Central Bank Digital Currency and Banking Choices

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Abstract

How would households allocate their liquid assets between a central bank digital currency (CBDC) and bank deposits, and to what extent would a CBDC crowd out bank deposits? By developing and estimating a structural model, we find that two non-price design attributes are important determinants of CBDC adoption and deposit crowding out: interoperability with banks, which allows CBDC holders to manage financial products offered by participating banks through a unified interface, and access to a network of service locations. CBDC design also has distributional consequences: service locations raise adoption and surplus more for rural households, while remuneration matters more for high-income households. Finally, a relatively high CBDC holding limit can substantially reduce deposit crowding out while only modestly reducing depositor welfare.

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1 Introduction

Many central banks are considering issuing a retail central bank digital currency (CBDC), a digital form of central bank money that is available to the general public and can be used for retail transactions.[1] By offering the public the option to hold the digital money in a CBDC instead of bank deposits, the CBDC would directly compete with bank deposits in the market for digital money. As a consequence, there are concerns that a CBDC could substantially crowd out bank deposits, which may undermine financial stability by raising the funding cost and reducing the profitability of the banking sector. The key to quantifying the potential demand for CBDC and its crowding-out effect is to understand how a CBDC would differ from bank deposits. This paper highlights two important design features that can significantly affect the CBDC adoption and the crowding out of deposits: CBDC interoperability with incumbent banks and access to service locations.

First, commercial banks, unlike central banks, provide products complementary to deposits, such as mortgages and credit cards. Households often prefer to bundle these products at the same bank where they have deposit accounts. In Canadian household survey data from 2010–2017, 56% of mortgage borrowers and 45% of credit card holders obtain deposits and the respective product from the same bank. Similar patterns appear in the United States, where 45% of households prefer to obtain all banking products from the same financial institution, mainly for convenience.[2] A stand-alone CBDC would not provide this same-bank convenience, since the central bank does not provide credit cards or mortgage loans. An interoperable CBDC, however, could preserve this convenience by integrating CBDC wallets with participating banks' digital platforms.[3] Unlike a bank deposit account, whose convenience is tied to products held at the same bank, an interoperable CBDC could provide similar convenience for products held at any participating bank.

Second, banks typically provide access to extensive branch networks for in-person services, while the extent of comparable physical access for CBDC remains an open design question. In the same 2010–2017 Canadian household survey, around 60% of depositors reported that they had visited their branches at least once in the past month. Similarly, according to the 2024 Mintel report, 77% of respondents visited a bank branch within the past 12 months. Withdrawing cash and obtaining customer service and support are among the important reasons for branch visits.[4] These services are also relevant for CBDC adoption. Existing proposals discuss using post offices or bank branches for onboarding,[5] but the availability of broader in-person CBDC services remains uncertain. This paper therefore sheds light on the importance of service location design for CBDC adoption and

[1] According to the 2022 Bank for International Settlements (BIS) survey, 93% of the central banks are engaging in CBDC work (Kosse and Mattei, 2023). The Bahamas, Eastern Caribbean Central Bank, Jamaica, and Nigeria have already launched retail CBDCs.

[2] See https://www.pymnts.com/news/banking/2022/45-of-us-consumers-want-banking-bundles/.

[3] For example, households could use CBDC to make payments related to financial products, such as mortgages and credit cards, offered by any of the participating banks and manage those products through a unified interface.

[4] See Figure A2 in Online Appendix A.2.

[5] See https://www.ecb.europa.eu/euro/digital_euro/faqs/html/ecb.faq_digital_euro.en.html.

the crowding out of deposits.

Predicting the potential adoption of CBDC and the magnitude of the crowding out is a challenging question because retail CBDC has not yet been introduced in most countries. We use a structural model approach to view CBDC as a bundle of product attributes and use data on the existing products such as demand deposits to estimate households' preferences for those attributes. The focus on demand deposits is because they share core functions of a retail CBDC: storing liquid balances and making digital payments. Assuming these preference parameters remain unchanged after CBDC issuance, we combine them with CBDC attributes chosen by the central bank to predict CBDC demand. This structural approach has been used in recent work on CBDC demand (e.g., Li, 2023; Whited, Wu and Xiao, 2023).

We build on this approach to incorporate two important non-price design features of the CBDC: interoperability and service location. In our model, a household first chooses its deposit bank, considering the varying deposit rates, complementary financial products, and branch network offered by each institution. Then it allocates its endowed liquid assets between demand deposits and cash. Banks offering differentiated deposits compete under Bertrand-Nash competition. In the absence of CBDC, the only available digital money is demand deposits provided by private banks. With CBDC in the counterfactual analysis, banks also compete with CBDC, a new digital money alternative.

We exploit a unique Canadian household survey to estimate households' preference parameters for different attributes, such as deposit rate, complementarity, and branch network. In particular, observing households' bank choices for different financial products allows us to estimate how likely a household is to obtain a credit card or mortgage loan from its deposit bank, which is crucial for identifying households' preferences for complementarities between deposits and other financial products at the same bank. We supplement the survey with detailed branch location data and households' residential locations, which allows us to construct household-specific measures of local branch networks and estimate the preferences for branch access.

The estimated model is then used to conduct counterfactual analyses on CBDC. On the extensive margin, some households would switch from bank deposits to CBDC, reducing the number of bank depositors. On the intensive margin, the availability of CBDC tends to make deposit demand more elastic, inducing banks to raise deposit rates and thereby increasing deposits held by remaining depositors. In equilibrium, the extensive margin tends to dominate, resulting in fewer bank deposits.

The design of the CBDC is crucial for the magnitude of the crowding out. In addition to the level of CBDC interoperability and service location network, we also consider the CBDC interest rate, which is still a relevant design choice and is frequently discussed in the literature. While many central banks are proposing a non-interest-bearing CBDC, e-CNY will be interest-bearing. Other CBDC attributes, such as payment convenience, privacy, and trust in the issuer, are not modeled separately in the baseline analysis.[6] We capture them through an assumed level of unobserved CBDC appeal, or CBDC fixed effect, which we set to the estimated fixed effect of the big five

[6]In an extension, we include payment attributes including payment convenience and privacy.

banks in the baseline counterfactuals. The quantitative results should therefore be interpreted as conditional on this assumption and on the specific CBDC designs considered. Lastly, our model is also well suited for evaluating CBDC holding limits because it distinguishes between the extensive margin, whether households switch from deposits to CBDC, from the intensive margin, how much of their liquid assets they allocate to CBDC conditional on adoption.[7]

The main findings are as follows. First, service locations and interoperability are important non-price design attributes that can significantly increase the adoption of a CBDC and its crowding-out effect. A non-interest-bearing CBDC with neither interoperability nor service locations has a negligible effect, crowding out about 1% of demand deposits. Adding post offices as service locations raises deposit crowding out to 7%. If the CBDC is also interoperable with the big five banks, crowding out rises to 21%. Interoperability has a large effect because it broadens complementarity beyond a single bank: a deposit account provides convenience only for products held at the same bank, whereas an interoperable CBDC can provide convenience for products held at any participating bank. CBDC remuneration further increases crowding out. The importance of CBDC designs on adoption is consistent with the early e-CNY experience. Bai et al. (2025) document limited individual e-CNY adoption and argue that incumbent payment platforms offer more appealing ecosystems, leaving users with weak incentives to switch.

Second, the effects of a CBDC are heterogeneous across both banks and households. Banks with higher initial market shares respond more to the CBDC issuance, raising deposit rates by more and thereby losing fewer deposits.[8] For households, we find that rural households hold more CBDC and gain more consumer surplus when CBDC provides a service location network. This difference is especially pronounced when post offices are used as service locations, since post offices are more accessible to rural households than bank branches. We also find that high-income households are more sensitive to interest rates,[9] and therefore hold more CBDC and benefit more when the CBDC interest rate is attractive. When the CBDC interest rate is low, they hold less CBDC; nevertheless, their consumer surplus gains are not necessarily lower, because they benefit more from the higher equilibrium deposit rates induced by CBDC competition. These heterogeneous effects highlight that CBDC design involves important distributional implications.

Third, if a CBDC is designed to be very attractive, a relatively high holding limit on CBDC can substantially reduce deposit crowding out while only modestly reducing depositor welfare. For example, a limit of CAD 25,000, far above the EUR 3,000 limit discussed by the ECB (Panetta, 2022), can lower aggregate CBDC holdings by about 40%. Only slightly more than 10% of households are constrained by this limit, but these households tend to be in the right tail of the liquid asset distribution and would hold large CBDC balances without the holding limit. As a result, the

[7]Holding limits are caps on the amount of CBDC an individual can hold, which are being considered by central banks including the European Central Bank (ECB) and the Bank of England.

