randomly matched with merchants. Random matching does not guarantee that a merchant will always accept the payment method chosen by a consumer (unless it is cash).

Equilibrium concept. Our equilibrium concept is a subgame perfect Nash equilibrium. In what follows, we assume that the set of transactions, $\mathcal{J}_b$, the parameters of the consumers' transaction cost function (2), (c_{0bm}, c_{1bm}), and the distribution parameters of the consumers' adoption costs, $F_{b,\mathcal{M}_b'}$, for all consumer types, $b = 1, \ldots, N_b$, all payment instruments, $m \in \{ca, dc, cc\}$, and all adoption combinations, $\mathcal{M}_b \in \mathcal{M}$, are common knowledge. Similarly, the parameters of the merchant-transaction cost function (4), (c_{0sm}, c_{1sm}), $m \in \{ca, dc, cc\}$, market size, S_s, and parameters of the distribution of acceptance cost, $F_{s,\mathcal{M}_s}$, for all $s, \mathcal{M}_s \in \mathcal{M}$, are also common knowledge.

At the beginning of each period, consumers privately observe realizations of the random innovations to their adoption cost and choose $\mathcal{M}_b$. Simultaneously, merchants privately observe realizations of the acceptance cost innovations and choose $\mathcal{M}_s$. In the first stage, neither consumers nor merchants observe realizations of the second-stage (usage) innovations to the consumer utility function (1). Therefore, both sides form expectations with respect to ϵ_{bjm}, for which the distribution is known up to a parameter vector.

To make the optimal adoption decision, consumers form expectations about the merchant acceptance probabilities,

$$\bar{P}_{\mathcal{M}_s} = \frac{1}{N_s} \sum_{s=1}^{N_s} P_{s,\mathcal{M}_s}, \ \forall \quad \mathcal{M}_s \in \mathcal{M}, \tag{16}$$

which are then used to calculate the total expected utility (7) for each possible combination of payment instruments, $\mathcal{M}_b \in \mathcal{M}$. A solution to the first-stage consumer utility maximization problem is given by a vector of adoption probabilities, $\mathbb{P}_b = \left(P_{b,\{ca\}}, P_{b,\{ca,dc\}}, P_{b,\{ca,dc,cc\}}\right)$, with the elements that are defined in Equation (8). We denote the mapping from the distribution of the merchant acceptance probabilities to the optimal consumer adoption probability as the following best response function:

$$\mathbb{P}_b = BR_b\left(\{\mathbb{P}_s\}_{s=1}^{N_s}\right), \ \forall \quad b, \tag{17}$$

where $\mathbb{P}_s = \left(P_{s,\{ca\}}, P_{s,\{ca,dc\}}, P_{s,\{ca,dc,cc\}}\right)$ contains each merchant's acceptance probabilities.

As merchants know the parameters of the consumer utility function, they can evaluate (i) consumers' optimal choices, as in Equation (5); (ii) the per-transaction expected profits from informed and uninformed transactions, as in Equations (10) and (11); and (iii) the expected profits for every acceptance combination, which are provided in Equation (12). The optimal merchant acceptance probabilities are then defined by Equation (15). Let us denote the mapping from the distribution of the consumer adoption probabilities to the optimal merchant acceptance decisions, $\mathbb{P}_s$, as the best response function

$$\mathbb{P}_s = BR_s\left(\{\mathbb{P}_b\}_{b=1}^{N_b}\right), \forall \quad s. \tag{18}$$

We define the equilibrium in terms of vectors $\mathbb{P}_s^*$ and $\mathbb{P}_b^*$ for all s, b, such that $\mathbb{P}_b^*$ solves (17), given $\mathbb{P}_s^*$, and $\mathbb{P}_s^*$ solves (18), given $\mathbb{P}_b^*$. Given the adoption and acceptance probabilities, the vector of equilibrium usage probabilities is given by

$$P_{bjm}^* = \sum_{\mathcal{M}_b \in \mathcal{M}} P_{b,\mathcal{M}_b}^* \times P_{bjm}(\mathcal{M}_b), \tag{19}$$

where $P_{b,\mathcal{M}_b}^* \in \mathbb{P}_b^*$ is the first-stage optimal adoption combination; $P_{bjm}(\mathcal{M}_b)$ is defined by Equation (6) and depends on the transaction information status as well as the consumer adoption and merchant acceptance choices.

4 Specifications and Estimation

There are three layers of agents' decision making in our model: consumers choose which methods of payment to adopt and then use, while merchants choose which payment methods to accept. Given a vector of parameter values, our model generates probabilistic predictions for each of these choices. We use joint likelihood as a criterion function to match the model predictions to the observed consumer and merchant choices. This section defines the likelihood, describes the various distributional assumptions required, and outlines the algorithm used to obtain the estimates for the structural parameters. Notably, in the estimation we do not impose any assumptions on the behaviour of debit and credit cards issuers and acquirers, and we consider the fee structure in this market as given.[17] For simplicity, we assume that consumers always have enough cash to complete any desired transactions. Similarly, whenever consumers prefer to make debit transactions, we assume they always have a sufficient balance.

[17] Insights into the acquiring market in Canada are provided by Welte and Molnar (2020), while Ho et al. (2020) study the monopoly pricing of the Chinese payment card network.

Consumer adoption costs. We assume that the vector of consumer adoption costs, given by $\left(F_{b,\{ca\}}, F_{b,\{ca,dc\}}, F_{b,\{ca,dc,cc\}}\right)$, can be written as

$$\begin{cases} F_{b,\{ca\}} & = \varepsilon_{b,\{ca\}}, \\ F_{b,\{ca,dc\}} & = Z_b \ f^b_{\{ca,dc\}} + \varepsilon_{b,\{ca,dc\}}, \\ F_{b,\{ca,dc,cc\}} & = Z_b \ f^b_{\{ca,dc,cc\}} + \varepsilon_{b,\{ca,dc,cc\}}, \end{cases}$$

where the mean adoption cost for the cash-only combination is normalized to zero, $f^b_{\{ca,dc\}}$ and $f^b_{\{ca,dc,cc\}}$ are vectors of the parameters, and $\varepsilon_b = \left(\varepsilon_{b,\{ca\}}, \varepsilon_{b,\{ca,dc\}}, \varepsilon_{b,\{ca,dc,cc\}}\right)$ is a vector of the random innovations that are realized at the time of adoption. The vector Z_b includes the observed demographic variables. We also include additional variables such as consumer credit scores, as well as characteristics of the consumer-transaction endowment, $\mathcal{J}_b$, such as the number and total value of transactions. These variables affect consumer adoption decisions but not consumer usage decisions and, therefore, satisfy the exclusion restrictions for separate identification of the parameters in the first- and second-stage consumer decisions.[18]

Merchant acceptance costs. On the merchant side, we assume that the vector of acceptance costs $\left(F_{s,\{ca\}}, F_{s,\{ca,dc\}}, F_{s,\{ca,dc,cc\}}\right)$ can be written as

$$\begin{cases} F_{s,\{ca\}} & = \omega_{s,\{ca\}}, \\ F_{s,\{ca,dc\}} & = f^s_{0,\{ca,dc\}} + f^s_{1,\{ca,dc\}} S_s + \omega_{s,\{ca,dc\}}, \\ F_{s,\{ca,dc,cc\}} & = f^s_{0,\{ca,dc,cc\}} + f^s_{1,\{ca,dc,cc\}} S_s + \omega_{s,\{ca,dc,cc\}}, \end{cases}$$

where the mean acceptance cost for the cash-only combination is normalized to zero; $f^s_{0,\{ca,dc\}}$ and $f^s_{0,\{ca,dc,cc\}}$ are constant-acceptance-cost parameters; $f^s_{1,\{ca,dc\}}$ and $f^s_{1,\{ca,dc,cc\}}$ linearly relate the acceptance costs and market size; and $\omega_s = \left(\omega_{s,\{ca\}}, \omega_{s,\{ca,dc\}}, \omega_{s,\{ca,dc,cc\}}\right)$ is a vector of the choice-specific innovations at the POS.

To estimate the model parameters, we use the maximum likelihood approach and assume that the following are given by independent and identically distributed random draws from a standard Gumbel distribution: the vector of random innovations to consumer adoption costs in the first stage $\epsilon_b = \left(\epsilon_{b,\{ca\}}, \epsilon_{b,\{ca,dc\}}, \epsilon_{b,\{ca,dc,cc\}}\right)$; the vector of consumer usage cost innovations at the POS $\epsilon_{bj} = \left(\epsilon_{b,j,ca}, \epsilon_{b,j,dc}, \epsilon_{b,j,cc}\right)$; and the vector of merchant acceptance cost innovations, $\omega_s = \left(\omega_{s,\{ca\}}, \omega_{s,\{ca,dc\}}, \omega_{s,\{ca,dc,cc\}}\right)$.

With this, we obtain functional forms for the usage probabilities, expected utilities, and adoption and acceptance probabilities. In particular, using properties of the Gumbel distribution, we can rewrite the probability of using m, given a generic choice set $\tilde{\mathcal{M}}$ in Equation (5), as

$$\mathcal{P}^*_{bjm}(\tilde{\mathcal{M}}) = \frac{\exp(X_{bm}\beta + \alpha C_{bm}(p_{bj}) + \xi_m(D_b, T_j))}{\sum_{m' \in \tilde{\mathcal{M}}} \exp(X_{bm}\beta + \alpha C_{bm}(p_{bj}) + \xi_m(D_b, T_j))}.$$

Similarly, the expected per-transaction utilities summed up in Equation (7) can be written as

$$\mathbb{E}_\epsilon \left[\max_{m \in \tilde{\mathcal{M}}} \{U_{bjm}\} \right] = \ln \left(\sum_{m \in \tilde{\mathcal{M}}} \exp\left(X_{bm}\beta + \alpha C_{bm}(p_{bj}) + \xi_m(D_b, T_j)\right) \right) + c,$$

[18] Importantly, explicit exclusion restrictions are not necessary in our model because these decisions are modelled structurally. However, we believe that these additional variables are important for consumer adoption choice and, therefore, use them to facilitate identification. We discuss this further in Subsection 4.1.

where $c \approx 0.5772$ is the Euler constant. The probability a consumer adopts bundle $\mathcal{M}_b$ in Equation (8) is

$$P_{b,\mathcal{M}_b} = \frac{\exp(EU_b(\mathcal{M}_b) - F_{b,\mathcal{M}_b})}{\sum_{\mathcal{M}'_b \in \mathcal{M}} \exp(EU_b(\mathcal{M}'_b) - F_{b,\mathcal{M}'_b})}.$$

Finally, the probability a merchant accepts bundle $\mathcal{M}_s$ in Equation (15) becomes

$$P_{s,\mathcal{M}_s} = \frac{\exp(\mathrm{E}\Pi_s(\mathcal{M}_s) - F_{s,\mathcal{M}_s})}{\sum_{\mathcal{M}'_s \in \mathcal{M}} \exp(\mathrm{E}\Pi_s(\mathcal{M}'_s) - F_{s,\mathcal{M}'_s})}.$$

To conduct robustness checks, we also use alternative assumptions on the distribution of the merchant acceptance cost innovations.

We categorize the structural parameters of the model into (1) first-stage consumer adoption cost parameters, θ_1^b; (2) second-stage consumer usage utility parameters, θ_2^b; and (3) first-stage merchant acceptance cost parameters, θ_1^s, where

$$\theta_1^b = \left(f^b_{\{ca,dc\}},\ f^b_{\{ca,dc,cc\}}\right),\ \theta_2^b = (\beta,\ \alpha,\ \boldsymbol{\xi}),$$
$$\theta_1^s = \left(\gamma,\ f^s_{0,\{ca,dc\}},\ f^s_{0,\{ca,dc,cc\}},\ f^s_{1,\{ca,dc\}},\ f^s_{1,\{ca,dc,cc\}}\right).$$

We observe realizations of the adoption, acceptance, and usage decisions in the data. Let $A_{b,\mathcal{M}_b} \in \{0,1\}$ for all b, and $\mathcal{M}_b$ denote the observed realizations of consumer adoption decisions; let $A_{s,\mathcal{M}_s} \in \{0,1\}$ for all s, and $\mathcal{M}_s$ denote the realizations of merchant acceptance choices; and let $a_{bjm} \in \{0,1\}$ denote the observed realizations of usage decisions that take place at the POS. Note that $\sum_{\mathcal{M}'_b \in \mathcal{M}} A_{b,\mathcal{M}'_b} = \sum_{\mathcal{M}'_s \in \mathcal{M}} A_{s,\mathcal{M}'_s} = \sum_{m \in \{ca,dc,cc\}} a_{bjm} = 1$ for all b, s, j.

To estimate the structural parameters in the model, we use the following likelihood function:

$$\mathcal{L}(\theta_1^b, \theta_2^b, \theta_1^s) = \prod_{b=1}^{N_b} \prod_{\mathcal{M}_b \in \mathcal{M}} P^{*\ A_{b,\mathcal{M}_b}}_{b,\mathcal{M}_b} \times \prod_{b=1}^{N_b} \prod_{j \in \mathcal{J}_b} \prod_{m \in \{ca,dc,cc\}} P^{*\ a_{bjm}}_{bjm} \times \prod_{s=1}^{N_s} \prod_{\mathcal{M}_s \in \mathcal{M}} P^{*\ A_{s,\mathcal{M}_s}}_{s,\mathcal{M}_s}, \tag{20}$$

where $P^*_{b,\mathcal{M}_b} \in \mathbb{P}^*_b$, $P^*_{s,\mathcal{M}_s} \in \mathbb{P}^*_s$, and P^*_{bjm} $\forall b, j, m$ are the equilibrium adoption, acceptance, and conditional usage probabilities, respectively.[19]

We estimate the model, including the large number of fixed effects—216, to be specific—by using a non-linear optimization technique. This approach differs from the approach used in Huynh et al. (2022), which used an approach developed by Carranza and Navarro (2010) to concentrate out the fixed effects conditional on the remaining structural parameters.