[8]Similarly, Whited, Wu and Xiao (2023) find that when the banking sector is more concentrated, banks lose fewer deposits to a one dollar increase in CBDC. Garratt, Yu and Zhu (2022) find that the large bank raises its deposit rate by more in response to a higher CBDC interest rate.

[9]This is consistent with recent evidence from European countries showing that higher income and wealthier households are more rate sensitive (e.g., Cirelli and Olafsson, 2025; Albertazzi et al., 2026).

limit has a large effect on aggregate CBDC holdings. Its effect on welfare is much smaller because only a small fraction of households are constrained. This suggests that holding limits can reduce deposit crowding out while preserving the attractiveness of CBDC for most households.

While our main counterfactuals focus on CBDC, the framework can also be used to study the impact of stablecoins on the banking sector, an increasingly relevant question as stablecoin regulation has become a policy priority across jurisdictions (Financial Stability Board, 2024). On the households' demand side, similar to CBDC, stablecoin is a new digital money alternative with its own set of features. One key difference between CBDC and stablecoin is from the issuer's supply side. Unlike CBDC, stablecoins are private liabilities backed by a regulated reserve asset portfolio. If stablecoin issuers are required to hold part of their reserves as bank deposits, some of the funds flowing into stablecoins can return to banks as issuer reserve deposits, therefore dampening the effect of stablecoin adoption on aggregate bank deposits.

This paper complements the growing theoretical literature that studies the effects of a CBDC on banking (e.g., Andolfatto, 2021; Garratt, Yu and Zhu, 2022; Chang et al., 2023; Chiu et al., 2023; Keister and Sanches, 2023).[10] This literature typically assumes that the CBDC is a perfect substitute for bank deposits. Most papers also have limited discussions on the designs of the CBDC, focusing mainly on the interest rate. In contrast, we use rich micro-level data to estimate households' preferences over product characteristics such as branch networks and complementarity with other financial products, and use these preferences to predict the effect of a CBDC on banking under different designs.[11]

This paper contributes to an emerging empirical literature that uses structural models to study CBDC demand (Li, 2023; Whited, Wu and Xiao, 2023; Huynh et al., 2024; Lambert et al., 2024; Nocciola and Zamora-Pérez, 2024). Relative to this work, our contribution is twofold. First, we develop a framework and exploit a unique household survey dataset to study two non-price design features that are central to current CBDC debates: CBDC interoperability and service location access. We highlight the importance of these design features in shaping CBDC adoption and deposit crowding out. Second, we show that CBDC designs have important distributional implications. For example, service location access primarily benefits households with limited access to nearby branches, while remuneration primarily benefits high-income households that tend to be more rate sensitive.

[10] Existing theoretical literature also studies the effects of a CBDC on financial stability (e.g., Brunnermeier and Niepelt, 2019; Schilling, Fernández-Villaverde and Uhlig, 2020; Fernández-Villaverde et al., 2021; Ahnert et al., 2023), monetary policy (e.g., Bordo and Levin, 2017; Jiang and Zhu, 2021; Davoodalhosseini, 2022; Niepelt, 2024; Abad, Nuño and Thomas, 2025), macroeconomic volatility (e.g., Barrdear and Kumhof, 2022; George, Xie and Alba, 2022; Minesso, Mehl and Stracca, 2022), payment competition (Liu, Reshidi and Rivadeneyra, 2023; Cong and Mayer, 2024), and welfare (e.g., Piazzesi and Schneider, 2020; Assenmacher et al., 2021; Williamson, 2022). For policy discussions on the implications of CBDC issuance, see Mancini-Griffoli et al. (2018), Gross and Letizia (2023), Claessens et al. (2024), Priazhkina (2026), etc.

[11] While there are a few papers studying the non-price design features of a CBDC, such as anonymity (Garratt and Lee, 2021; Agur, Ari and Dell'Ariccia, 2022; Ahnert, Hoffmann and Monnet, 2022; Capponi, Lee and Zhu, 2025; Cheng and Izumi, 2026; Tinn, 2026) and expiry date on offline CBDC balances (Kahn, van Oordt and Zhu, 2026), we are the first to quantify the impact of the CBDC designs in terms of interoperability and the service location network.

An alternative approach is to use surveys or experiments to elicit consumers' willingness to adopt a hypothetical CBDC. Existing studies survey households in Austria (Abramova et al., 2022), the Netherlands (Bijlsma et al., 2024), the euro area (Georgarakos et al., 2025), South Korea (Choi et al., 2025*a*,*b*), and the UK (Buckley et al., 2025). These approaches provide useful evidence, but they need to rely on consumers' understanding of hypothetical products that do not yet exist. In contrast, our approach uses preferences revealed by households' choices among existing financial products.

The rest of the paper is organized as follows. Section 2 presents the structural model of households' banking choices. Section 3 presents our data sources, identification strategies and estimation results. Section 4 shows the counterfactual analyses for CBDC. Section 5 considers several extensions. Section 6 concludes.

2 Model

The model consists of two types of agents: households indexed by $i \in \mathcal{I}$ and banks indexed by $j \in \mathcal{J}$. A household first chooses a bank to open a deposit account and then decides on the deposit and cash holdings. Throughout the paper, we focus on demand deposits, as they face direct competition from the CBDC. Thus, any mention of "deposits" refers to "demand deposits" unless stated otherwise. After choosing a deposit bank, the household may need to choose a bank for other financial products. To capture the complementarity between deposits and financial products, we allow the household to get extra utility if it chooses financial products provided by its deposit bank. The household problem generates the demand for deposits. Banks take the deposit demand as given and engage in Bertrand competition with differentiated products in the deposit market. A bank sets its deposit rate to maximize profits.

2.1 Household's Problem

Household i is endowed with w_i liquid asset balances, which they would like to hold in both the physical form (cash) and the digital form. For now, there is no CBDC and bank deposits are the only available digital liquid asset. We introduce a CBDC in Section 4. To hold deposits, the household first opens an account at a bank selected from its choice set $\mathcal{J}_i \subseteq \mathcal{J}$. Conditional on choosing deposit bank j, the household optimally allocates w_i between cash and deposits. After this,[12] the household may need to obtain a financial product $k \in \mathcal{K}$, such as a mortgage loan or a credit card, with an exogenous probability ω^k. To obtain each product $k \in \mathcal{K}$, the household needs to choose a bank n from its choice set $\mathcal{J}_i^k \subseteq \mathcal{J}^k$. To capture complementarities between deposits and other financial products within the same bank, we allow the household to enjoy extra utility if it obtains the financial product from its deposit bank.

[12]This timing assumption is supported by the Canadian household survey data from 2010–2017, where around 80% of the mortgage borrowers take out a mortgage after getting the deposit account. The median household takes out a mortgage 8 years after having the deposit account.

The household's utility from opening a deposit account at bank j is

$$V_{i,j}^f = \theta \mathbb{E}V_{i,j}^b + \phi \sum_{k \in \mathcal{K}} \omega^k \mathbb{E}V_{i,j}^k + \boldsymbol{X}_{i,j}\boldsymbol{\beta}^f + \eta_j^f + \varepsilon_{i,j}^f, \tag{1}$$

where $\mathbb{E}V_{i,j}^b$ is the expected utility from holding the optimal portfolio of cash and deposits at bank j, and $\omega^k \mathbb{E}V_{i,j}^k$ is the expected utility from obtaining the financial product k, which equals the probability of needing the financial product, ω^k, multiplied by the expected value from the financial product, $\mathbb{E}V_{i,j}^k$. We assume that when the household first chooses the deposit bank, it does not know its idiosyncratic taste for holding deposits or its idiosyncratic tastes for the banks providing other financial products. Therefore, it considers the expected value from liquid asset portfolio and from each financial product. The parameters, θ and ϕ, capture the importance of the expected utility from liquidity holding and from complementary financial products, respectively. The vector $\boldsymbol{X}_{i,j}$ contains the branch network measures of bank j that are specific to household i's local area, and $\boldsymbol{\beta}^f$ consists of the preference parameters for each branch network measure. Lastly, η_j^f is the bank fixed effect that captures unobserved heterogeneity in the quality of bank services, and $\varepsilon_{i,j}^f$ is the idiosyncratic taste of the household for bank j.

Household i chooses a bank from its choice set $\mathcal{J}_i$ to maximize its overall expected utility $V_{i,j}^f$. Assuming $\varepsilon_{i,j}^f$ follows a Type-I extreme value distribution and is independent across banks, the probability of choosing bank $j \in \mathcal{J}_i$ has the standard logit form:

$$\mathbb{P}(j_i^* = j | r_j, \boldsymbol{r}_{-j}) = \frac{\exp\left(\theta \mathbb{E}V_{i,j}^b + \phi \sum_{k \in \mathcal{K}} \omega^k \mathbb{E}V_{i,j}^k + \boldsymbol{X}_{i,j}\boldsymbol{\beta}^f + \eta_j^f\right)}{\sum_{m \in \mathcal{J}_i} \exp\left(\theta \mathbb{E}V_{i,m}^b + \phi \sum_{k \in \mathcal{K}} \omega^k \mathbb{E}V_{i,m}^k + \boldsymbol{X}_{i,m}\boldsymbol{\beta}^f + \eta_m^f\right)}, \tag{2}$$

where j_i^* denotes the optimal choice, r_j is the deposit rate of bank j, and $\boldsymbol{r}_{-j}$ is the vector of deposit rates set by banks other than j. We next discuss $\mathbb{E}V_{i,j}^b$ and $\mathbb{E}V_{i,j}^k$ in detail.

Value from Liquid Asset Portfolios. Household i obtains utility from holding $c_{i,j}$ in cash and $d_{i,j}$ in deposits at bank j:

$$\ln\left[c_{i,j}^\sigma + \left(u_{i,j}^b d_{i,j}\right)^\sigma\right]^{1/\sigma}, \tag{3}$$

where $\sigma \in (0,1)$ controls the level of substitution between physical and digital liquid assets and $u_{i,j}^b$ captures the value of deposits relative to cash. The latter depends on the after-tax deposit rate $r_{i,j}$, branch network measures $\boldsymbol{X}_{i,j}$, household characteristics $\boldsymbol{Z}_i$, bank fixed effect η_j^b, a deposit-specific constant ζ^b, and a household's idiosyncratic taste for deposits ε_i^b:

$$u_{i,j}^b = \exp\left(\alpha^b r_{i,j} + \boldsymbol{X}_{i,j}\boldsymbol{\beta}^b + \boldsymbol{Z}_i\boldsymbol{\gamma}^b + \eta_j^b + \zeta^b + \varepsilon_i^b\right), \tag{4}$$

where the parameters α^b and $\boldsymbol{\beta}^b$ measure how much the households value the respective bank-specific characteristics. The parameter vector $\boldsymbol{\gamma}^b$ captures the effects of household characteristics on $u^b_{i,j}$. The household's value from the optimal portfolio at bank j is $\mathbb{E}V^b_{i,j}$, where

$$V^b_{i,j} = \left\{ \max_{c_{i,j}, d_{i,j}} \ln \left[c^{\sigma}_{i,j} + \left(u^b_{i,j} d_{i,j} \right)^{\sigma} \right]^{1/\sigma} \right\} \quad \text{s.t.} \quad c_{i,j} + d_{i,j} = w_i \tag{5}$$

and the expectation is taken with respect to ε^b_i which is unknown at the time of choosing the deposit bank. After substituting for the optimal $d_{i,j}$ and $c_{i,j}$, one can obtain

$$\mathbb{E}V^b_{i,j} = \mathbb{E}\frac{1-\sigma}{\sigma} \ln \left[1 + \left(u^b_{i,j} \right)^{\frac{\sigma}{1-\sigma}} \right] + \ln w_i. \tag{6}$$

Moreover, household i's optimal deposit holding is

$$d_{i,j}(r_j) = \frac{(u^b_{i,j})^{\sigma/(1-\sigma)}}{1 + (u^b_{i,j})^{\sigma/(1-\sigma)}} w_i. \tag{7}$$

Therefore, household i's expected demand for deposits at bank j is $\mathbb{E}d_{i,j}(r_j)$ multiplied by the choice probability (2), where $\mathbb{E}$ is taken with respect to ε^b_i.

Value from Financial Products. If household i needs a financial product $k \in \mathcal{K}$, it will choose a bank n from its choice set $\mathcal{J}^k_i$. If the deposit bank is j, the utility of obtaining the financial product from bank n is

$$U^k_{i,n}(j) = \kappa^k \mathbb{1}(n = j) + \boldsymbol{X}_{i,n} \boldsymbol{\beta}^k + \eta^k_n + \varepsilon^k_{i,n}, \tag{8}$$

where κ^k captures the complementarity between deposits and the financial product k. All else being equal, a household prefers to obtain the product k from its deposit bank if $\kappa^k > 0$. This complementarity could reflect the convenience in paying off credit card balance from the deposit account or managing different products at the same bank, for instance. The vector $\boldsymbol{X}_{i,n}$ consists of the bank branch network measures, η^k_n is the bank fixed effect, and $\varepsilon^k_{i,n}$ is an idiosyncratic taste that follows a Type-I extreme value distribution. We assume that there is no direct complementarity among the financial products and the only complementarity is through household's deposit relationship and each other financial product. Under this assumption, bank choices for each product can be estimated separately. The unobserved idiosyncratic tastes $\varepsilon^k_{i,n}$ need not be independent across $k \in \mathcal{K}$; such cross-product correlation affects the joint distribution of choices, but it does not by itself affect the consistency of the product-specific estimates.

The parameter $\boldsymbol{\beta}^k$ reflects the importance of the branch network measures in the bank choice for product k. Let $\mathbb{E}V^k_{i,j}$ denote the expected value from product k if the deposit bank is j:

$$\mathbb{E}V^k_{i,j} = \mathbb{E}[\max_{n \in \mathcal{J}^k_i} \ U^k_{i,n}(j)], \tag{9}$$

where the expectation is taken with respect to $\varepsilon^k_{i,n}$. It can be shown that $\mathbb{E}V^k_{i,j}$ has the following closed-form expression:

$$\mathbb{E}V_{i,j}^{k} = \ln\left(\sum_{n\in\mathcal{J}_i^k} \exp\left(\kappa^k \mathbb{1}(n=j) + \boldsymbol{X}_{i,n}\boldsymbol{\beta}^k + \eta_n^k\right)\right) + C, \tag{10}$$

where C is a known constant. If $\kappa^k = 0$ for all $k \in \mathcal{K}$, the expected value from each financial product is independent of the deposit bank and thus would not affect the deposit bank choice.

The derivations above require three independence assumptions. First, within each discrete choice problem, the bank-specific idiosyncratic tastes ($\varepsilon_{i,n}^k$ and $\varepsilon_{i,j}^f$) are independent across banks. This is a standard assumption for the random utility model. Second, the idiosyncratic taste for the deposit bank $\varepsilon_{i,j}^f$ is independent of the idiosyncratic taste for holding deposits ε_i^b. This implies that $\mathbb{E}V_{i,j}^b$ in the deposit bank choice does not depend on $\varepsilon_{i,j}^f$, and preserves the logit form of the choice probabilities. Third, $\varepsilon_{i,n}^k$ is independent of $\varepsilon_{i,j}^f$. This assumption is important for identifying κ. These assumptions greatly simplify the estimation, and Section 3.2 discusses their implications.

2.2 Banks' Problem

Aggregating across the households' individual deposit demand, we obtain the deposit demand for each bank j:

$$D_j(r_j, \boldsymbol{r}_{-j}) = \sum_{i\in\mathcal{I}} \mathbb{P}(j_i^* = j | r_j, \boldsymbol{r}_{-j}) \mathbb{E}d_{i,j}(r_j), \tag{11}$$

where $\mathbb{P}(j_i^* = j|r_j, \boldsymbol{r}_{-j})$ is defined by (2) and $d_{i,j}$ is defined by (7). We assume banks invest in assets with an exogenous return r_j^l. Let mc_j denote bank j's marginal cost. Bank j takes the deposit rates of other banks, $\boldsymbol{r}_{-j}$, as given and chooses a deposit rate r_j to maximize its profit:

$$\pi_j(r_j, \boldsymbol{r}_{-j}) = (r_j^l - r_j - mc_j) D_j(r_j, \boldsymbol{r}_{-j}). \tag{12}$$

Let $\boldsymbol{r^*} = (r_1^*, r_2^*, \cdots, r_J^*)$ denote the equilibrium deposit rates. They satisfy the set of first-order conditions of banks:

$$r_j^l - r_j^* - mc_j = \left[\frac{\partial D_j(r_j^*, \boldsymbol{r^*}_{-j})}{\partial r_j^*} \frac{1}{D_j(r_j^*, \boldsymbol{r^*}_{-j})}\right]^{-1}, \ \forall j, \tag{13}$$

where the left-hand side is the markup and the right-hand side is the inverse semi-elasticity of deposit demand. Once a CBDC is introduced, a household can choose to hold its digital money in either the CBDC or an incumbent bank. This tends to reduce the probability of choosing any existing bank and makes the deposit demand more elastic. Online Appendix E.6 considers an extension in which banks earn profits from broader customer relationships associated with deposit customers, not only from deposit balances. This extension changes the interpretation of the calibrated marginal cost: observed rates and market shares pin down the net value of retaining a deposit customer, so allowing for relationship profits mainly reallocates that net value between deposit costs and non-deposit relationship profits, leaving the counterfactual incentives essentially unchanged.