4.1 Identification

While our model makes strong distributional assumptions that help identification, the identification is predominantly data-driven. Specifically, the separate identification of the first- and second-stage parameters for consumers is established in two ways. First, consumers have heterogeneous transaction endowments, $\mathcal{J}_b$'s; that is, they differ in the number and types of transactions as well as in the distribution of the transaction prices. Therefore, these heterogeneous consumer endowments represent "shifters" of the first-stage decisions only. Accordingly, individual second-stage usage decisions do not depend on the total number or the types of the other transactions in the consumer endowment. Hence, even without the variables being explicitly included in the first-stage specifications, our model structure provides implicit

[19] Note that merchant acceptance practices are accounted for in the definition of P^*_{bjm}, see Equation (19). Using joint estimation provides additional identification power due to the fact that consumer and merchant choices are interdependent. Therefore, consumer-side data provides additional information on the merchant-side parameters and vice versa.

exclusion restrictions via a summation over the elements of the set $\mathcal{J}_b$ as in the definition of the expected consumer utility in Equation (7). Second, we use the variables that satisfy the exclusion restrictions: that is, the variables that are excluded from the second stage but are relevant for the adoption stage, such as the credit scores and the self-reported perceptions of merchants' acceptance decisions. In our most flexible specification, we also use the parameters of $\mathcal{J}_b$, such as the total number and value of transactions.

The distribution of merchant acceptance costs can be nonparametrically identified if we know the merchants' profit margins, γ_s. In this case, we can assign a cardinal measure to the profits of the cash-only merchants, and the variations in the market size and the merchant costs would identify the distribution of the acceptance costs (see Matzkin 1992, Theorem 1 on p. 244). However, we do not observe profit margins. Instead, we estimate them. Therefore, identification of the merchant acceptance costs and the profit margin rely on the constant-margin assumption 2 and parametric restrictions (10) and (11).

5 Estimation Results

In this section, we discuss the estimates obtained. The main results are summarized in Table 7, which contains results for both the first (adoption) and second (usage) stage on the consumer side along with the first stage (acceptance) of the merchant side. Where applicable, we contrast the results from the hybrid model provided in this paper (third column) to those introduced in Huynh et al. (2020) (DPS, first column) and Huynh et al. (2022) (2SM, second column).

5.1 Consumer Preferences

Adoption stage. We begin with a discussion of the adoption cost parameters. To convert the adoption cost coefficients to dollar values, we divide them by the coefficient of the transaction costs and multiply by ten to pro-rate the value to a monthly level. Note that consumer perceptions of the ease of use and security for each payment instrument are structurally included in the consumer decision problem via the expectation of the usage stage. Therefore, a set of variables that satisfies the exclusion restrictions contains the number and value of all transactions in the consumer endowment, the perceptions of the merchants' acceptance choices, and the consumers' beliefs regarding the ease of setting up the most advanced payment option in their adoption combination.

Overall, the estimates across the three specifications paint a qualitatively comparable picture: consumers are more likely to adopt (lower fixed cost of adoption) payment bundles that they perceive to be widely accepted, easy and secure to use, and exhibiting a low setup cost.

Figure 3 illustrates the estimated distribution of consumers' fixed adoption costs for each combination of payment instruments. On average, the estimates of adoption costs for both combinations fall almost exclusively in the range of $[-10, 10]$ CAD/month. On average, the cash and debit bundle has a net adoption cost to consumers of 33c/month, while the bundle containing credit cards provides a net benefit of 72c/month. It is instructive to compare these values with the results in Huynh et al. (2022), who report average adoption benefits of 15c/month and CAD 1.18/month, respectively. The differences highlight the importance of accounting for credit card rewards and consumers' revolver status in the estimation of the usage stage utilities, which impacts the first stage estimates, as well as the improvements in estimation routines, which estimates all 216 fixed effects using a non-linear optimization technique.

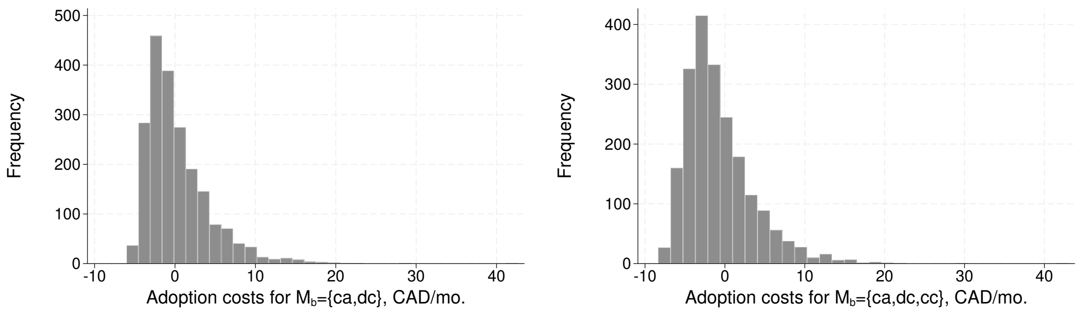
It is also important to note that the distributions are not centred around the mean. This is evidenced by the median estimates, which show that the median consumer in fact obtains a net benefit of 74c/month when adopting debit in addition to cash, and CAD 1.77/month when adopting all payment methods.

Table 7: Estimation results

Variable	DPS	(s.e.)	2SM	(s.e.)	Hybrid	(s.e.)
Consumers, stage 1 (adoption)						
$f^b_{0,\{ca,dc\}}$, constant	-1.685	(0.134)	-2.318	(0.607)	-2.051	(1.670)
$f^b_{0,\{ca,dc,cc\}}$, constant	1.450	(0.130)	-2.972	(0.575)	-2.924	(1.654)
$f^b_{age,\{ca,dc\}}$, age			0.028	(0.010)	-0.039	(0.031)
$f^b_{age,\{ca,dc,cc\}}$, age			0.001	(0.009)	-0.055	(0.030)
$f^b_{\#t,\{ca,dc\}}$, # of transactions			-0.224	(0.101)	0.029	(0.238)
$f^b_{\#t,\{ca,dc,cc\}}$, # of transactions			-0.057	(0.096)	0.159	(0.233)
$f^b_{Vt,\{ca,dc\}}$, value of transactions			0.969	(0.269)	2.527	(0.694)
$f^b_{Vt,\{ca,dc,cc\}}$, value of transactions			1.078	(0.262)	2.542	(0.691)
$f^b_{ac,\{ca,dc\}}$, perceived acceptance			-3.881	(1.536)	-2.566	(1.556)
$f^b_{ac,\{ca,dc,cc\}}$, perceived acceptance			-3.258	(0.909)	-4.988	(1.018)
$f^b_{ea,\{ca,dc\}}$, perceived ease			-5.416	(1.586)	-5.185	(11.556)
$f^b_{ea,\{ca,dc,cc\}}$, perceived ease			-5.779	(1.213)	-5.327	(1.410)
$f^b_{se,\{ca,dc\}}$, perceived security			-1.757	(0.953)	-0.970	(1.473)
$f^b_{se,\{ca,dc,cc\}}$, perceived security			-1.153	(0.806)	-0.404	(1.276)
$f^b_{sc,\{ca,dc\}}$, perceived setup cost			-4.417	(1.306)	0.968	(12.481)
$f^b_{sc,\{ca,dc,cc\}}$, perceived setup cost			-5.202	(0.778)	0.694	(1.220)
Consumers, stage 2 (usage)						
Transaction cost	-9.590	(0.005)	-7.302	(0.184)	-8.980	(0.269)
Ease of use	7.078	(0.242)	6.406	(0.348)	3.292	(0.337)
Security	1.040	(0.129)	1.053	(0.171)	2.242	(0.224)
Affordability	3.041	(0.117)	2.203	(0.133)	1.783	(0.191)
Reward (credit card only)	1.323	(0.029)	-	-	1.612	(0.077)
Revolver (credit card only)	-	-	-	-	-0.861	(0.065)
Merchants, stage 1 (acceptance)						
$f^s_{0,\{ca,dc\}}$, constant	-	-	2.196	(0.247)	2.124	(0.378)
$f^s_{0,\{ca,dc,cc\}}$, constant	-	-	0.541	(0.102)	0.644	(0.102)
$f^s_{1,\{ca,dc\}}$, size	-	-	5.190	(0.118)	5.835	(0.981)
$f^s_{1,\{ca,dc,cc\}}$, size	-	-	8.030	(0.201)	10.350	(2.580)
$\gamma = \frac{p-mc}{p}$, markup	-	-	0.052	(0.001)	0.065	(0.010)
Log-likelihood value	-	-	-12,076.62		-9,756.50	

Notes: DPS refers to Huynh et al. (2020) and 2SM refers to Huynh et al. (2022). "s.e." stands for "standard error." All specifications include consumer×transaction type×payment instrument fixed effects. Subscripts ca, dc and cc stand for cash, debit card, and credit card, respectively.

Figure 3: Expected adoption costs/benefits for $\mathcal{M}_b = \{ca, dc\}$ and $\mathcal{M}_b = \{ca, dc, cc\}$



Adoption costs/benefits	Mean	Median	Minimum	Maximum	SD
Cash and debit	0.33	-0.74	-6.03	42.59	4.08
All payment methods	-0.72	-1.77	-8.36	42.93	4.41

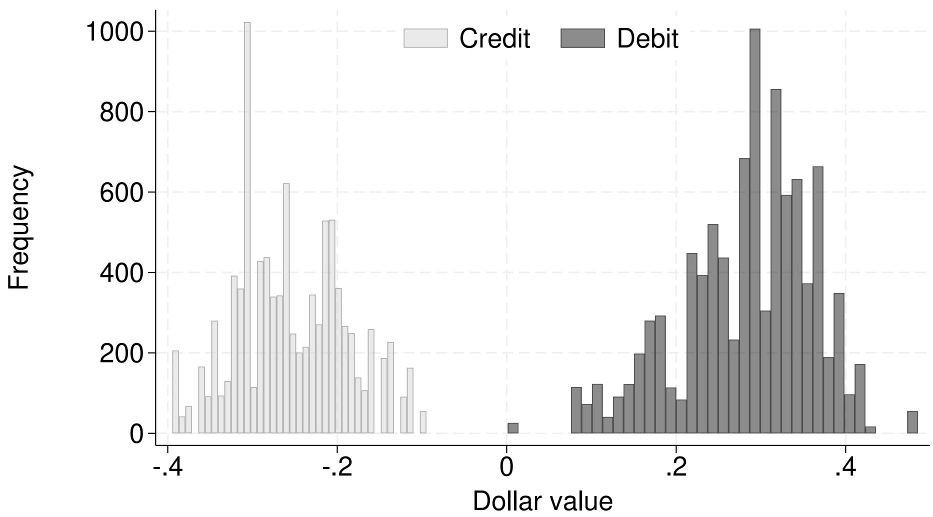
Notes: SD stands for "standard deviation." The left-hand panel is a histogram of adoption costs for the cash and debit combination, and the right-hand panel is a histogram of adoption costs for the combination including all means of payments. All values are in Canadian dollars per month.

Usage stage. Next, we discuss the consumer preference parameters in the usage stage. They include the observable characteristics of the payment methods as well as the unobserved match values between consumers' demographics, transaction type, and payment instruments. The latter are estimated as fixed effects. In the usage stage, consumers enjoy payment instruments that are easy to use, secure, and perceived as inexpensive. Our estimate of the coefficient on the actual transaction costs has a strong and statistically significant negative impact on the probability of use. Moreover, we find a significant impact of the newly included variables capturing credit card rewards and consumers' revolver status: consumers like using cards that provide them with rewards, while revolvers are less likely to use their credit cards. Both findings are intuitively sensible, and—as discussed above—have a significant impact on more tightly estimated net adoption costs and benefits in the first stage.

It is important to note that for the current results, we re-purposed the original model specification used with 2013/2014 data on both sides of the market from Huynh et al. (2022). While we re-estimated all the model parameters using 2017 data on the consumer side and 2014 data on the merchant side, we cannot guarantee that the specification itself provides the best fit of the newer data.[20] While we expect parameter estimates to be potentially different in an ideal specification, the material differences in model predictions are likely to be very small.

From Section 4, we define 108 consumer-transaction-method fixed effects for debit and credit cards, while all cash match values are normalized to zero. Hence, the estimated match values for debit and credit cards are computed relative to cash. Figure 4 illustrates histograms for the estimates reports and summary statistics. Throughout, we report values in Canadian dollars/month. We find that debit cards

Figure 4: Match values between consumers, transactions, and payment methods



Fixed effect	Mean	Median	Minimum	Maximum	SD
Debit	0.28	0.29	0.00	0.49	0.08
Credit	-0.25	-0.26	-0.39	-0.09	0.07

Notes: SD stands for "standard deviation." Match values are estimated as fixed effects. All values are in Canadian dollars.

tend to have positive match values, whereas the fixed effects for credit cards are typically negative. It is conceivable that debit cards can be easier to use (given that they have been adopted) relative to cash due to potential cash withdrawal costs. Credit card use may require overhead costs related to various fees and interest on credit card balances. Comparing our results to Huynh et al. (2022), we find that results

[20]For example, Tables 14 (p. 53) and 15 (p. 55) in Huynh et al. (2022) report robustness exercises performed while choosing the best specification for 2013 consumer data. A comparable exercise has not yet been done for the 2017 data used in the current analysis.

are qualitatively comparable.

To illustrate the main determinants of usage for alternative payment methods, we regress our estimates of debit and credit card fixed effects on a set of demographic variables. Table 8 shows the results. Results

Table 8: Consumer-transaction-method match values, dependent variable in CAD

Variable	Debit fixed effect		Credit fixed effect	
	Coefficient	(s.e.)	Coefficient	(s.e.)
Constant	0.60873***	(0.01253)	-0.37510***	(0.00716)
Age	-0.00143***	(0.00006)	-0.00098***	(0.00003)
Ln(income)	0.00117	(0.00111)	0.00491***	(0.00064)
Education	-0.05747***	(0.00179)	0.05737***	(0.00092)
Male	-0.01467***	(0.00157)	0.01361***	(0.00091)
Urban	0.00384*	(0.00222)	-0.00279**	(0.00129)
Married	0.00245	(0.00172)	-0.00067	(0.00100)
Number of transactions	0.00002	(0.00030)	-0.00036**	(0.00018)
Value of transactions	-0.00001	(0.00001)	0.00000	(0.00000)
Credit score	-0.00004***	(0.00001)	0.00001**	(0.00000)
Credit fixed effects, ξ_{cc}	0.82654***	(0.01550)	.	(.)
Debit fixed effects, ξ_{dc}	.	(.)	0.27876***	(0.00523)
Observations	9,515		9,515	
R-squared	0.437		0.580	

Notes: "s.e." stands for "standard error." The estimation method is ordinary least squares.

are broadly comparable to those in Huynh et al. (2022).[21] Consumers' utility from electronic payment instruments declines with age, and does so more steeply for debit cards. An increase in income increases the utility from using credit cards, while higher education is associated with lower utility from debit cards and higher utility from credit cards. This pattern is also on display for the credit score. Male consumers have a higher utility from using credit cards, while they rank debit cards as less attractive than cash. Overall, it is important to note that the economic magnitude of the impact of the individual factors is small, while there is a strong positive correlation between the unobserved match values for the two types of electronic payments: consumers who like to use one of these electronic payment instruments are also likely to prefer the other one relative to cash.

5.2 Merchant Parameters

On the merchant side, we estimate acceptance costs as linear functions of market size. We also recover the constant-profit-margin parameter under the assumption that it is common for all merchants. All parameter estimates are statistically significant. We estimate an average merchant profit margin of 6.5%, which is larger than the profit margin of 5.2% estimated in Huynh et al. (2022).

Table 9 summarizes the various measures of merchant profits and costs. The first column tabulates the merchant size in terms of total revenues. The second column reports the gross merchant profit, which is simply the revenue multiplied by the estimated profit margin defined in Assumption 2. From gross profits, merchants pay various banking fees (e.g., interchange fee) as well as incur their own expenses related to processing each payment instrument used at the POS. Note that these costs can be more than half of the gross profits earned. Column (3) reports the average merchant profits after all operating costs are paid off, while Column (4) computes the corresponding profit margin. Finally, merchants pay fixed acceptance fees for the combination of payment methods they choose to accept in the first stage. Column (5) summarizes the average profits net of the acceptance costs, while Column (6) indicates the net profit margin in the industry. Our estimates suggest that the net profit margin is between 1.5% and 2.6% of the transaction price, which is substantially lower than the gross profit margin. Interestingly, the

[21]The scale of the reported coefficients differs as we report results for the dependent variable in CAD to align with the

Table 9: Merchant profit measures (Canadian dollars in thousands)

Revenue, R_s	Gross as given by $\gamma \times R_s$	Net of banking fees		Net of acceptance cost	
		Profit	Margin, %	Profit	Margin, %
50	3.23	2.21	4.43	1.28	2.56
175	11.32	7.92	4.53	3.69	2.11
375	24.25	17.50	4.67	5.80	1.55
625	40.42	28.63	4.58	9.85	1.58
875	56.59	40.54	4.63	12.67	1.45
3,000	194.03	137.34	4.58	44.88	1.50
7,500	485.07	339.72	4.53	113.28	1.51
Average	85.65	60.52	4.56	20.18	1.82

Notes: For the computation of the profits net of banking fees, we subtract the model-implied usage costs on a per-transaction basis. To account for the acceptance cost, we pro-rate the model-implied fixed costs of acceptance.

average net profit margin in 2013 for non-chain retail stores in Canada for businesses with net revenues of $7.5 billion was 2.7% (Statistics Canada, Tables 20-10-0066-01 and 20-10-0068-01, Annual Retail Trade Survey), which is close to our estimates of the profit margins.[22]

The data indicate merchants' self-reported costs of operating debit and credit card terminals. Table 10 compares our estimates of acceptance costs with the terminal costs reported by merchants. The results are qualitatively sensible and largely in line with prior findings by Huynh et al. (2022). The one notable difference is that Huynh et al. (2022) found acceptance of cash and debit to be more costly than accepting all payment methods for small merchants (revenue less than CAD 175 thousand). While we have a subset of low-revenue merchants (CAD 50 thousand or less) for whom that holds true in the revised estimation, it no longer holds true on average, as evidenced by the first line of Table 10. By comparing the average

Table 10: Merchant cost measures (Canadian dollars)

Revenue (in thousands)	Total acceptance cost		Cost of terminals	
	Cash and debit	All methods	Cash and debit	All methods
50	4,973.97	5,699.17	311.76	336.18
175	9,029.33	12,892.69	90.16	409.15
375	12,127.89	18,388.99	459.36	549.61
625	17,549.55	28,006.07	300.00	518.89
875	20,392.74	33,049.39	618.21	751.59
3,000	67,485.70	116,584.12	500.00	948.88
7,500	165,064.56	289,672.08	-	1,318.67
Average	32,217.27	54,024.07	407.66	695.34

Notes: The left panel lists estimates of total acceptance costs by merchant revenue. The right panel lists merchants' self-reported costs of terminals. Note that in our data, we do not observe merchants with revenues of $7.5 million choosing cash and debit combinations.

cost of using terminals with our estimates of the overall acceptance costs, we conclude that the rental cost of terminals represents only a small proportion of the total costs. Various fees paid by the merchants to acquirers as well as their operational costs constitute the bulk of merchant expenditures related to the acceptance of electronic means of payment.

results presented in Figure 4.

[22]Recall that the stores in our sample are typically small and may be less profitable. Moreover, the difference occurs due to the fixed costs, and it is not clear whether these costs should be included in the profit margin as they do not vary with sales.

6 Counterfactual Analysis: Introduction of CBDC

6.1 Technological Advances

A key issue is that the merchant data are drawn from 2014 and that there have been significant changes in the observed acceptance rates since then. As indicated in Table 2, the number of merchants accepting electronic means of payment and in particular all methods (cash, debit, and credit) has risen significantly.

To account for the technological advances that are a potential explanatory factor for these shifts, we conduct the following exercise. Starting from the model estimates presented in Section 5, we look for the reduction in merchant acceptance costs of debit cards and credit cards, respectively, relative to the estimated costs so that the equilibrium merchant acceptance of all payment methods and the equilibrium fraction of cash-only merchants match the data observed in 2023.

Formally, we take as given the estimated merchant-specific acceptance costs estimated in the previous section, $\left(F_{s,\{ca\}}, F_{s,\{ca,dc\}}, F_{s,\{ca,dc,cc\}}\right)$, and look for parameters $t_{ca,dc}$ and $t_{ca,de,cc}$ such that the modified merchant-specific acceptance costs $\left(F_{s,\{ca\}}, t_{ca,dc} \cdot F_{s,\{ca,dc\}}, t_{ca,de,cc} \cdot F_{s,\{ca,dc,cc\}}\right)$ induce equilibrium acceptance of all payment methods of 89% and an equilibrium share of cash-only merchants of 8%.

We obtain values of $t_{ca,dc} = 0.791$ and $t_{ca,dc,cc} = 0.815$, implying that a reduction of merchant acceptance costs of 20.9% for the $\{ca, de\}$ and 18.5% for the $\{ca, dc, cc\}$ bundle are—all else equal—sufficient to match the most recently observed merchant acceptance rates.

For the remainder of our analysis, we use the equilibrium with the technological advances as the baseline setting prior to the introduction of CBDC.[23] Table 11 summarizes the equilibrium consumer adoption, merchant acceptance, and usage shares. The table illustrates a key feature that is recurrent

Table 11: Market outcomes

Adoption and acceptance by instrument

	Consumer adoption		Merchant acceptance	
Instrument	Baseline	Technological advance	Baseline	Technological advance
Cash	1.000	1.000	1.000	1.000
Debit	0.997	0.997	0.758	0.920
Credit	0.912	0.913	0.730	0.890

Equilibrium usage at point of sale (POS)

	Usage at POS		Value-weighted usage at POS	
Instrument	Baseline	Technological advance	Baseline	Technological advance
Cash	0.345	0.339	0.159	0.151
Debit	0.261	0.263	0.329	0.331
Credit	0.394	0.398	0.512	0.518
Total	1.000	1.000	1.000	1.000

throughout our analysis: market outcomes are predominantly shaped by consumers. This is particularly evidenced by the fact that both the equilibrium consumer adoption of the different payment instruments and the usage at the POS—where the ultimate choice rests with consumers—are largely unaffected, despite the sizeable uptick in merchant acceptance of debit and credit cards.

[23] Qualitative insights are not materially affected by this modification. Primarily, the reduction in merchant acceptance costs and subsequent lower cost for merchants to accept CBDC (see CBDC characteristics choices in Section 6.2) implies that CBDC sees slightly more widespread adoption, acceptance, and usage compared with the setting without accounting for technological innovation.

6.2 Introducing CBDC

The purpose of our analysis is to assess the impact of the introduction of CBDC on the market for payments at the POS. To achieve this, we simulate the introduction of CBDC by expanding the set of available bundles to include CBDC, and we allow for CBDC to be added to any of the existing bundles. This implies that both merchants and consumers choose from a set,

$$\mathcal{M}' = \big(\{ca\}, \{ca, dc\}, \{ca, dc, cc\}, \{ca, cbdc\}, \{ca, dc, cbdc\}, \{ca, dc, cc, cbdc\}\big).$$

We simulate the counterfactual outcome given the expanded choice set for consumers and merchants in terms of adoption and acceptance, and usage at the POS. Naturally, the introduction of CBDC requires us to take a stance on the characteristics of CBDC, such as the utility that consumers and merchants derive at the usage stage, and the cost of adoption and acceptance. We describe the specific choices and their motivation in detail below. Note that the analysis can conceptually account for the influence of other potential assumptions about the nature and cost of CBDC.

CBDC characteristics We consider two types of CBDC: a debit-like CBDC, and a CBDC that encompasses the best features of cash and debit. The decision to exclude credit-like characteristics derives from the fact that a CBDC is highly unlikely to offer features of credit cards, such as charge-backs or the ability to borrow. Specifically, this implies that the CBDC we consider has either debit-like ease of use, security, and perceived affordability or the consumer-specific preferred attribute drawn from either cash or debit (evaluated attribute by attribute and consumer by consumer). The latter in particular represents an ideal CBDC that is not practically achievable but that provides a useful benchmark regarding the ceiling of the market penetration of a CBDC. In line with this specification, consumers' method-specific match values at the usage stage are set to either those of debit, $\xi_{bj,cbdc} \equiv \xi_{bj,dc}$ or the maximum between cash and debit $\xi_{bj,cbdc} \equiv \max\{\xi_{bj,ca}, \xi_{bj,dc}\}$.

Consumer usage costs. For both types of CBDC, we let usage costs equal those of debit: that is, $C_{b,cbdc}(p_{bj}) = C_{b,dc}(p_{bj})$ for all consumers b and all transactions j. We make this choice because CBDC is by its nature a digital means of payment, so that existing digital means of payment are likely to serve as the best reference point. Between debit and credit, in turn, CBDC is unlikely to capture unmodelled usage credit benefits that lead to low consumer usage costs, such as zero-cost intra-month credit.

Merchant usage costs. Merchant usage costs of CBDC are similarly set to be equal to the merchant usage of debit cards estimated from the available data: that is, $C_{s,cbdc}(p_{bj}) \equiv C_{s,dc}(p_{bj})$ for transaction j by consumer b conducted at merchant m. This applies to both the debit-like CBDC and the best-of-cash-and-debit CBDC. Similar to consumers, this is motivated by the choice of an existing digital means of payment as a useful starting point, while the involvement of the central bank in the design and implementation of the CBDC system implies that costs for merchants are unlikely to be as high as those of credit card transactions.

Merchant acceptance costs. Merchant acceptance costs for CBDC are set equal to the estimated marginal fixed acceptance cost of adding credit cards to a previously accepted bundle of cash and debit, as explained in Section 5. Specifically, the marginal cost of adding CBDC to an existing bundle is given by $f_{cbdc} \equiv F_{s,\{ca,dc,cc\}} - F_{s,\{ca,dc\}}$ so that

$$\begin{aligned} F_{s,\{ca,cbdc\}} &\equiv F_{s,\{ca\}} + f_{cbdc} \\ F_{s,\{ca,dc,cbdc\}} &\equiv F_{s,\{ca,dc\}} + f_{cbdc} \\ F_{s,\{ca,dc,cc,cbdc\}} &\equiv F_{s,\{ca,dc,cc\}} + f_{cbdc}. \end{aligned} \tag{21}$$

The motivation for this choice is two-fold. First, as before, it appears reasonable to anchor costs for merchants of accepting CBDC to be chosen in relation to costs of accepting existing digital means of payment. Second, it is cheaper to accept credit in addition to cash and debit than to accept debit in addition to cash (formally, $F_{s,\{ca,dc,cc\}} - F_{s,\{ca,dc\}} < F_{s,\{ca,dc\}} - F_{s,\{ca\}}$) for all merchants in our sample. Therefore, the parameterization above anchors CBDC acceptance costs to the cheapest estimated costs of an existing digital means of payment.

Consumer adoption costs. There is no a priori indication of what the costs consumers bear when adopting a novel payment instrument such as CBDC entail. On the one hand, the public nature of CBDC as a currency issued by the central bank suggests moderate costs for consumers, which are also affected by policy decisions such as subsidies or price regulations. On the other hand, consumers are likely to face substantial non-monetary costs, encompassing considerations such as learning about CBDC or the technology, or acquiring and maintaining a digital wallet in addition to other accounts. Moreover, even on the monetary side, we need to consider actual costs faced by consumers in light of the objectives of the issuing central bank (e.g., cost recovery).

For our analysis, we therefore consider an *ideal-CBDC* as a reference point and otherwise express results with reference to adoption frictions relative to this baseline case. Specifically, we consider as the *ideal-CBDC* a CBDC that entails consumer adoption costs equal to those of adopting a debit card when moving from cash only to the $\{ca, cbdc\}$-bundle, and that entails zero additional costs when adding it to a payment mix that already encompasses digital payments. Formally, we obtain

$$\begin{aligned} F_{b,\{ca,cbdc\}} &\equiv F_{b,\{ca,dc\}} + \kappa \\ F_{b,\{ca,dc,cbdc\}} &\equiv F_{b,\{ca,dc\}} + \kappa \\ F_{b,\{ca,dc,cc,cbdc\}} &\equiv F_{b,\{ca,dc,cc\}} + \kappa, \end{aligned} \tag{22}$$

where κ is the adoption friction so that we obtain the *ideal-CBDC* case for $\kappa = 0$. Throughout, we consider values for κ that correspond to monthly CAD values between -2 and 5. This frame is motivated by the average bank account fee in Canada borne by consumers, which is about \$6/month derived from the 2023 MOP Survey (see Henry et al. 2024). Specifically, our goal is to impose a gross adjustment cost anchored to real-world costs borne by consumers while at the same time retaining the feature wherein consumers endogenously value the benefit of the CBDC and make adoption decisions based on their assessment of the net benefit.