2.3 Applying the Model for CBDC Counterfactuals

In this section, we clarify the key assumptions for using this model to study CBDC counterfactuals. Since retail CBDC has not yet been introduced in most countries, empirically studying CBDC is a challenging question. We use a random utility model to model CBDC as a new digital money alternative with a bundle of attributes and unobserved appeal. We use data on existing products (i.e., demand deposits) that are close alternatives to CBDC, to estimate household preferences for those attributes. Assuming these preference parameters remain unchanged after CBDC issuance, we combine them with CBDC attributes chosen by the central bank to predict CBDC demand. This structural approach has been used in recent work on CBDC demand (e.g., Li, 2023; Whited, Wu and Xiao, 2023).

A key feature of the random utility model is that household choices depend not only on observed product attributes, but also on idiosyncratic tastes. The implication is that if CBDC is a slightly better product in the observed attributes, it will not capture the entire market, because some households may still have strong idiosyncratic preferences for bank deposits. Conversely, the model does not mechanically rule out high CBDC adoption. In a random utility model, the extent of market tipping depends on the importance of observed attributes relative to idiosyncratic tastes. If observed attributes are sufficiently important relative to idiosyncratic tastes, even a small advantage in those attributes can lead nearly all households to adopt the CBDC. This relative importance is disciplined by the estimated coefficients, so the counterfactual adoption patterns reflect the strength of preferences in the data rather than a mechanical restriction against large CBDC adoption. As shown in Section 4.1, the CBDC will dominate the market under certain designs.

Second, there are other attributes that we do not separately model in the baseline specification, such as payment convenience and privacy, which are instead captured by the CBDC fixed effect. While bank fixed effects can be estimated from observed deposit choices, the CBDC fixed effect must be specified in the counterfactuals. The results should therefore be interpreted as conditional predictions under the specified CBDC design and fixed effect assumptions. In an extension in Online Appendix E.3, we incorporate payment-related features through their effects on households' willingness to hold CBDC. We do not directly model the CBDC payment network or the transaction volume of CBDC.

3 Data and Estimation Results

Section 3.1 provides a detailed discussion on the data used for estimating the model. Section 3.2 discusses estimation and identification. Section 3.3 then presents the estimation results for the households' preferences on the demand side and banks' marginal costs on the supply side.

3.1 Data

Estimating the model requires (1) information on households, including their bank choices for different financial products, allocations of liquid assets, residential locations, and other demographic characteristics, and (2) information on banks, such as their interest rates and branch locations. We obtain this information by combining three main data sources, i.e., the Canadian Financial Monitor (CFM) household survey, the Financial Consumer Agency of Canada (FCAC) data on branch locations, and CANNEX data on interest rates.

The CFM household survey is a syndicated survey run by Ipsos, a large international market research firm. Details on survey recruitment and participation incentives are provided in Online Appendix A.1. A unique feature of the data is that they contain information on a household's deposit bank and its bank choices for other financial products, including mortgage loans, credit cards, and guaranteed investment certificates (GICs).[13] For each product, we observe household choices across a diverse set of banks and credit unions, which we collectively refer to as banks for convenience.[14] This allows us to estimate the preference parameter for complementarity for each of these financial products – if a bank is chosen as a deposit bank, how likely a household will choose it for another financial product.

The data also contain information on a household's allocation of liquid assets, defined as the sum of cash and demand deposits. Cash is measured by the sum of cash in the wallet and precautionary holdings of cash. Demand deposits are measured by the sum of chequing, chequing/saving, and saving account balances. In our sample, a median household holds around 5% of its liquid assets in cash ($195 in cash and $3,500 in demand deposits). Moreover, the data record each household's residential location by postal code, which provides relatively precise geographic information. In many cases, postal codes uniquely identify areas as small as a condominium building or a group of houses in a suburb (Perez-Saiz and Xiao, 2022). We use the sample period of 2010–2017 because the survey questions on cash are consistent throughout this period.

The FCAC data contain addresses of all existing branches of banks and credit unions in 2019. They also record all branch closures between 2005 and 2020. We combine the two sets of information to construct bank branch locations in years other than 2019. Together with households' locations, we calculate the great-circle distance from each household to each branch location, allowing us to construct the accessible branch network for each household. Based on this distance measure, we construct the choice set of each household by assuming that a household considers all available banks that have a branch within a certain distance from its residence. Since the travel cost is

[13] More than 70% of households go to one bank for demand deposits, as shown in Table A1 in Appendix A.3. The fraction of households that have a single mortgage bank, credit card issuer, and GIC issuer is 98%, 42%, and 78%, respectively. For households that have multiple deposit banks, we use their main financial institution where they have the largest deposit balance. Similarly, we assume their main mortgage bank, credit card issuer, and GIC issuer are the ones with the largest remaining mortgage payment, the highest current balance, or the highest GIC balance, respectively.

[14] More precisely, we observe 20 deposit-taking banks in total. For other financial products, we observe a few additional institutions. For example, in addition to the banks available for deposits, households can also choose American Express and Capital One for credit cards.

different between urban and rural areas, we assume that an urban household considers all banks with a branch within 15 kilometers of its residence and a rural household considers banks with a branch within 50 kilometers.[15] We measure a bank's branch network using the distance from a household to the nearest branch of the bank, and the number of the bank's branches located within the household's choice set.[16]

CANNEX provides bank-level interest rates of demand deposits and mortgage loans. We observe the rates on demand deposits for the big five banks, National Bank, and Laurentian Bank from 2010 to 2017. In our sample, 70% of households choose the big five banks and National Bank as their main financial institutions. We assume the deposit rates of the other banks are equal to the average rates of the big five banks and National Bank. We did not use Laurentian Bank for imputation because it is a small bank that mostly operates in Quebec and offers much higher rates than the other banks. Alternative imputation methods yield very similar results.[17] Since households care about the after-tax interest income, we calculate the after-tax interest rates by combining the bank-level deposit rates with household income information from the CFM data and the federal and provincial income tax rates from the Government of Canada website.

We use mortgage rates to measure the exogenous return on assets r_j^l. This is without loss of generality because $(r_j^l - mc_j)$ is identified from (13) given the demand-side parameters and is sufficient for counterfactual analysis. The level of r_j^l does not affect the counterfactual analysis and is only used as a sanity check for the estimated marginal costs. For the mortgage rate, we consider the 5-year closed mortgages, which are the most popular product in Canada. The mortgage rates are available for the big five banks and National Bank, and the average mortgage rate of these six banks is used for mortgage loans at other banks. Summary statistics of the key variables are shown in Online Appendix A.6.

3.2 Estimation and Identification of the Demand Parameters

We estimate the demand-side parameters in three steps. First, we estimate parameters governing households' portfolio allocation between cash and deposits. Second, we estimate the parameters in bank choices for mortgage loans, credit cards, and GICs using conditional logit models. Third, for each household-bank pair, we use the first two sets of estimates to construct two inputs to the household's utility from choosing each deposit bank: the expected utility from liquid asset holdings and the expected utility from complementary financial products. We then estimate the parameters

[15]The estimation and counterfactual results are robust to alternative choice set definitions – such as 10 km, as in Allen, Clark and Houde (2019), or 30 km for urban households, and 30 km or 70 km for rural households.

[16]For online banks, we include a separate fixed effect to account for their unobservable branch presence. For estimation, we assume online banks have no physical branches and assign a distance of 15 km for urban households and 50 km for rural ones. The results are robust to this assumption due to the presence of the fixed effect. For example, we used 50 km or 100 km uniformly across all households and obtained nearly identical estimates.

[17]For example, including Laurentian Bank for imputation leads to similar estimates. We also tried using the average spread between GIC and demand deposit rates for the big five banks and National Bank to impute deposit rates for six additional banks with available short-term GIC rates but unobserved demand deposit rates. As shown in Table D11 in Online Appendix D.3, adding the cross-bank variation from those six banks has a negligible impact on the deposit rate coefficient.

in the deposit bank choice problem. With the estimates of all the demand-side parameters, we can obtain bank j's deposit demand as a function of the deposit rates, $D_j(r_j, \boldsymbol{r}_{-j})$. Then the estimates of banks' marginal costs are obtained from (13) once we replace $D_j(r_j, \boldsymbol{r}_{-j})$ by their estimates. Online Appendix B provides the identification and estimation details. Below, we summarize the main identifying variation and assumptions.