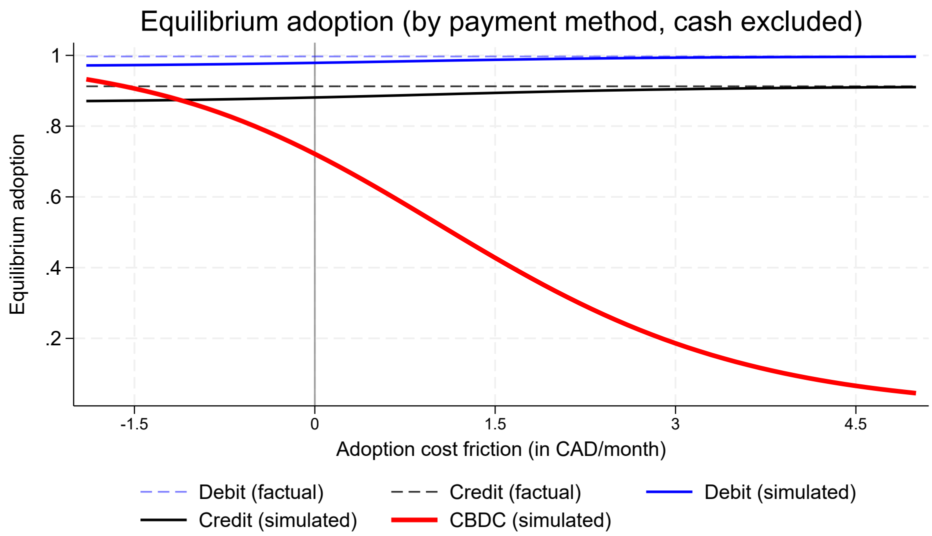
Additionally, recall that the median consumer obtains a net benefit of 74c/month when adopting cash and debit. This implies that our *ideal-CBDC* similarly provides a net benefit to the majority of consumers when adding it to the cash-only bundle.

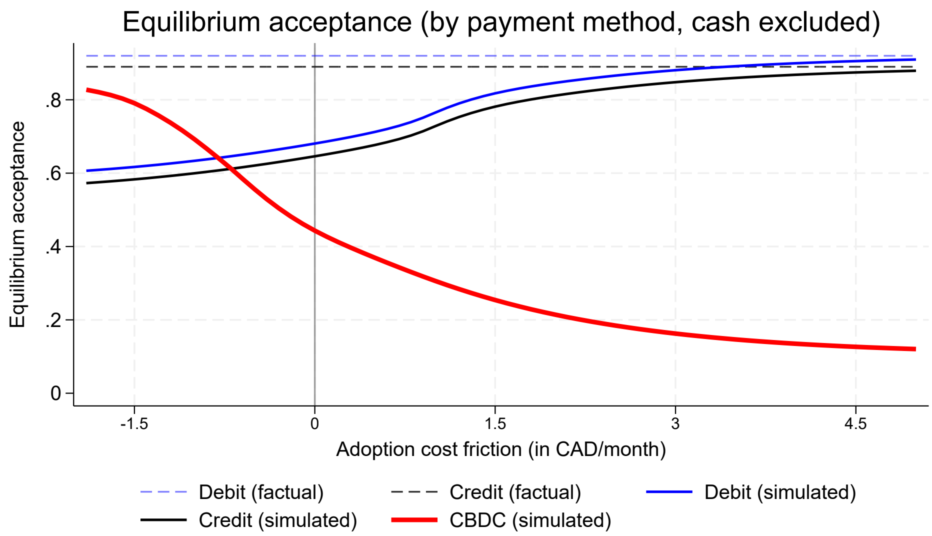
6.3 Results

In what follows, we first present results for the introduction of a debit-like CBDC. Subsequently, we discuss the introduction of a CBDC that encompasses the best of cash and debit on the consumer side.

Debit-like CBDC Figure 5 presents results regarding equilibrium adoption and acceptance by payment method. As discussed above, we consider monthly adoption cost frictions between CAD −2 and CAD 5 per month relative to the *ideal-CBDC* outlined above. The key takeaway is that when adoption frictions are

Figure 5: Adoption and acceptance by payment method (debit-like CBDC)

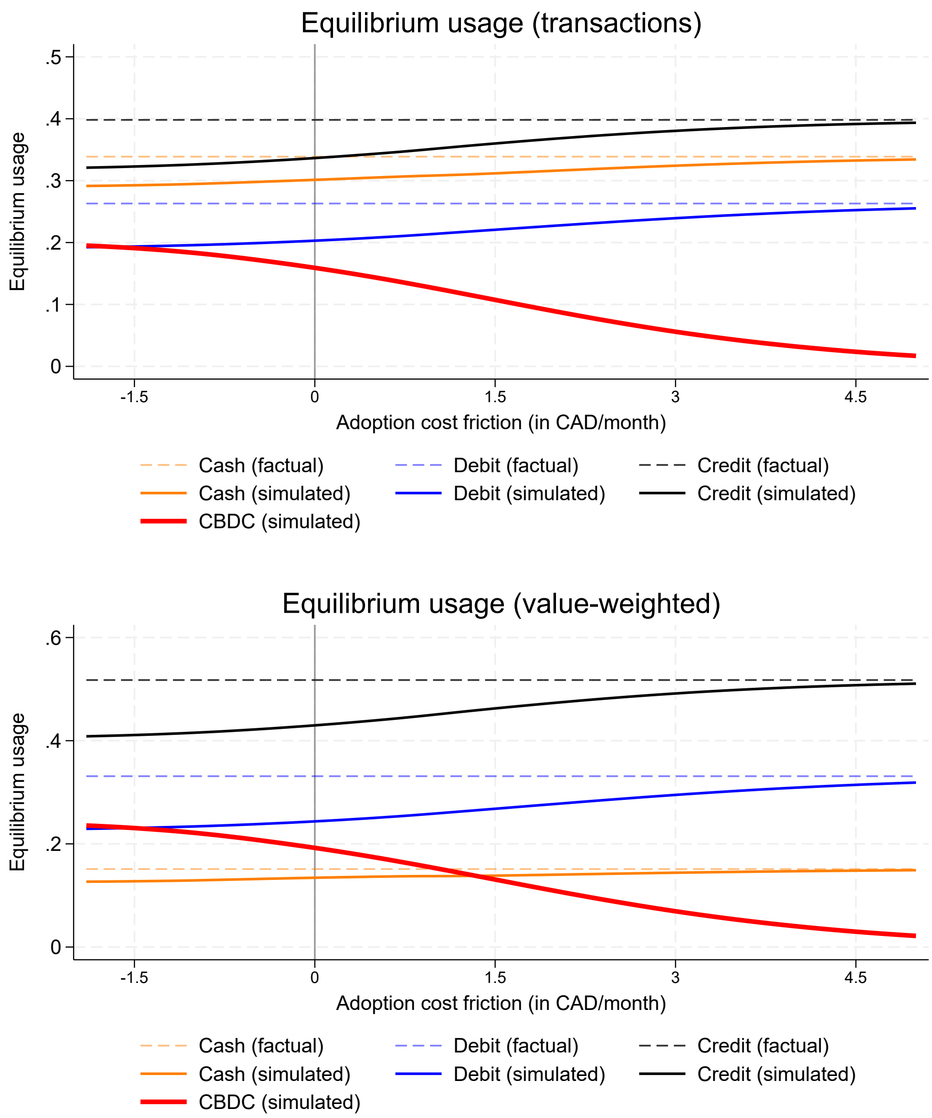




low, CBDC sees widespread adoption (around 72% of consumers adopt the *ideal-CBDC*), with adoption very sensitive to the adoption cost friction. At a moderate friction of around CAD 3/month, adoption drops to around 19%. On the merchant side, the *ideal CBDC* is accepted by around 44% of merchants, with acceptance falling to 16% at a friction of CAD 3/month.

Notably, the introduction of CBDC into the market with zero adoption frictions has a sizeable impact on merchant acceptance of debit and credit cards: acceptance falls from 92% to 68% for debit, and from 89% to 65% for credit. This corresponds to a relative drop of 26% and 27%, respectively. While the comparable impact on merchant acceptance of debit and credit may at first glance appear puzzling—as the CBDC is debit-like—it is important to bear in mind that merchant acceptance decisions reflect merchants' assessments of the relative profitability of accepting different bundles of payment instruments. The drop in credit acceptance derives from credit being a costly payment method for merchants so that even a moderate drop in usage of credit cards due to the introduction of CBDC renders it unprofitable to accept for merchants (relative to other payment bundles). For larger adoption frictions, the impact on equilibrium acceptance is much more muted, with less than a 5% reduction in acceptance at a friction of CAD 3/month. The adoption and acceptance decisions are motivated by consumers' use of the different

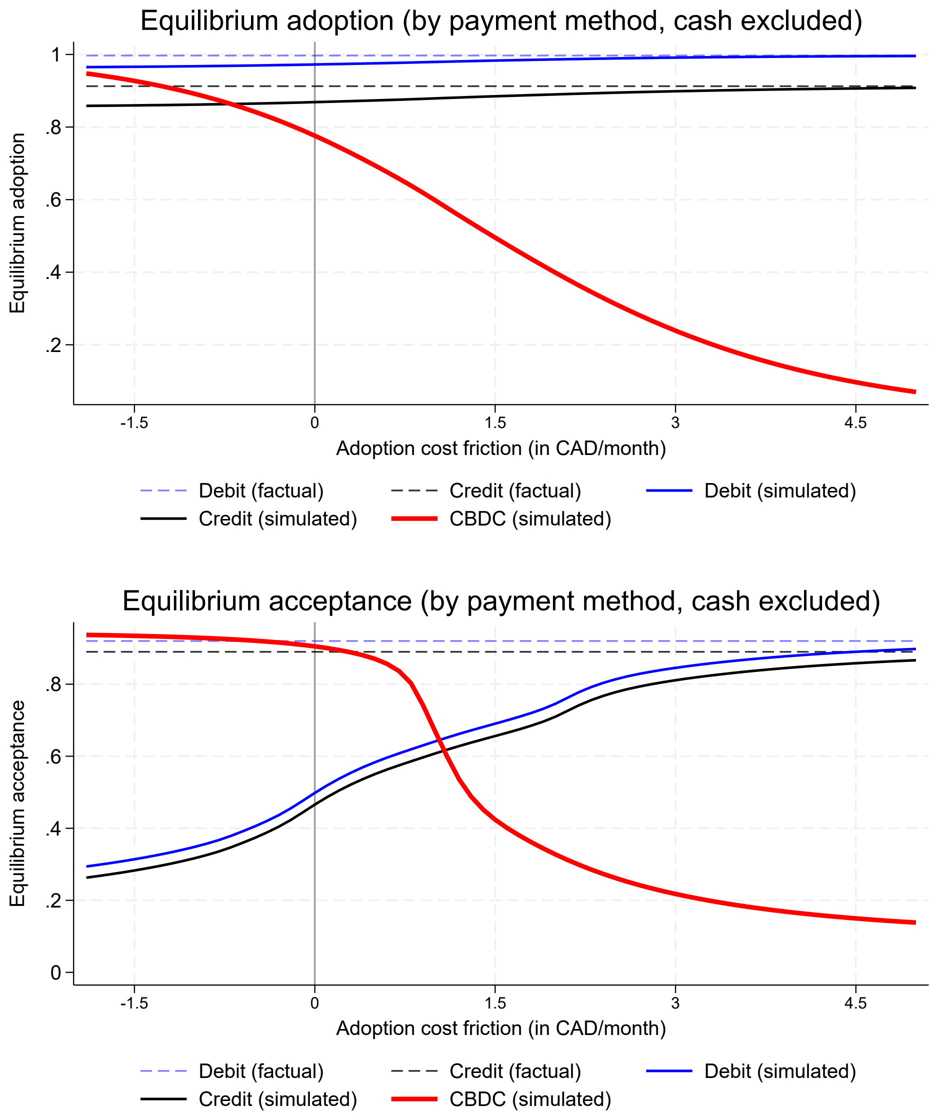
Figure 6: Usage of payment methods (debit-like CBDC)



payment instruments at the POS. Figure 6 presents equilibrium usage shares with respect to the number of transactions (top panel) and value-weighted transactions (bottom panel). The main takeaway is two-fold. First, CBDC usage caps out at around a 20% (volume) and 24% (value-weighted) market share even when adoption is heavily subsidized (indicated by negative adoption frictions). The *ideal-CBDC*—at zero adoption frictions—would garner a market share of 16% (volume; 19% value-weighted), which shrinks to 6% (7%) at an adoption friction of CAD 3/month.

Second, usage shares also provide insights with respect to what drives merchant acceptance decisions. The usage shares of CBDC are drawn predominantly from debit and credit, with a larger share drawn from debit cards. In contrast, the impact on cash is less pronounced. This is natural given that the CBDC in this specification is debit-like. Importantly, while the drop in, for example, credit card use at the POS is moderate (15–17% for the *ideal-CBDC*), it has a substantial impact on the relative profitability of the different merchant acceptance bundles. Accepting credit cards is no longer necessarily worthwhile in terms of the trade-off between acceptance costs and benefits in the form of additional sales. At the same time, the market penetration of *ideal-CBDC* is insufficient to incentivize a broad acceptance of CBDC. As a consequence, the share of merchants accepting only cash increases by 80%, as seen in the breakdown of acceptance decisions by bundles (see Figure 17 in Appendix C.1).[24]

Figure 7: Adoption and acceptance by payment method (best-of-cash-and-debit CBDC)



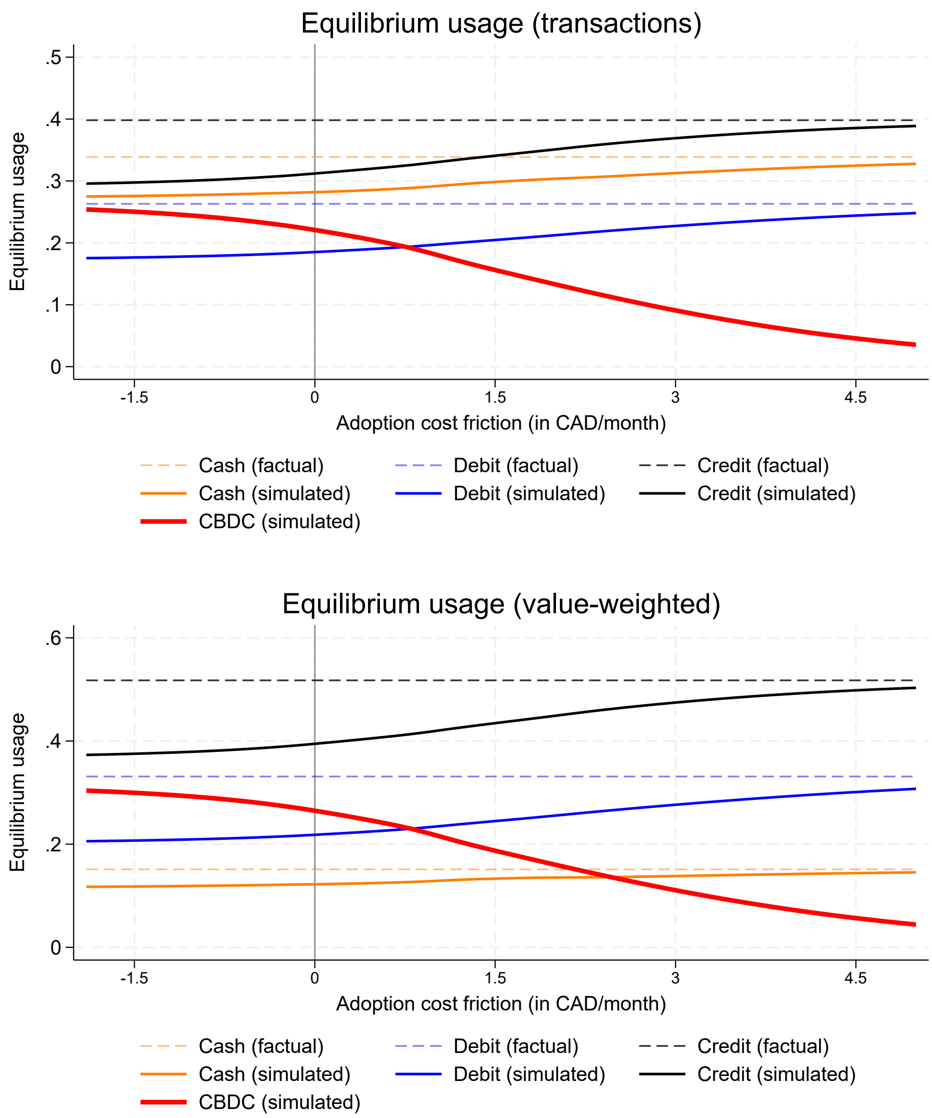
Best-of-cash-and-debit We next turn to the analysis involving a CBDC that encompasses the best features of cash and debit. Figure 7 presents results regarding equilibrium adoption and acceptance by payment method. While qualitative patterns are comparable to those of a debit-like CBDC, a CBDC encompassing the best features of cash and debit sees wider adoption (around 78% of consumers adopt the *ideal-CBDC* compared with 72% for a debit-like *ideal-CBDC*) and much wider merchant acceptance (90% instead of 44%). However, at the moderate friction of around CAD 3/month, the differences become smaller, with adoption dropping to 24% (instead of 19%) and acceptance falling to 22% (instead of 16%). Importantly, the increased uptake of CBDC by merchants at low adoption frictions—which is the most

[24]Appendix C.1 also contains detailed breakdowns of the *ideal-CBDC* case and the case where the adoption friction equals CAD 3/month.

notable difference to a debit-like CBDC—is accompanied by a larger drop in merchant acceptance of traditional digital means of payments: both debit and credit are accepted by less than 50% of merchants for the *ideal-CBDC*.

These differences are driven largely by changes in consumer usage relative to a debit-like CBDC. Figure 8 presents equilibrium usage shares with respect to both the number of transactions (top panel) and value-weighted transactions (bottom panel). Importantly, while CBDC usage at the POS remains limited to around 25% of transactions and 30% of value, the impact on debit and cash is larger for a best-of-cash-and-debit CBDC, which, in contrast to a debit-like CBDC, also draws usage shares from cash.

Figure 8: Usage of payment methods (best-of-cash-and-debit CBDC)



6.4 Takeaways

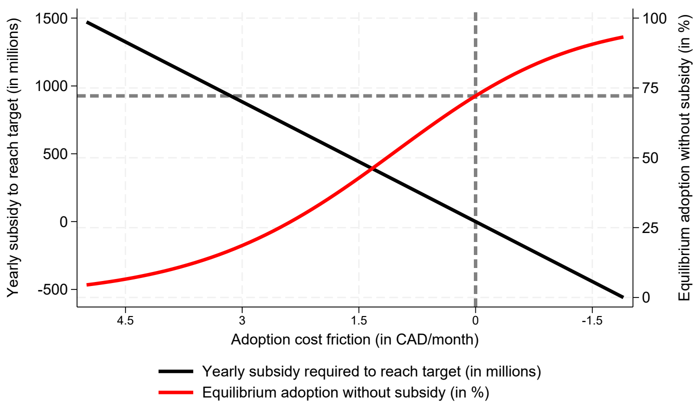
Overall, the results of this analysis and comparison with a debit-like CBDC reinforce several key takeaways. First, a CBDC that is better than the *ideal-CBDC* in that adoption frictions are negative (e.g., via the use of adoption subsidies) and that encompasses the best features of cash and debit will not exceed a usage share of 25%. This is notable given that such a CBDC presents a scenario that is unlikely to be achievable due to information and adoption frictions and the imposed bundle of characteristics (such as universal offline accessibility).

Second, merchant acceptance is heavily driven by consumer usage decisions, while the reverse impact is moderate. This is particularly evidenced by the small differences in usage shares despite the large differences in merchant acceptance across the debit-like and best-of-cash-and-debit CBDC specifications. This reinforces the idea that it is consumers that "drive the bus" in the market for payments at the POS.

Third, a successful CBDC—in the sense of widespread adoption and usage around 20%—is associated with a sizeable drop in merchant acceptance of existing digital means of payment. This "disintermediation in the payments space" is driven by the relative undesirability of credit cards for merchants—in the sense of their cost to the merchants. As a result, even moderate CBDC usage at the POS is sufficient to shift the relative profitability of different payment bundles so that traditional digital means of payment are no longer accepted. Interestingly, this can even lead to a substantial rise in cash-only merchants: for these merchants, accepting CBDC is not profitable due to its limited use, while the same limited use is simultaneously sufficient to no longer render the acceptance of credit cards worthwhile relative to relying solely on cash. An important caveat to this analysis is that it considers unchanged acceptance costs for merchants for the traditional means of payment. To further explore this issue, we analyze the required response by acquirers to preserve their market share in detail in Section 7.

Fourth, even moderate adoption frictions are sufficient to substantially reduce consumer adoption, merchant acceptance, and use of CBDC at the POS. Given the uncertainty about the precise level of frictions faced by consumers, this serves as a warning point: if frictions were to materialize, they would either endanger the success of a potential CBDC rollout or, alternatively, entail substantial costs to overcome them. This is illustrated in Figure 9, which depicts the yearly subsidy required to reach the *ideal-CBDC* outcome and the equilibrium adoption of CBDC without such a subsidy.[25]

Figure 9: Subsidies to restore *ideal-CBDC* outcome (debit-like CBDC)



6.5 Robustness: Consumer travel costs

A key feature of the baseline model is that for informed transactions, consumers can costlessly find a merchant that accepts their preferred payment method. This assumption is sensible in the context of

[25] The derivation of this subsidy is as follows and reflects the total adult population in Canada of 34 million together with the target adoption level of an *ideal-CBDC* (debit-like) of 72.5%:

$$\underbrace{YTC}_{\text{total cost per year}} = \underbrace{12}_{\text{months}} \times \underbrace{c}_{\text{cost/subsidy per consumer}} \times \underbrace{34\text{Mil.}}_{\text{adult Canadians}} \times \underbrace{0.725}_{\text{target adoption}}.$$

near-universal acceptance of existing payment methods but may be less innocuous when assessing the introduction of a new means of payment and the associated impact on equilibrium acceptance. Specifically, it seems unrealistic as a good approximation of reality whenever equilibrium acceptance for a given payment method falls below certain thresholds.

To alleviate this issue and explore the impact of the relaxation of this assumption on our results, we consider the following modification of the interaction between consumers and merchants for informed transactions. As for uninformed transactions, consumers are randomly matched with their local merchant, giving them the option to undertake their transaction using a payment method from the intersection between their adopted and the merchant's accepted payment methods. In addition, consumers have the option to search for a merchant that accepts their most preferred payment method. However, this search is not free but instead entails a search or travel cost inversely proportional to the equilibrium acceptance probability by merchants of the desired payment method.

In a nutshell, a consumer conducting an informed transaction with a given payment method does not necessarily reveal that this payment method was their most preferred. Instead, they reveal that it was *either* the most preferred payment method *or* the best of all payment methods accepted by the local merchant, with other payment methods requiring a costly search for and travel to a merchant that accepts additional methods.

Formally, the above entails several modifications of the existing model. First, denote the search cost for a payment method m by t_m with $t_m = t \cdot \max\{0.7 - \bar{\mathbb{P}}_m, 0\}$. Here, $t \geq 0$ is a parameter capturing the intensity of the search friction, while $\bar{\mathbb{P}}_m$ is the average acceptance probability of payment method m in equilibrium. Note that in this formulation, the search friction matters only if the equilibrium acceptance falls below a threshold chosen to be 70%.[26]

Second, for informed transactions, consumers choose either to use a payment method from their randomly matched merchant or to search and incur the cost. The probability that a consumer uses method m given their adopted set of payment methods $\mathcal{M}_b$ is therefore given by

$$\sum_{\mathcal{M}_s \in \mathcal{M}} \bar{P}_{\mathcal{M}_s} \times \left[(1 - I_{bj}) \cdot \mathcal{P}^*_{bjm}(\mathcal{M}_b \cap \mathcal{M}_s) + I_{bj} \cdot Pr \left\{ m \in \underset{m' \in \mathcal{M}_b}{\arg\max}\, U_{bjm'} - \mathbb{1}_{m' \notin \mathcal{M}_s} t_{m'} \right\} \right]. \tag{23}$$

Put differently, a lower equilibrium acceptance of a given payment method makes consumers—all else equal—less likely to use it (relative to the baseline). This is because when matched with a merchant that does not accept the desired method, the consumer would have to incur a search/travel cost to use the method when conducting an informed transaction.

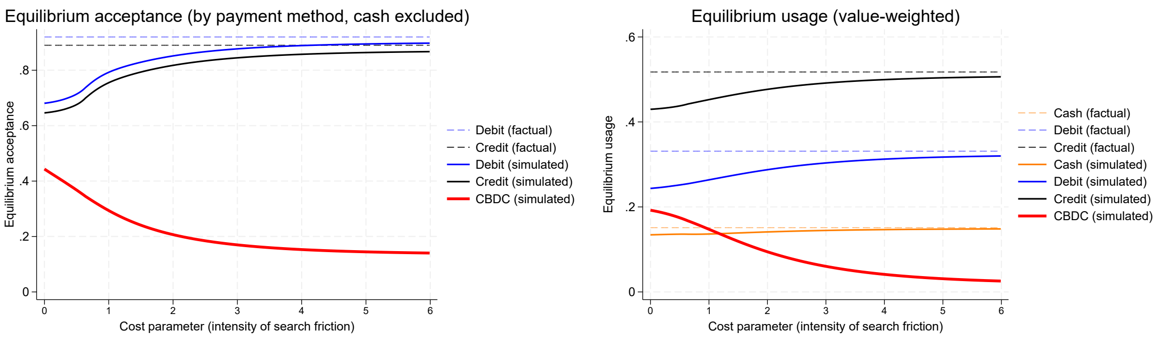
Conversely, merchants are also affected. Specifically, not accepting a given payment method results in a lost sale only if it is cheaper for a consumer to travel to a store accepting it instead of choosing from the set of payment methods both adopted by the consumer and accepted by the merchant under consideration. This implies that the expected profit from an informed transaction becomes

$$\sum_{\mathcal{M}_b \in \mathcal{M}} P_{b,\mathcal{M}_b} \times \sum_{m \in \mathcal{M}_s} Pr \left\{ m \in \underset{m' \in \mathcal{M}_b}{\arg\max}\, U_{bjm'} - \mathbb{1}_{m' \notin \mathcal{M}_s} t_{m'} \right\} \left[\gamma p_{bj} - C_{bm}(p_{bj}) \right]. \tag{24}$$

Implementing the above changes, we find that the incorporation of travel costs reinforces previously described results: as travel costs increase (t goes up), payment methods that were widely adopted, accepted, and used become even more prevalent, while the opposite holds for payment methods whose adoption, acceptance, and usage were not widespread prior to the incorporation of travel costs. To illustrate this, we consider the *ideal-CBDC* case for both the debit-like CBDC and the CBDC encompassing the best

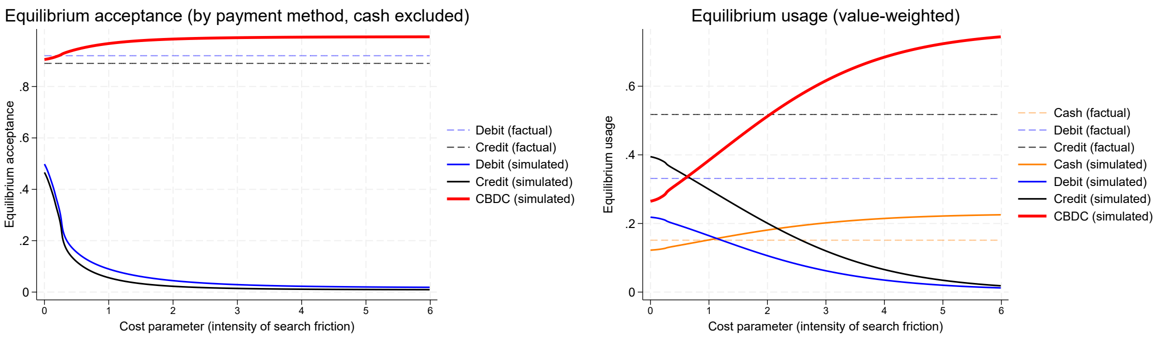
[26]While the choice of 70% is ad-hoc, results are qualitatively robust to the choice of different thresholds. The key goal is to have a search friction that is relevant only when acceptance shares fall substantially below current equilibrium acceptance levels prior to the introduction of the CBDC.