First, the deposit rate in the portfolio choice is potentially endogenous because it may respond to unobserved demand shocks. We follow Egan, Hortaçsu and Matvos (2017) and instrument the deposit rate using interactions between bank indicators and the policy rate. Year fixed effects absorb the common policy rate movement, so identification comes from heterogeneous pass-through of policy rate changes across banks. This heterogeneity reflects differences in banks' funding models, asset portfolios, and pricing strategies. The key identifying assumption is that, conditional on the included controls and fixed effects, banks' heterogeneous pass-through of policy rate changes is not systematically correlated with unobserved bank-specific time-varying shocks that affect consumers' portfolios of cash and deposits. This assumption would be violated, for example, if policy rate changes responded to demand shocks specific to a subset of banks, or if other unobserved shocks affected consumers' deposit demand differentially across banks in a way correlated with banks' policy rate pass-through.

The difference from Egan, Hortaçsu and Matvos (2017) is that we control for bank heterogeneity using the grouped bank fixed effects rather than the individual bank fixed effects. Including individual bank fixed effects absorbs much of the identifying variation, leaving the excluded instruments with limited explanatory power for deposit rates and a weak first stage. We therefore group banks into the big five banks, small banks, online banks, Desjardins credit union, and other credit unions, and include a fixed effect for each group. The grouping is based on standard institutional distinctions in the Canadian deposit market. The big five category captures nationally dominant banks with broad branch networks and large customer bases. We separate Desjardins from other credit unions because it is a large cooperative financial group whose local member institutions operate under a common brand and institutional structure. These grouped fixed effects absorb the main persistent differences across institution types while preserving enough variation in deposit rate pass-through to obtain a relevant first stage.

Second, we observe portfolio allocation only at the chosen deposit bank. Under our baseline timing assumption, the idiosyncratic taste shock for holding deposits relative to cash, ε_i^b, is not realized when the household chooses its deposit bank. Therefore, this unobserved shock does not affect which bank the household chooses, allowing us to estimate the portfolio allocation and deposit bank choice problems separately. Online Appendix D.5 considers an alternative timing assumption in which this shock is known at the time of deposit bank choice, so ε_i^b affects both the portfolio allocation and the deposit bank choice. Under that assumption, we estimate the two equations jointly; the results are similar.

Third, the complementarity parameter κ^k is identified from households' higher propensity to choose their deposit bank for financial product k, conditional on bank characteristics. If idiosyncratic tastes for product k's bank choice $\varepsilon_{i,n}^k$ are positively correlated with the idiosyncratic tastes for deposit bank choice $\varepsilon_{i,j}^f$, κ^k may overstate the true complementarity. As a result, CBDC adoption can be understated if the CBDC has a low level of interoperability with banks and overstated if it has a high level of interoperability. To partly control for the correlated tastes, we report robustness checks that add interaction terms between bank fixed effects and household characteristics in the bank choices for each product k in Online Appendix D.4; the estimates of κ^k are similar.

Fourth, branch networks may be endogenous because banks choose branch locations strategically. If banks open branches in neighborhoods where they expect stronger demand or higher-income customers, the branch network coefficients may partly capture unobserved local bank attractiveness, which could overstate the value of branch access. Conversely, if banks expand into markets where they are otherwise less attractive, the estimates could understate it. To alleviate this concern, we report robustness checks that interact grouped bank fixed effects with household demographics and with local population density groups in Online Appendix D.2. In both cases, the branch network remains important.

Finally, we can only identify the scaled coefficients $\tilde{\nu} = \sigma\nu/(1-\sigma)$ for each parameter $\nu \in \{\alpha^b, \boldsymbol{\beta}^b, \boldsymbol{\gamma}^b, \boldsymbol{\eta}^b, \zeta^b, \varepsilon_i^b\}$ because the value of deposits relative to cash in the portfolio allocation problem depends on σ and ν in a multiplicative way. Similarly, in the deposit bank choice equation, we can only identify the scaled coefficient $\tilde{\theta} = (1-\sigma)\theta/\sigma$ on $\mathbb{E}\tilde{V}_{i,j}^b = \mathbb{E}\ln\left[1 + u_{i,j}^{\sigma/(1-\sigma)}\right]$. The scaled parameters are sufficient for constructing the expected value from liquid asset holdings used in the deposit bank choice equation and for the main counterfactuals. Only the CBDC holding limit counterfactual scenarios require a calibrated value of σ, in which case we show that our results are robust to a wide range of σ values.

3.3 Estimation Results

Table 1 shows the estimated parameters for the deposit rates and the branch network measures (i.e., $\tilde{\alpha}^b$, $\tilde{\boldsymbol{\beta}}^b$) in the portfolio allocation problem. The parameters for the household characteristics, bank fixed effects, and the deposit-specific constant (i.e., $\tilde{\boldsymbol{\gamma}}^b$, $\tilde{\boldsymbol{\eta}}^b$, $\tilde{\zeta}^b$) are shown in Table B5 in Online Appendix B.4. As discussed in Section 3.2, we instrument the deposit rate using the bank-specific pass-through of the policy rate. The deposit rate has a significantly positive effect on the allocation of liquid assets. Overall, easier access to bank branches increases the deposit-to-cash ratio, which is consistent with the classic Baumol-Tobin model.

Table 2 shows the estimates for the preference parameter for complementarity κ^k and bank branch network $\boldsymbol{\beta}^k$ in the households' bank choices for credit cards, mortgage loans, and GICs. Individual bank fixed effects are included to absorb the cross-bank variation in prices and other unobserved bank quality,[18] which are shown in Table B7 in Online Appendix B.4. The estimated κ^k implies that households have a strong preference for getting the considered financial product from their deposit banks. This is not surprising because 45% of credit card holders get their credit

[18]We report robustness checks that include GIC and mortgage rates in the respective bank choices in Online Appendix D.1; the estimates of κ^k and the counterfactual results are similar.

Table 1: Estimated Parameters in Portfolio Allocation Choice

Dependent variable: Log of deposit-to-cash ratio	
Post-tax deposit rate	0.714***
	(0.269)
ln(Distance to branch)	0.004
	(0.011)
ln(Distance to branch) × Live in rural area	-0.053***
	(0.016)
ln(Number of branches + 1)	0.024***
	(0.009)
ln(Number of branches + 1) × Live in rural area	-0.026
	(0.017)
Observations	62,504
Olea-Pflueger effective F	59.78
Olea-Pflueger 10% critical value	16.96

Standard errors clustered at bank-year level in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Data sources: CFM 2010–2017, CANNEX 2010–2017, FCAC, Government of Canada website, Statistics Canada
Note: The table shows a subset of the estimated parameters from the IV regression of the log of deposit-to-cash ratio on the post-tax deposit rates, bank branch network, grouped bank fixed effects, and household characteristics (including region and year fixed effects), instrumenting for the deposit rate using banks' heterogeneous pass-through of policy rates. "Observations" shows the number of households in the CFM sample.

Table 2: Estimated Parameters from Bank Choices of Different Financial Products

	(1) Credit Card	(2) Mortgage	(3) GIC
Preference for Complementarity	2.351***	2.671***	2.916***
	(0.010)	(0.016)	(0.018)
ln(Distance to branch)	-0.117***	-0.123***	-0.156***
	(0.008)	(0.015)	(0.015)
ln(Distance to branch) × Live in rural area	0.003	-0.026	-0.055**
	(0.013)	(0.024)	(0.025)
ln(Number of branches + 1)	0.083***	0.132***	0.086***
	(0.007)	(0.014)	(0.014)
ln(Number of branches + 1) × Live in rural area	0.030**	0.044*	-0.026
	(0.014)	(0.026)	(0.026)
Observations	1,075,719	314,230	292,732
Number of choice sets	72,449	24,603	22,858

Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Data sources: CFM 2010–2017, CANNEX 2010–2017, FCAC, Government of Canada website
Note: Each column corresponds to a conditional logistic regression of the bank choice for a given financial product (i.e., credit card, mortgage loan, guaranteed investment certificate GIC) on the deposit bank indicator, branch network variables, and bank fixed effects. "Number of choice sets" denotes the number of households in the sample, while "Observations" represents the cumulative total of alternatives/banks within each household's choice set.

cards from their deposit banks and more than half of mortgage borrowers borrow from their deposit banks, as shown in Table 3.