Figure 10: Impact of search friction (debit-like *ideal-CBDC*)



features of cash and debit. For the debit-like *ideal-CBDC*, CBDC acceptance was intermediate, as was its usage. Importantly, existing digital means of payment in the form of debit and credit were more widely accepted and used. As Figure 10 illustrates, an increased search friction that makes it harder for consumers to use non-widely accepted payment methods reduces consumers' use of CBDC at the POS and thus also further reduces merchant acceptance incentives. In contrast, the already prevalent digital payment methods see increased use relative to the case without search frictions, and hence see further acceptance by merchants who previously did not find their acceptance to be profitable. We observe the

Figure 11: Impact of search friction (best-of-cash-and-debit *ideal-CBDC*)



reverse pattern for the best-of-cash-and-debit *ideal-CBDC*. As Figure 11 shows, the fact that this CBDC is more widely accepted than debit and credit means that a search friction reinforces the use of CBDC at the expense of debit and credit and thus leads to even more widespread acceptance of CBDC, while debit and credit cards fade out and eventually become barely accepted.

7 Response by Incumbents

One of the key findings of the baseline results is the potential "disintermediation in the market for payments": that is, the substantial drop in the market share of credit and debit (both for merchant acceptance and consumer usage). However, this drop is contingent on the assumption that incumbents do not strategically respond to the entry of a new payment option in the form of CBDC. This naturally begets the question of the impact of such a response.

To explore this issue, we consider the following setup: as before, we take as given the characteristics of CBDC (debit-like or best-of) and consider a range of levels of the adoption friction relative to the *ideal-CBDC*. We then explore a strategic response by incumbents by asking the question of how much they would reduce their fees to preserve a percentage of their pre-CBDC market share.

We let incumbents focus on merchant acceptance because it displays the steepest decline following the introduction of CBDC and is most prone to disintermediation. Towards this, we explore two types of responses. In the first, we focus on acquirers and let them reduce merchant acceptance costs for the $\{ca, dc\}$ and $\{ca, dc, cc\}$ bundles by $r^{acc}_{ca,dc}\%$ and $r^{acc}_{ca,dc,cc}\%$, respectively.[27] In this exercise, we fix the marginal merchant acceptance cost of CBDC f_{cbdc} (see above) at the level prior to the cost reduction by acquirers. In other words, we keep the marginal cost of adding CBDC to any bundle of accepted payment methods fixed while varying the cost of the incumbent bundles (and thus also the cost of the bundles that add CBDC). With these reductions, acquirers aim to restore merchant acceptance to a share of pre-CBDC levels.

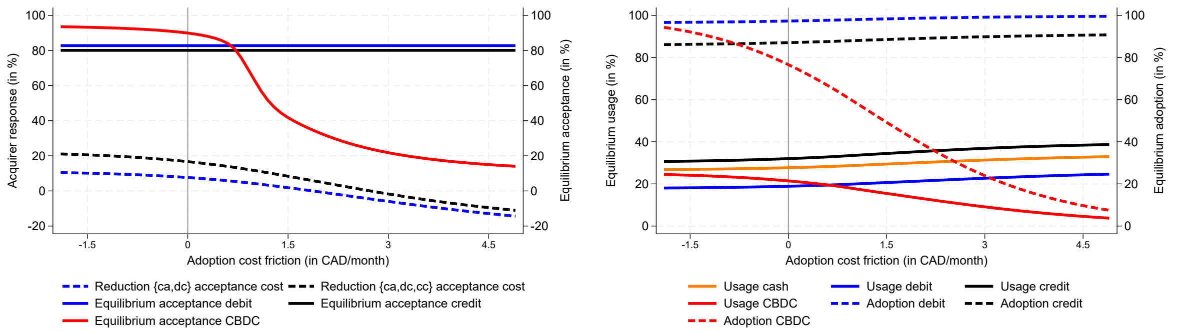
In the second case, we assess the impact of a joint response by acquirers (via merchant acceptance costs) and by issuers and networks (via consumer and merchant usage costs). Specifically, we consider reductions r^{all}_{de} and r^{all}_{cr} such that the merchant acceptance costs for the $\{ca, dc\}$ and $\{ca, dc, cc\}$ bundles are reduced by $r^{all}_{de}\%$ and $r^{all}_{cr}\%$, respectively, while the same reductions apply to the merchant and consumer usage costs of debit and credit.[28]

Throughout, we focus on the case where where incumbents aim to restore pre-CBDC levels minus a 10% reduction. We do not target a full restoration of pre-CBDC market shares as the introduction of the new payment method will cede some market share due simply to the love-of-variety effect.[29]

Acquirer response. We first present results for the CBDC encompassing the best-of-cash-and-debit in Figure 12. The left panel depicts the equilibrium reductions and induced equilibrium acceptances following the response, while the right panel depicts the equilibrium adoption and usage (volume of transactions) by payment method. There are three main takeaways.

First, the acquirer response is always able to avoid disintermediation in the payments market. This is especially apparent when contrasting the left panel with Figure 7, which also highlights that CBDC acceptance remains higher even as the adoption friction increases. This is because the cost reduction for digital payments overall reduces the relative attractiveness of the cash-only bundle for merchants. At the same time, consumer adoption and usage decisions are not substantially affected by acquirer responses—as evident when contrasting the right panel of Figure 12 with Figure 7 and Figure 8—which further reinforces the notion that consumers "drive the bus": while consumer-side changes to equilibrium behaviour substantially affect merchant-side outcomes, the reverse is true only to a much lesser extent.

Figure 12: Acquirer response via acceptance cost (90% target, best-of-cash-and-debit CBDC)



[27] This implies that the new acceptance costs are given by $F'_{ca,dc} \equiv (1-r^{acc}_{ca,dc})F_{ca,dc}$ and $F'_{ca,dc,cc} \equiv (1-r^{acc}_{ca,dc,cc})F_{ca,dc,cc}$.

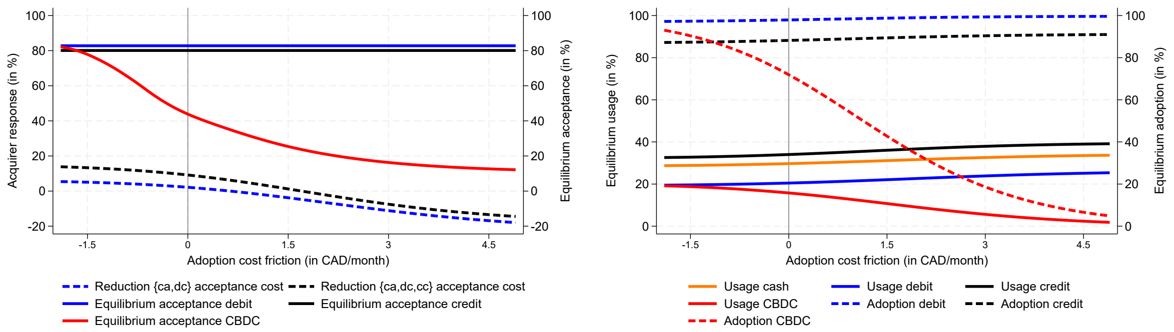
[28] This implies that the new acceptance costs are given by $F'_{ca,dc} \equiv (1-r^{all}_{dc})F_{ca,dc}$ and $F'_{ca,dc,cc} \equiv (1-r^{all}_{cr})F_{ca,dc,cc}$, while usage costs for merchants are given by $C'_{s,dc}(p_{pj}) \equiv (1-r^{all}_{dc})C_{s,dc}(p_b j)$ and $C'_{s,cc}(p_{pj}) \equiv (1-r^{all}_{cr})C_{s,dc}(p_c r)$. Finally, consumer usage costs are given by $C'_{b,dc}(p_{pj}) \equiv (1-r^{all}_{dc})C_{b,dc}(p_b j)$ and $C'_{b,cc}(p_{pj}) \equiv (1-r^{all}_{cr})C_{b,dc}(p_c r)$.

[29] We report results for this exercise in Appendix D. Qualitative insights are unchanged, but incumbent responses are naturally higher.

Second, the acquirer response required to preserve their market share is moderate for the most plausible scenarios. For the *ideal-CBDC*, the necessary responses are below 20% (cash, debit, and credit bundle) and 10% (cash and debit bundle), respectively, even when adoption frictions are negative. They also decline sharply as the CBDC adoption cost friction increases. For example, the *ideal-CBDC* induces cost reductions of 16.69% ($\{ca, dc, cc\}$-bundle) and 7.64% ($\{ca, dc\}$-bundle), while an adoption friction of CAD 1.5/month reduces the responses to 8.37% and 1.8%, respectively. Importantly, the bundle allowing acceptance of credit cards sees a significantly stronger response throughout. Overall, these results point towards a moderate competitive response in light of the impossibility of achieving the best-of-cash-and-debit CBDC's features and the possibility of non-zero adoption frictions.

Third, and perhaps most importantly, the introduction of CBDC is not necessarily able to exert sufficient competitive pressure on incumbents to induce them to lower prices. Depending on the adoption cost friction, it is even possible that CBDC (i) fails to gain a sufficient market-wide adoption, acceptance, and usage and (ii) simultaneously does not lead to a substantial reduction in fees for market participants for existing payment methods. The analysis suggests that acquirers could *increase* their prices and still meet the target of restoring 90% of pre-CBDC market share—this is because CBDC in this case is sufficiently unattractive to reduce incumbents' market shares by less than 10% even absent a response. All

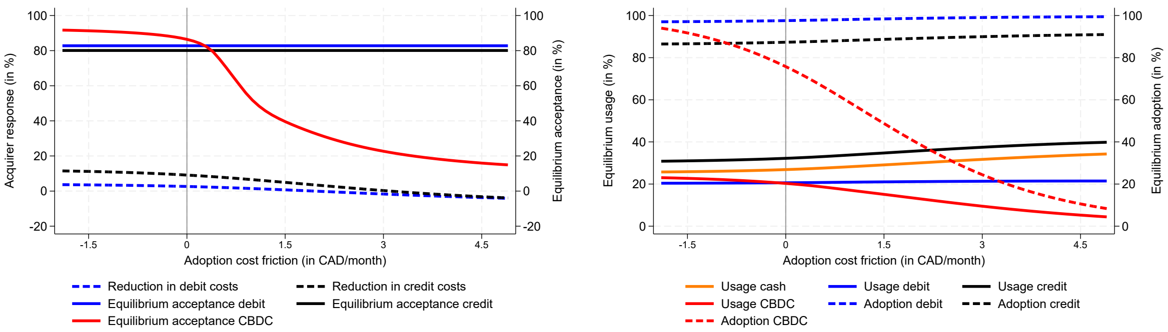
Figure 13: Acquirer response via acceptance cost (90% target, debit-like CBDC)



of these findings are further exemplified in the case of a debit-like CBDC, illustrated in Figure 13, which is less attractive to market participants than the best-of-cash-and-debit CBDC given its characteristics. It is thus intuitive that this CBDC would result in an even lower incumbent response. For example, the debit-like *ideal-CBDC* induces cost reductions of 9.17% ($\{ca, dc, cc\}$-bundle) and 2.16% ($\{ca, dc\}$-bundle), which become reductions of 1.23% and a markup of 3.81%, respectively, at an adoption friction of CAD 1.5/month. In line with this, the response turns to a markup at lower levels of the adoption cost friction for both bundles. Finally, CBDC market shares in the adoption, acceptance, and usage dimensions are consistently lower for the same level of adoption friction compared with the best-of-cash-and-debit CBDC.

Joint response by incumbents. We next present results for a joint response by incumbents that simultaneously affects merchant acceptance costs and consumer and merchant usage costs. As before, we first present results for a best-of-cash-and-debit CBDC in Figure 14 before turning to the debit-like CBDC in Figure 15. Inspecting Figure 14, it is useful to compare the joint incumbent responses to those when only the acquirers react by reducing merchant acceptance fees. It is immediately apparent that whenever the introduced best-of-cash-and-debit CBDC exhibits low adoption cost frictions, the required incumbent responses are much lower when they affect multiple margins. Specifically, the *ideal-CBDC* triggers only a 9.12% reduction in costs associated with credit and 2.62% reduction in costs associated

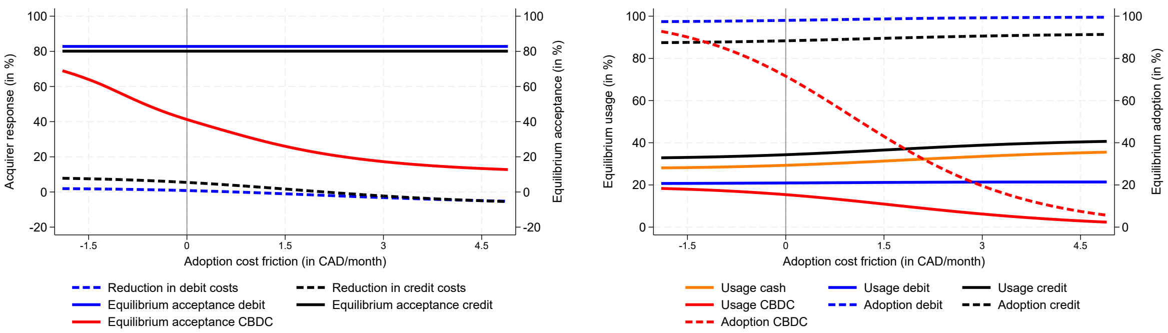
Figure 14: Joint response (90% target, best-of-cash-and-debit CBDC)



with debit.[30]

There is also a slightly stronger negative impact of the response on CBDC market shares in all dimensions. When CBDC adoption cost frictions are high, we again see a markup by incumbents. While the lower markup relative to the response via acceptance costs only may appear odd at first glance, it follows immediately from our counterfactual setup, which targets *exactly* 90% of the pre-CBDC acceptance market shares. A stronger response here would "overshoot"; that is, it would induce higher merchant acceptance, further highlighting that an insufficiently attractive or overly costly CBDC has little to no impact on the competitive landscape in the market for payments at the POS. As before, the required

Figure 15: Joint response (90% target, debit-like CBDC)



responses by incumbents are lower for a debit-like CBDC as shown in Figure 15. An *ideal-CBDC* triggers a response of only 5.44% (credit) and 0.82% (debit), respectively. Moreover, CBDC market shares in all dimensions are significantly lower—especially along the acceptance dimension—following the incumbent response.

8 Conclusion

We counterfactually simulate the introduction of CBDC into the market for payments at the POS. We discuss the modelling and conceptual innovations relative to prior work, especially Huynh et al. (2020) and Huynh et al. (2022) in detail, and provide an overview of robustness checks which validate our main findings.

The key takeaways are three-fold. First, according to this model, CBDC has the potential for material consumer adoption and merchant acceptance along with moderate usage at the POS. However, the

[30]These numbers are in fact almost identical to those when affecting only a single margin with a debit-like CBDC, which is inherently a less attractive entrant compared with a best-of-cash-and-debit CBDC.

realization of this potential is contingent on the absence of adoption cost frictions that complicate consumer adoption (e.g., informational frictions, acquiring and maintaining a digital wallet in addition to other accounts, learning about the technology). Modest adoption frictions substantially reduce consumer adoption, merchant acceptance, and usage of CBDC, even if the CBDC encompasses the best features of cash and debit. Second, consumer subsidies could offset the effects of adoption cost frictions. However, the costs of such subsidies could be large and entail a response by incumbent market participants who lose market share due to the introduction of CBDC. This applies particularly to merchant acquirers where a sizeable drop in merchant acceptance of debit and credit is a direct consequence of a successful CBDC introduction. Third, the response required by incumbents—in terms of a reduction in costs to downstream market participants—to restore their pre-CBDC market shares is moderate to small and can substantially reduce CBDC adoption, acceptance, and usage.

Overall, this implies that an introduction of CBDC into the market for payments is by no means guaranteed or even likely to be successful. If it entails significant adoption frictions or does not include compelling features, it would have little effect on market outcomes. But even if it were successful given present market conditions, it would trigger a strategic response by incumbents that is likely to hinder the market penetration of CBDC, while the incumbent response would not be sufficient to provide substantial price reduction benefits. These potential issues therefore need to be considered along with the costs associated with the introduction and rollout of CBDC.

The present analysis can be extended in future work along several avenues. Our analysis focuses on SMEs and thus does not capture the acceptance decisions by large merchants. Their study is therefore of natural interest. However, our analysis clearly establishes that "consumers drive the bus": that is, that more widespread merchant acceptance (e.g., if large merchants mostly accept CBDC) has only moderate effects on consumer adoption and usage decisions.[31] Additionally, acceptance practices by large merchants are likely to be more robust to any change in consumer behaviour given CBDC than those of price-taking SMEs in the model, further limiting the impact on our results. It may also be of interest to estimate potential consumer adoption frictions using additional data in the spirit of Nocciola and Zamora-Pérez (2024) and to embed this within a model featuring endogenous merchant decisions such as ours. Finally, we are working on micro-founding consumer–merchant interactions and endogenizing consumers' information sets about merchant acceptance practices. This would, for example, allow us to consistently incorporate the degree of search frictions both when estimating the current state of the market for payments at the POS and in the counterfactual following the introduction of CBDC.

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[31]The limited impact of merchant-side focused interventions on outcomes in the market for payments is also highlighted by Fujiki (2023).

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Appendix

A Overview

Figure 16: Overview of model ingredients and data sources

	Huynh et al. (2020)	Huynh et al. (2022)	This work
Endogenous consumer adoption and usage	✓	✓	✓
Endogenous merchant acceptance		✓	✓
Recognition of credit card rewards	✓		✓
Accounting for revolver status			✓
Accounting for technological progress			✓
Assessment of incumbent responses			✓
Counterfactual introduction of CBDC	✓		✓
Consumer data	2009, 2013 & 2017 MOP	2013 MOP	2017 MOP
Merchant data	-	2015 RSCPM	2015 RSCPM & 2023 MAS
Cost data	Kosse et. al. (2017)	Kosse et. al. (2017)	Kosse et. al. (2017)

Notes: MOP stands for "Methods-of-Payment Survey." RSCPM stands for the "Retailer Survey on the Cost of Payment Methods." MAS stands for "Merchant Acceptance Survey."

B Likelihood of Repeat Transactions

We estimate a probit model that relates the observed indicator variable of whether a given transaction j by consumer b is a repeat purchase to consumer demographics as well as transaction-specific characteristics. Formally, we estimate

$$Pr\{Y_{bj} = 1\} = \phi(X_{bj}\beta),$$

where X_{bj} contains a rich set of consumer and household demographics (e.g., gender, location, education level, household size, employment status) as well as transaction characteristics (e.g., choice of payment method, transaction size, purchase category). Results of the probit regression are displayed in Table 12. We then utilize the model estimates to predict $\hat{Y}_{bj}$, which we employ in our estimation.

Table 12: Probit regression of repeat purchase status

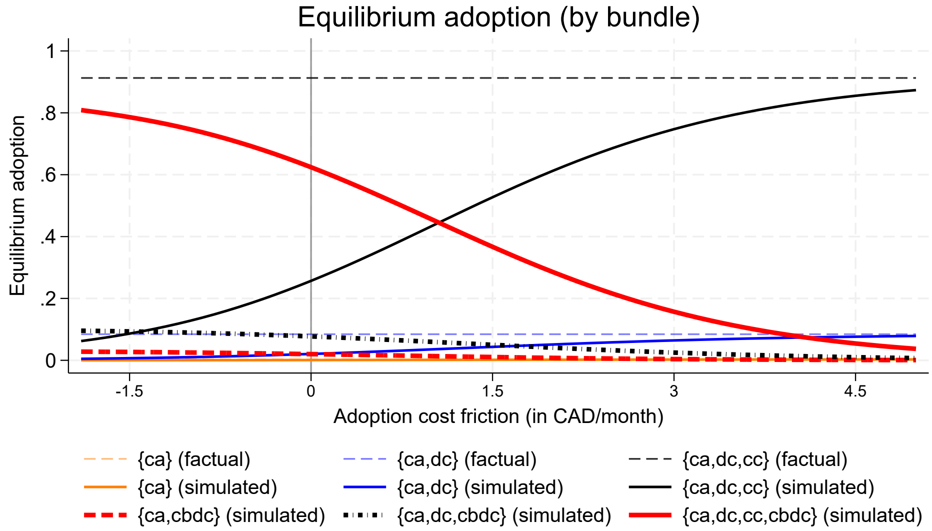
Variable	Repeat purchase (indicator)	
	coefficient	(s.e.)
Female	-0.0627588	(0.594246)
Medium financial literacy	-0.0026443	(0.0845357)
High financial literacy	-0.1670523**	(0.0811176)
Internet access	0.0481891	(0.3285183)
Age	0.0012351	(0.0021005)
Urban	-0.0023679	(0.0740729)
Purchase amount	-0.0001497***	(0.0000545)
Purchase category (baseline: groceries)		
Gasoline	-0.3528901***	(0.1147557)
Personal attire	-0.6774324***	(0.1133162)
Health care	-0.7311962***	(0.1555650)
Hobby/sporting goods	-0.7744395***	(0.1275944)
Professional/personal services	-1.149407***	(0.1327857)
Travel/parking	-0.8415297***	(0.1431210)
Entertainment/meals	-0.7248303***	(0.0710365)
Other	-0.6119489***	(0.0800992)
Region controls	Yes	
Education controls (by category)	Yes	
Household size controls	Yes	
Marital status controls	Yes	
Employment status controls (by category)	Yes	
Number of credit card controls	Yes	
Credit score controls (bins)	Yes	
Payment method controls	Yes	
Observations	8,356	
Pseudo R2	0.0935	

Note: "s.e." stands for "standard error."

C Additional Figures

C.1 Debit-like CBDC

Figure 17: Adoption and acceptance by bundle (debit-like CBDC)



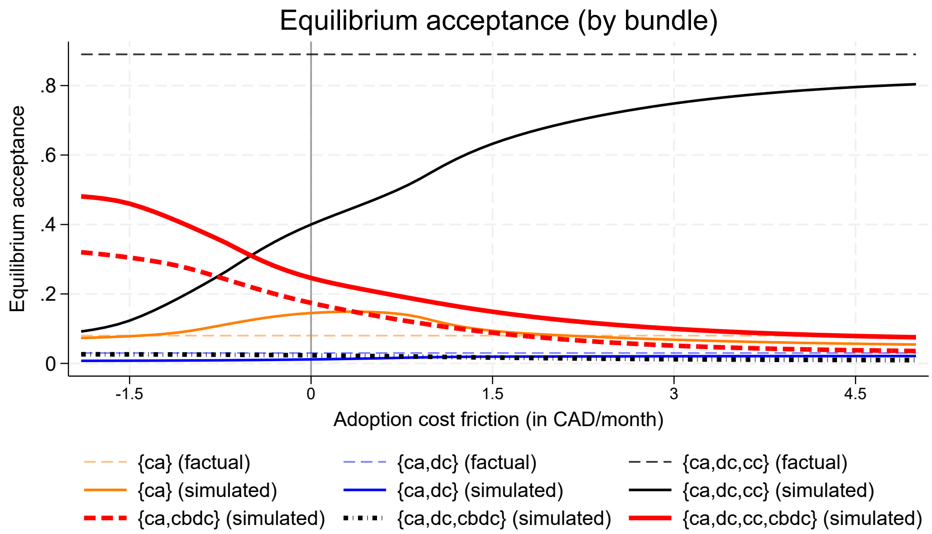


Table 13: Market outcomes for *ideal-CBDC* (debit-like)

Adoption and acceptance by bundle

	Consumers				Merchants			
Bundle	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
ca	0.003	0.001	-0.002	-68.316	0.080	0.145	0.065	81.384
ca,dc	0.084	0.021	-0.064	-75.561	0.030	0.012	-0.018	-61.620
ca,dc,cc	0.913	0.257	-0.656	-71.851	0.890	0.400	-0.490	-55.053
ca,cbdc	0.000	0.020	0.020		0.000	0.174	0.174	
ca,dc,cbdc	0.000	0.077	0.077		0.000	0.023	0.023	
ca,dc,cc,cbdc	0.000	0.624	0.624		0.000	0.246	0.246	
Total	1.000	1.000	-0.000		1.000	1.000	-0.000	

Adoption and acceptance by instrument

	Consumer adoption				Merchant acceptance			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	1.000	1.000	0.000	0.000	1.000	1.000	0.000	0.000
Debit	0.997	0.979	-0.018	-1.813	0.920	0.681	-0.239	-26.007
Credit	0.913	0.881	-0.032	-3.461	0.890	0.646	-0.244	-27.417
CBDC	0.000	0.722	0.722		0.000	0.443	0.443	

Equilibrium usage at point of sale (POS)

	Usage at POS				Value-weighted usage at POS			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	0.339	0.301	-0.037	-11.049	0.151	0.134	-0.017	-11.146
Debit	0.263	0.203	-0.060	-22.828	0.331	0.244	-0.088	-26.449
Credit	0.398	0.336	-0.062	-15.488	0.518	0.430	-0.088	-16.968
CBDC	0.000	0.159	0.159		0.000	0.192	0.192	
Total	1.000	1.000	0.000		1.000	1.000	0.000	

Notes: Throughout, "pre" and "post" columns refer to outcomes prior to and after the introduction of CBDC, respectively. Δ (abs) shows the absolute difference in market shares due to the introduction of CBDC, while Δ (%) shows the relative difference.

Table 14: Market outcomes with CAD 1.5/month friction (debit-like CBDC)

Adoption and acceptance by bundle

	Consumers				Merchants			
Bundle	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
ca	0.003	0.002	-0.001	-39.658	0.080	0.094	0.014	17.470
ca,dc	0.084	0.043	-0.041	-48.506	0.030	0.019	-0.011	-35.147
ca,dc,cc	0.913	0.527	-0.386	-42.242	0.890	0.632	-0.258	-28.939
ca,cbdc	0.000	0.011	0.011		0.000	0.088	0.088	
ca,dc,cbdc	0.000	0.050	0.050		0.000	0.017	0.017	
ca,dc,cc,cbdc	0.000	0.367	0.367		0.000	0.149	0.149	
Total	1.000	1.000	-0.000		1.000	1.000	-0.000	

Adoption and acceptance by instrument

	Consumer adoption				Merchant acceptance			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	1.000	1.000	0.000	0.000	1.000	1.000	0.000	0.000
Debit	0.997	0.988	-0.009	-0.943	0.920	0.818	-0.102	-11.124
Credit	0.913	0.894	-0.019	-2.039	0.890	0.781	-0.109	-12.207
CBDC	0.000	0.428	0.428		0.000	0.254	0.254	

Equilibrium usage at point of sale (POS)

	Usage at POS				Value-weighted usage at POS			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	0.339	0.312	-0.027	-7.954	0.151	0.138	-0.013	-8.439
Debit	0.263	0.221	-0.042	-16.112	0.331	0.268	-0.063	-19.052
Credit	0.398	0.360	-0.038	-9.565	0.518	0.463	-0.055	-10.623
CBDC	0.000	0.107	0.107		0.000	0.131	0.131	
Total	1.000	1.000	0.000		1.000	1.000	0.000	

Notes: Throughout, "pre" and "post" columns refer to outcomes prior to and after the introduction of CBDC, respectively. Δ (abs) shows the absolute difference in market shares due to the introduction of CBDC, while Δ (%) shows the relative difference.

Table 15: Market outcomes with CAD 3/month friction (debit-like CBDC)

Adoption and acceptance by bundle

	Consumers				Merchants			
Bundle	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
ca	0.003	0.002	-0.001	-16.895	0.080	0.068	-0.012	-14.729
ca,dc	0.084	0.064	-0.020	-23.723	0.030	0.021	-0.009	-31.163
ca,dc,cc	0.913	0.747	-0.165	-18.128	0.890	0.748	-0.142	-15.901
ca,cbdc	0.000	0.004	0.004		0.000	0.051	0.051	
ca,dc,cbdc	0.000	0.025	0.025		0.000	0.012	0.012	
ca,dc,cc,cbdc	0.000	0.157	0.157		0.000	0.100	0.100	
Total	1.000	1.000	-0.000		1.000	1.000	-0.000	

Adoption and acceptance by instrument

	Consumer adoption				Merchant acceptance			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	1.000	1.000	0.000	0.000	1.000	1.000	0.000	0.000
Debit	0.997	0.994	-0.003	-0.347	0.920	0.881	-0.039	-4.278
Credit	0.913	0.904	-0.008	-0.919	0.890	0.848	-0.042	-4.719
CBDC	0.000	0.186	0.186		0.000	0.163	0.163	

Equilibrium usage at point of sale (POS)

	Usage at POS				Value-weighted usage at POS			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	0.339	0.324	-0.015	-4.307	0.151	0.144	-0.007	-4.714
Debit	0.263	0.239	-0.024	-9.007	0.331	0.295	-0.036	-10.944
Credit	0.398	0.380	-0.018	-4.444	0.518	0.492	-0.026	-5.023
CBDC	0.000	0.056	0.056		0.000	0.069	0.069	
Total	1.000	1.000	0.000		1.000	1.000	0.000	

Notes: Throughout, "pre" and "post" columns refer to outcomes prior to and after the introduction of CBDC, respectively. Δ (abs) shows the absolute difference in market shares due to the introduction of CBDC, while Δ (%) shows the relative difference.