Table 4 shows the estimated coefficients (i.e., $\tilde{\theta}, \phi, \boldsymbol{\beta}^f$) on the expected utility from liquid asset holdings, $\mathbb{E}\tilde{V}_{i,j}^b$, the sum of expected utilities from other financial products, $\sum_{k\in\mathcal{K}} \omega^k \mathbb{E}V_{i,j}^k$, and the

Table 3: Fraction of Households with Different Financial Products

	Have the product	Have the product from deposit bank
Credit Card	0.90	0.45
Mortgage	0.30	0.56
Guaranteed Investment Certificates	0.29	0.55

Data sources: CFM 2010–2017. Note: The table reports, for each financial product, the share of households that hold the product and, among holders, the share that obtain it from their deposit bank.

Table 4: Estimated Parameters in Deposit Bank Choice

Variables	Estimates
Expected utility from liquidity holding	1.623***
	(0.147)
Sum of expected utilities from financial products	1.364***
	(0.038)
ln(Distance to branch)	-0.175***
	(0.008)
ln(Distance to branch) × Live in rural area	0.112***
	(0.014)
ln(Number of branches + 1)	0.439***
	(0.010)
ln(Number of branches + 1) × Live in rural area	0.229***
	(0.021)
Observations	674,536
Number of choice sets	62,504

Robust standard errors in parentheses. * $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$
Data sources: CFM 2010–2017, CANNEX 2010–2017, FCAC, Government of Canada website, Statistics Canada
Note: The table reports selected parameters from a conditional logistic regression of the deposit bank choice on the expected utility from liquid asset holdings, the sum of expected utilities from financial products, the branch network measures, and grouped bank fixed effects. "Number of choice sets" denotes the number of households in the sample, while "Observations" represents the cumulative total of alternatives/banks within each household's choice set.

branch networks, respectively, in the deposit bank choice problem. The estimated bank fixed effects $\boldsymbol{\eta}^f$ are shown in Table B8 in Online Appendix B.4. As seen in Table 4, the estimates of $\tilde{\theta}$ and ϕ indicate that households take into account the expected utility from liquidity holding and from complementarity with financial products when choosing their deposit banks.

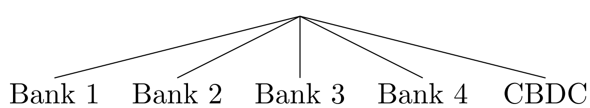
The branch network affects the choice probabilities of the deposit bank through one direct and two indirect channels. First, it directly affects the choice probabilities through the preference over the branch network, which is captured by $\boldsymbol{\beta}^f$. Second, it indirectly affects the choice probabilities through the value from liquid asset holdings and the value from complementary financial products. Through the direct channel, an increase in 1 km of the branch distance would reduce the choice probability by around 10% in urban areas. Adding a branch increases a bank's probability of being selected by about 14%. Rural households are more tolerant of distance, with a 1 km increase in distance barely reducing the likelihood of choosing a bank. However, given the low number of branches in rural areas, adding one branch would increase the choice probability by around 25%.

With the demand-side estimates, we obtain the estimated markups, or equivalently, the inverse semi-elasticities of deposit demand. We then use (13) to obtain the supply-side parameters, i.e., banks' marginal costs. Figure B5 in Online Appendix B.4.2 plots banks' markups and marginal costs against their market shares in the year 2017. The estimated markups range from 1.4% to around 2.6%, which are comparable to findings in existing studies using the US data. For example, the deposit demand elasticity is around 0.73, with an average deposit rate of 1.7% in Xiao (2020) and 0.56 at a deposit rate of 1% in Egan, Hortaçsu and Matvos (2017). This implies a markup of around 2.3% and 1.8%, respectively. The estimated marginal costs range from 2.2% to 3.3%, with a mean of around 3.1% in 2017.

4 Counterfactual Analyses

This section evaluates what would have been the impact of introducing a CBDC in 2017 on the Canadian banking sector. We model the CBDC as a new product that is added to every household's choice set for digital money, as illustrated in Figure 1. Households can choose to hold either the CBDC or bank deposits but not both. Section 5.2 studies an extension that allows a household to hold both the CBDC and deposits.

Figure 1: Choice Set for Holding Liquid Digital Assets after CBDC Issuance



We assume that households' preference parameters and banks' cost parameters remain unchanged after CBDC issuance.[19] We then combine the estimated preference parameters with exogenously chosen CBDC design attributes to obtain each household's utility from holding CBDC. This allows us to compute the new deposit demand faced by each bank and solve for the resulting equilibrium. Online Appendix C.1 provides additional details.

4.1 CBDC Designs and Aggregate Impact of CBDC

This section studies how the CBDC design attributes affect CBDC adoption and its crowding-out effect, focusing on three design attributes: the interest rate, the service location, and interoperability with incumbent banks. Each remains an active design choice in current CBDC projects, as will be discussed below.

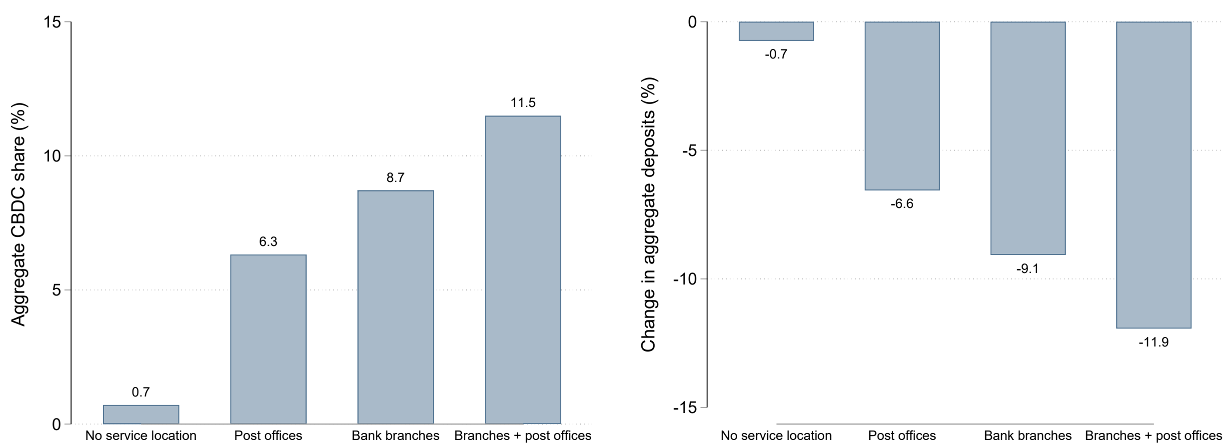
[19]For example, households value CBDC service locations in the same way they value bank branches. This is plausible because the important functions of branches, such as cash withdrawal and customer service/support, are also likely to matter for CBDC. Online Appendix D.6 relaxes this assumption by varying the CBDC service location preferences.

Minimal Design. We start with a minimal design where the CBDC is non-interest-bearing and is not interoperable with banks. We consider four service location networks: no service location, all Canada Post offices, all bank branches, and both bank branches and Canada Post offices. This minimal design provides a clean reference point for evaluating richer designs that add interoperability or remuneration.

Figure 2 reports the aggregate CBDC share and the change in aggregate deposits for this minimal design, isolating the role of the service location network. If the CBDC has no service location, households allocate only about 1% of their liquid assets to it, and the effect on aggregate deposits is correspondingly small. Providing services at all post offices raises the CBDC share to about 6%. The most extensive network, combining all bank branches and post offices, raises the CBDC share to more than 11% and reduces aggregate deposits by around 12%. Thus, even without interest or interoperability, the service location network alone can make a CBDC attractive.

Figure 2: Non-interest-bearing CBDC with No Interoperability

(a) Aggregate CBDC share (b) Percentage change in deposits



Data sources: CFM 2017, FCAC 2017, Canada Post 2021, Government of Canada website, Statistics Canada
Note: This figure shows (a) the aggregate CBDC share, measured as the share of liquid assets that households allocate to CBDC in equilibrium, and (b) the percentage decline in aggregate deposits relative to the pre-CBDC equilibrium, across four service location networks. Here, CBDC is non-interest-bearing, with no interoperability, and has a fixed effect equal to the estimated fixed effect for the big five banks.

Introducing CBDC Interoperability. In the absence of CBDC, a household enjoys the complementarity κ^k if it obtains financial product k from its same deposit bank. Although the central bank does not provide these products, an *interoperable* CBDC can provide broader complementarity by integrating with banks' digital platforms. In principle, this could allow users to easily use CBDC to make payments related to the other financial products offered by any of the participating banks and manage those products through a unified interface, for instance.[20] However, in reality,

[20]For example, the e-CNY app is an official platform that integrates the wallet services of authorized operators. See https://play.google.com/store/apps/details?id=cn.gov.pbc.dcep. For the digital euro, banks and other payment

the exact functionalities are still evolving design questions. As a consequence, we assume that a household i choosing CBDC for digital money can enjoy complementarity $\iota\,\kappa^k$ if it obtains financial product k from any of the participating banks $n \in \mathcal{B}$:

$$U^k_{i,n}(cbdc;\iota) = \iota\,\kappa^k \mathbb{1}\{n \in \mathcal{B}\} + \boldsymbol{X}_{i,n}\boldsymbol{\beta}^k + \eta^k_n + \varepsilon^k_{i,n}, \tag{14}$$

where $\mathcal{B}$ is the set of participating banks, which we assume to be the big five banks in the main counterfactuals, and ι measures the degree of interoperability. This implies

$$\mathbb{E}V^k_{i,cbdc}(\iota) = \ln\left(\sum_{n\in\mathcal{J}^k_i} \exp\left(\iota\,\kappa^k \mathbb{1}\{n \in \mathcal{B}\} + \boldsymbol{X}_{i,n}\boldsymbol{\beta}^k + \eta^k_n\right)\right) + C, \tag{15}$$

where $\mathcal{J}^k_i$ is household i's choice set of banks for product k, which does not include CBDC. When $\iota = 0$, CBDC is not interoperable and provides no complementarity benefit. When $\iota > 0$, CBDC preserves a fraction ι of the same-bank complementarity for products offered by big five banks. Unlike a bank deposit account, which provides κ^k only when product k is held at the *same deposit bank*, as shown in (10), an interoperable CBDC provides $\iota\,\kappa^k$ for product k held at *any of the big five banks*.

Figure 3 shows that interoperability is an important design attribute. With post offices as service locations, adding interoperability raises the CBDC share from about 6% to about 21% and increases the corresponding crowding-out effect. In an upper-bound scenario with $\iota = 1$, where CBDC fully preserves the estimated same-bank complementarity κ^k for financial products from the big five banks, the CBDC share rises to 62% with post offices as service locations. Interoperability has a larger effect when CBDC is already attractive through its service location network because the added benefit makes CBDC preferable to deposits for many more households. In the remaining counterfactuals, we focus on Big Five interoperability with $\iota = 0.5$. The idea is that CBDC may be widely integrated into banks' digital platforms while offering more limited functionality than bank deposits for managing bank-specific products. For example, China's e-CNY is integrated with the mobile apps of authorized banks, but it appears to offer more limited functionality for bank-product services than bank deposits.

Adding CBDC Interest Rate to the Design. While many central banks have discussed a non-interest-bearing CBDC, e-CNY will be made interest-bearing, showing that CBDC remuneration remains a relevant design choice.[21] Figure 4 adds the CBDC interest rate to the design by varying the CBDC interest rate from 0 to 1%. For each rate, it reports equilibrium outcomes for four combinations of service location and interoperability designs: no service locations or post offices,

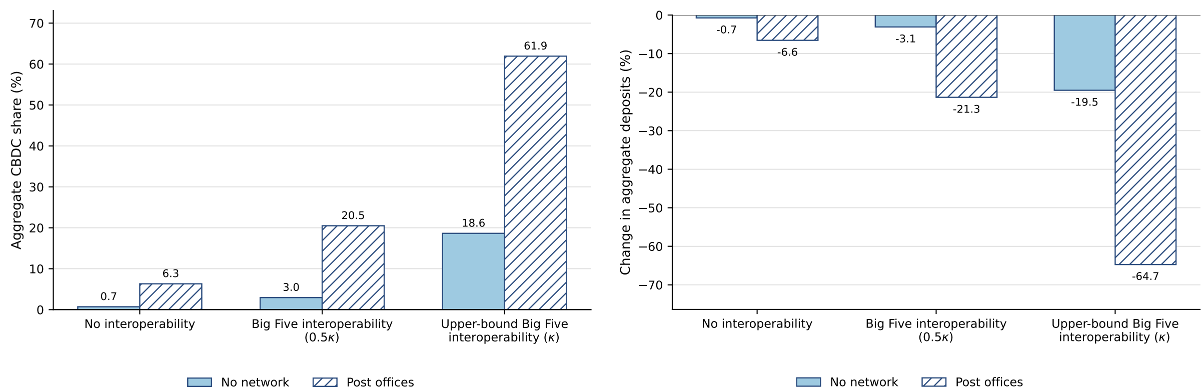
service providers could also integrate digital euro services into their existing apps. See the ECB digital euro explainer, https://www.ecb.europa.eu/euro/digital_euro/timeline/profuse/shared/pdf/ecb.dedocs231018_2.en.pdf.

[21] We treat the CBDC rate as an exogenous design choice, consistent with current CBDC proposals that specify remuneration as part of the policy design. Online Appendix E.5 considers endogenous rate-setting by the central bank as an extension.

Figure 3: CBDC Share and Change in Aggregate Deposits by Degree of CBDC Interoperability

(a) Aggregate CBDC share

(b) Change in aggregate deposits



Data sources: CFM 2017, FCAC 2017, Canada Post 2021, Government of Canada website, Statistics Canada
Note: This figure reports (a) aggregate CBDC share, measured as the share of liquid assets that households allocate to CBDC in equilibrium, and (b) the percentage change in aggregate deposits relative to the pre-CBDC equilibrium under three different levels of interoperability. Bars compare CBDC with no service location network vs with post offices as service locations. In the (upper-bound) Big Five interoperability case, a CBDC holder can enjoy 50% (100%) of the estimated same-bank complementarity benefit if it obtains financial products from any of the big five banks. Here, the CBDC is non-interest-bearing with a fixed effect equal to that of the big five banks.

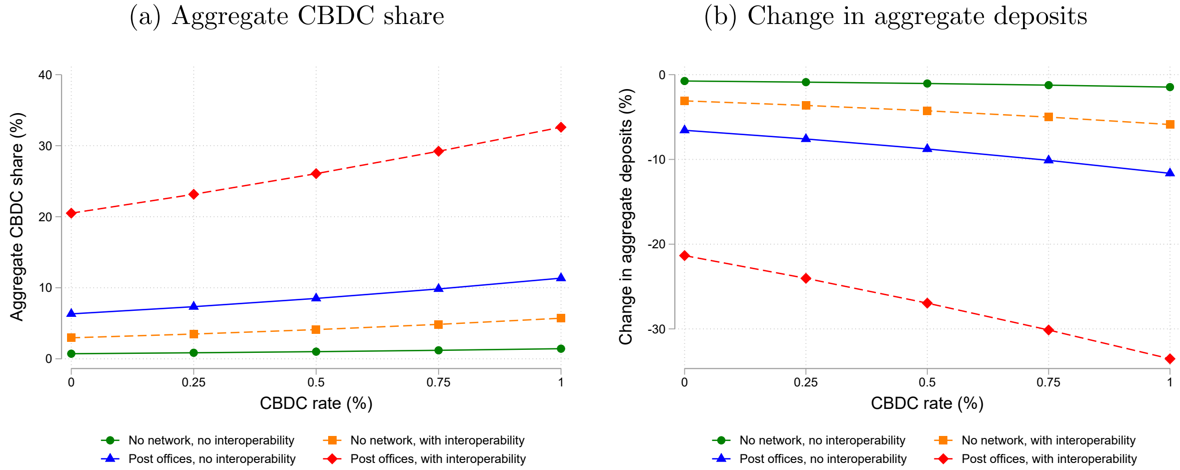
each with and without interoperability. A higher CBDC interest rate further increases the aggregate CBDC share and its crowding-out effect, especially for CBDC that is already attractive in terms of the service location and interoperability. With post offices and interoperability set to $\iota = 0.5$, the CBDC share increases from around 20% to more than 30%.

Varying CBDC Fixed Effects. The CBDC fixed effect captures unobserved CBDC appeal not explained by the modeled attributes. Because CBDC is not observed in the estimation sample, its fixed effect is not directly identified from households' choices. In the main counterfactuals, we set it equal to the fixed effect estimated for the big five banks. Online Appendix C.4.2 reports equilibrium outcomes under alternative CBDC fixed effect assumptions spanning the full range of the estimated bank fixed effects. A more favorable fixed effect raises CBDC adoption and the crowding out of deposits, especially when CBDC is already attractive through its modeled attributes. Under the minimal design, with no remuneration, no interoperability, and no service locations, deposit crowding out remains between about 0.6% and 1.5% across fixed effect assumptions. Under the most extensive service location network, the deposit decline ranges from about 9% to 20%.

More CBDC Design Features. In addition to the three design features studied above, payment characteristics, privacy, safety, issuer quality or trust can all be important attributes that differentiate between CBDC and deposits. Our baseline analysis does not separately model these attributes. Instead, their net effect is captured by the assumed CBDC fixed effect, which represents unobserved product appeal not explained by the modeled attributes.