C.2 Best-of-Cash-and-Debit CBDC

Figure 18: Adoption and acceptance by bundle (best-of-cash-and-debit CBDC)

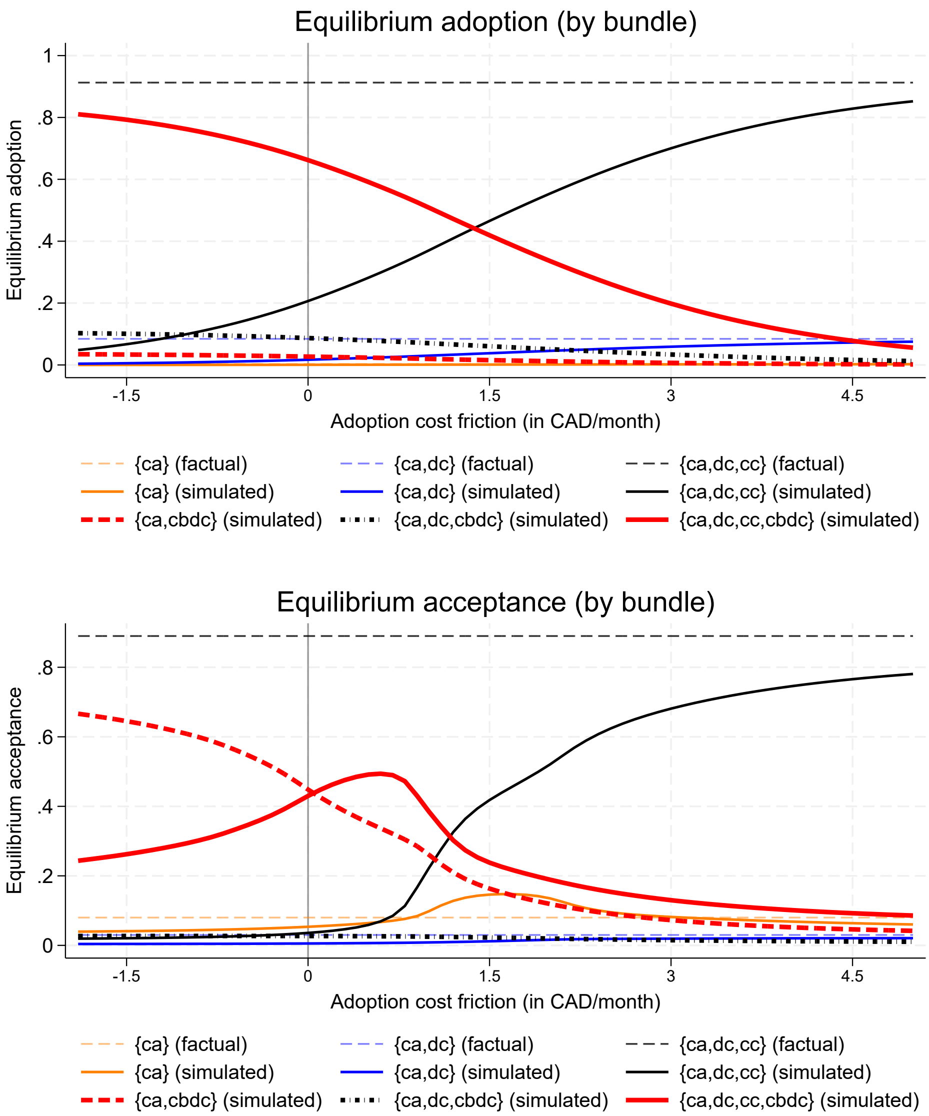


Table 16: Market outcomes for *ideal-CBDC* (best-of-cash-and-debit)

Adoption and acceptance by bundle

	Consumers				Merchants			
Bundle	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
ca	0.003	0.001	-0.002	-81.503	0.080	0.054	-0.026	-33.088
ca,dc	0.084	0.017	-0.068	-80.029	0.030	0.005	-0.025	-81.714
ca,dc,cc	0.913	0.207	-0.706	-77.368	0.890	0.036	-0.854	-95.971
ca,cbdc	0.000	0.027	0.027		0.000	0.448	0.448	
ca,dc,cbdc	0.000	0.087	0.087		0.000	0.027	0.027	
ca,dc,cc,cbdc	0.000	0.662	0.662		0.000	0.430	0.430	
Total	1.000	1.000	-0.000		1.000	1.000	-0.000	

Adoption and acceptance by instrument

	Consumer adoption				Merchant acceptance			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	1.000	1.000	0.000	0.000	1.000	1.000	0.000	0.000
Debit	0.997	0.972	-0.025	-2.466	0.920	0.498	-0.422	-45.852
Credit	0.913	0.869	-0.044	-4.815	0.890	0.466	-0.424	-47.669
CBDC	0.000	0.776	0.776		0.000	0.905	0.905	

Equilibrium usage at point of sale (POS)

	Usage at POS				Value-weighted usage at POS			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	0.339	0.282	-0.057	-16.775	0.151	0.122	-0.029	-19.099
Debit	0.263	0.185	-0.078	-29.624	0.331	0.218	-0.113	-34.110
Credit	0.398	0.312	-0.086	-21.630	0.518	0.395	-0.123	-23.764
CBDC	0.000	0.221	0.221		0.000	0.265	0.265	
Total	1.000	1.000	0.000		1.000	1.000	0.000	

Notes: Throughout, "pre" and "post" columns refer to outcomes prior to and after the introduction of CBDC, respectively. Δ (abs) shows the absolute difference in market shares due to the introduction of CBDC, while Δ (%) shows the relative difference.

Table 17: Market outcomes with CAD 1.5/month friction (best-of-cash-and-debit CBDC)

Adoption and acceptance by bundle

	Consumers				Merchants			
Bundle	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
ca	0.003	0.001	-0.002	-58.684	0.080	0.146	0.066	82.634
ca,dc	0.084	0.038	-0.046	-55.064	0.030	0.012	-0.018	-60.584
ca,dc,cc	0.913	0.466	-0.447	-48.990	0.890	0.418	-0.472	-53.025
ca,cbdc	0.000	0.016	0.016		0.000	0.163	0.163	
ca,dc,cbdc	0.000	0.060	0.060		0.000	0.023	0.023	
ca,dc,cc,cbdc	0.000	0.419	0.419		0.000	0.238	0.238	
Total	1.000	1.000	-0.000		1.000	1.000	-0.000	

Adoption and acceptance by instrument

	Consumer adoption				Merchant acceptance			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (p%erc)
Cash	1.000	1.000	0.000	0.000	1.000	1.000	0.000	0.000
Debit	0.997	0.983	-0.014	-1.386	0.920	0.691	-0.229	-24.943
Credit	0.913	0.885	-0.028	-3.051	0.890	0.656	-0.234	-26.275
CBDC	0.000	0.495	0.495		0.000	0.424	0.424	

Equilibrium usage at point of sale (POS)

	Usage at POS				Value-weighted usage at POS			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	0.339	0.298	-0.040	-11.919	0.151	0.133	-0.018	-11.878
Debit	0.263	0.205	-0.058	-22.206	0.331	0.245	-0.086	-26.094
Credit	0.398	0.341	-0.057	-14.408	0.518	0.435	-0.083	-16.034
CBDC	0.000	0.156	0.156		0.000	0.187	0.187	
Total	1.000	1.000	0.000		1.000	1.000	0.000	

Notes: Throughout, "pre" and "post" columns refer to outcomes prior to and after the introduction of CBDC, respectively. Δ (abs) shows the absolute difference in market shares due to the introduction of CBDC, while Δ (%) shows the relative difference.

Table 18: Market outcomes with CAD 3/month friction (best-of-cash-and-debit CBDC)

Adoption and acceptance by bundle

	Consumers				Merchants			
Bundle	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
ca	0.003	0.002	-0.001	-35.752	0.080	0.082	0.002	2.360
ca,dc	0.084	0.059	-0.025	-30.139	0.030	0.019	-0.011	-35.312
ca,dc,cc	0.913	0.700	-0.212	-23.268	0.890	0.681	-0.209	-23.476
ca,cbdc	0.000	0.007	0.007		0.000	0.073	0.073	
ca,dc,cbdc	0.000	0.034	0.034		0.000	0.015	0.015	
ca,dc,cc,cbdc	0.000	0.198	0.198		0.000	0.130	0.130	
Total	1.000	1.000	-0.000		1.000	1.000	-0.000	

Adoption and acceptance by instrument

	Consumer adoption				Merchant acceptance			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	1.000	1.000	0.000	0.000	1.000	1.000	0.000	0.000
Debit	0.997	0.991	-0.006	-0.565	0.920	0.845	-0.075	-8.102
Credit	0.913	0.899	-0.014	-1.534	0.890	0.811	-0.079	-8.864
CBDC	0.000	0.239	0.239		0.000	0.218	0.218	

Equilibrium usage at point of sale (POS)

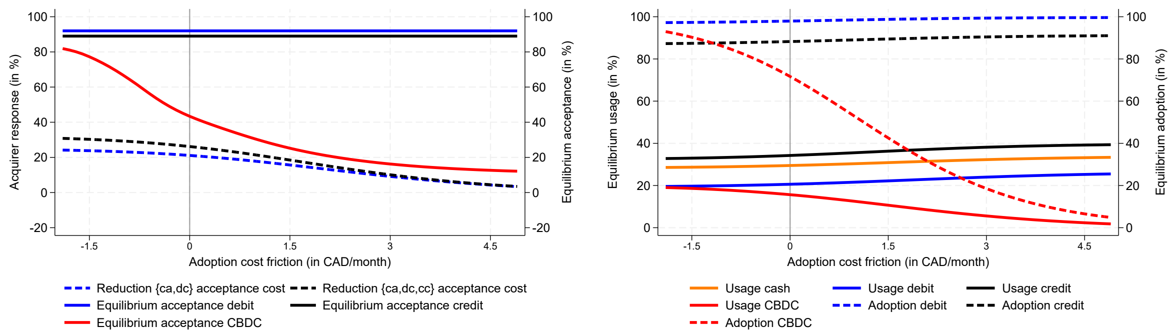
	Usage at POS				Value-weighted usage at POS			
Instrument	pre	post	Δ (abs)	Δ (%)	pre	post	Δ (abs)	Δ (%)
Cash	0.339	0.313	-0.026	-7.694	0.151	0.138	-0.013	-8.557
Debit	0.263	0.227	-0.036	-13.595	0.331	0.276	-0.055	-16.536
Credit	0.398	0.369	-0.029	-7.296	0.518	0.475	-0.043	-8.311
CBDC	0.000	0.091	0.091		0.000	0.111	0.111	
Total	1.000	1.000	0.000		1.000	1.000	0.000	

Notes: Throughout, "pre" and "post" columns refer to outcomes prior to and after the introduction of CBDC, respectively. Δ (abs) shows the absolute difference in market shares due to the introduction of CBDC, while Δ (%) shows the relative difference.

D Incumbent Responses

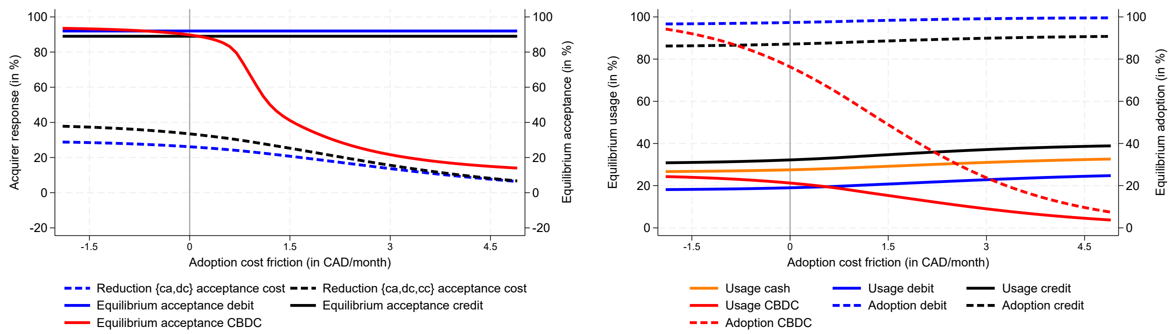
D.1 Debit-like CBDC – Acquirer Response

Figure 19: Acquirer response via acceptance cost (100% target, debit-like CBDC)



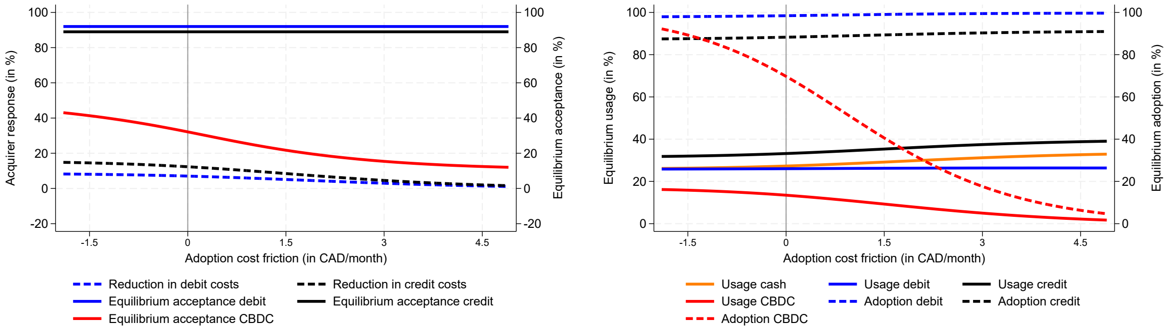
D.2 Best-of-cash-and-debit CBDC – Acquirer Response

Figure 20: Acquirer response (100% target) via acceptance cost (best-of-cash-and-debit CBDC)



D.3 Debit-like CBDC – Joint Response

Figure 21: Joint response (100% target, debit-like CBDC)



D.4 Best-of-cash-and-debit CBDC – Joint Response

Figure 22: Joint response (100% target, best-of-cash-and-debit CBDC)