Online Appendix E.3 studies an extension that incorporates five payment characteristics: ease

Figure 4: CBDC Share and Change in Aggregate Deposits by CBDC Interest Rates



Data sources: CFM 2017, FCAC 2017, Canada Post 2021, Government of Canada website, Statistics Canada
Note: This figure plots (a) aggregate CBDC share, measured as the share of liquid assets that households allocate to CBDC in equilibrium, and (b) the percentage change in aggregate deposits relative to the pre-CBDC equilibrium across CBDC designs that vary the CBDC interest rate, service location network, and degree of interoperability. "With interoperability" means a CBDC holder can enjoy 50% of the estimated same-bank complementarity benefit if it obtains financial products from any of the big five banks. Here, the CBDC fixed effect is set to equal the estimated fixed effect of the big five banks.

of use, cost, security, anonymity and budgeting usefulness into the portfolio allocation problem between deposits and cash. These variables are available only for the small subset of CFM households who also completed the Methods-of-Payment survey. We use this merged sample to re-estimate the model. Among these features, we find that security, anonymity, and budgeting usefulness are more important, which is consistent with the findings in the literature (e.g., Li, 2023). When CBDC is assigned the most favorable payment characteristics, its aggregate share reaches 23% under the most extensive service location network, even with zero remuneration and no interoperability. Online Appendix E.4 uses JD Power's bank-level customer satisfaction score to proxy for issuer quality and re-estimate the model with the score included in the deposit bank choice. As shown, a higher calibrated CBDC issuer quality similarly raises adoption.

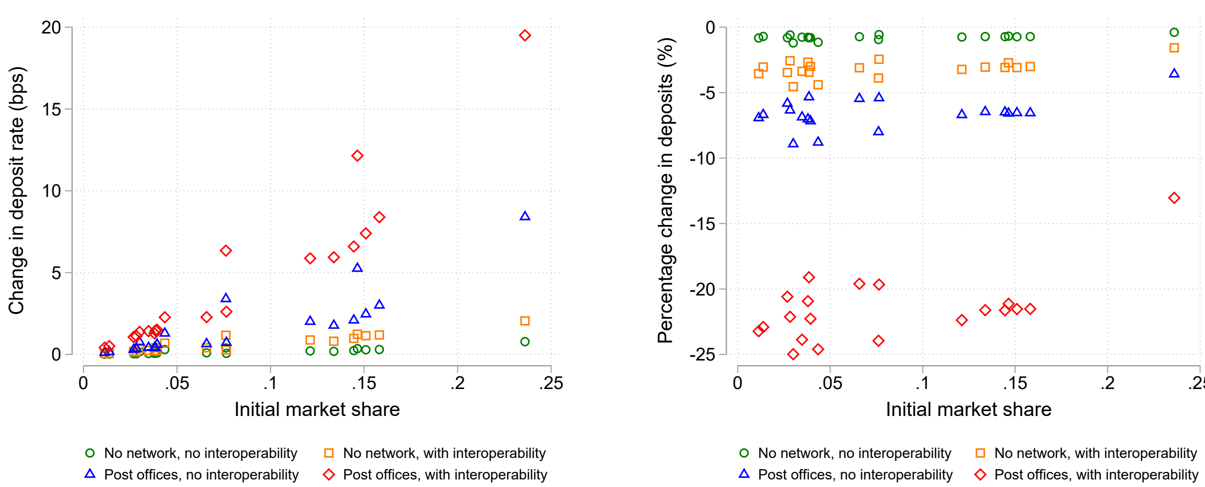
4.2 Heterogeneous Impact of CBDC on Banks and Households

This section studies how the impact of CBDC varies across banks and households. For banks, we focus on how the impact depends on banks' market power. For households, we examine heterogeneity in CBDC adoption and consumer surplus gains by urban vs rural, income, and age groups. Following the insight in Petrin (2002), we interpret the level of model-implied consumer surplus gains with caution and view them as depositor surplus changes under specified CBDC designs, rather than assumption-free estimates of the welfare value of CBDC entry. The heterogeneity analysis below compares these model-implied gains across household groups, rather than emphasizing their absolute level.

Impact of CBDC on Banks with Different Market Shares. We measure banks' market power using their initial market shares before the CBDC is introduced; using markups gives a similar ordering because market shares and markups are highly correlated. Figure 5a shows that, across all four designs, banks with larger initial market shares raise deposit rates more in response to the CBDC. The heterogeneity in rate responses is greater when the CBDC design is more attractive, primarily because banks with greater market power respond more aggressively. Figure 5b further shows that larger banks experience smaller deposit losses, consistent with their stronger deposit rate response.[22]

Figure 5: Impacts of CBDC on Banks with Different Initial Market Shares

(a) Level change in deposit rate (b) Percentage change in deposits



Data sources: CFM 2017, FCAC 2017, Canada Post 2021, Government of Canada website, Statistics Canada
Note: This figure reports bank-level responses to a non-interest-bearing CBDC with the big five bank fixed effect. The four designs vary service locations and interoperability as in Figure 4. The x-axis is each bank's initial market share, calculated by averaging the estimated probabilities of households choosing the bank across all local markets (around households' residences) in which the bank operates.

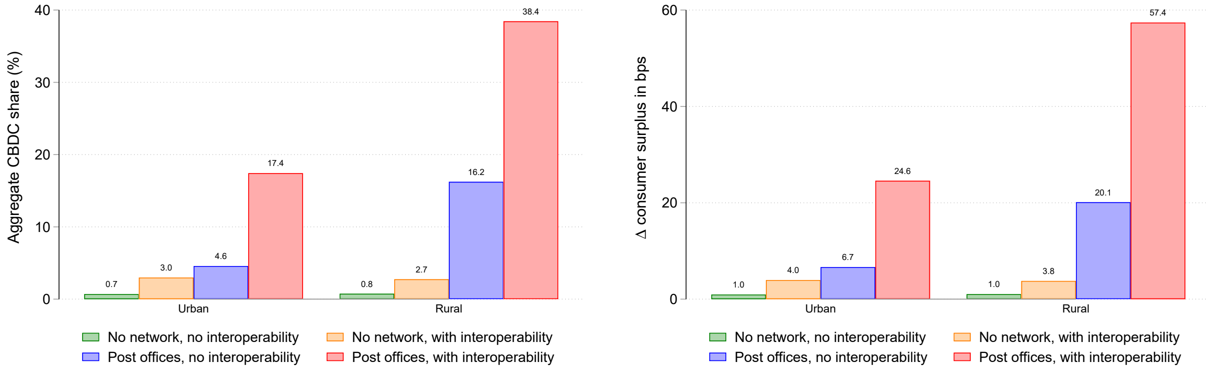
Rural vs Urban Households: Heterogeneous Tastes for Service Locations. Figure 6 shows that when CBDC has no service locations, the adoption and consumer surplus gains are similar for both urban and rural households. In contrast, when post offices are used as service locations, rural households hold more CBDC and gain more because their access to branches is more limited. In addition, Figure C10 in Online Appendix C.4.3 shows that compared to bank branches as service locations, post offices would make the rural households gain more because postal network provides broader coverage in rural areas than the bank branch network.

Low- vs High-Income Households: Heterogeneous Rate Sensitivity. Our baseline specification estimates a single deposit rate coefficient common to all households. To capture potential

[22] Figure C7 in Online Appendix C.4.1 shows this pattern more clearly by separately plotting each design.

Figure 6: CBDC Share and Consumer Surplus by Urban and Rural Households

(a) Aggregate CBDC share (b) Change in consumer surplus



Data sources: CFM 2017, FCAC 2017, Canada Post 2021, Government of Canada website, Statistics Canada
Note: This figure reports CBDC adoption and equivalent-variation gains for urban and rural households. The CBDC is non-interest-bearing and has the Big Five fixed effect. The four designs match Figure 4.

heterogeneity in rate sensitivity, we re-estimate the model to allow heterogeneous rate sensitivity by interacting the deposit rate with household income groups (below \$45k, between \$45k and \$100k, and above \$100k). Table E16 in Online Appendix E.1 shows that the estimated rate sensitivity increases with income: the deposit rate coefficient is about 0.35 for the low-income group, 0.64 for the middle group, and 1.65 for the high-income group. This pattern is consistent with recent deposit market evidence showing that higher-income and wealthier households are more rate sensitive (e.g., Cirelli and Olafsson, 2025; Albertazzi et al., 2026).

At the aggregate level, allowing rate sensitivity to vary by household income leaves the main CBDC adoption results close to the baseline. However, it provides interesting distributional implications. When CBDC pays an attractive interest rate of 1%, high-income group would hold more CBDC and gain more consumer surplus as they are more rate sensitive. When CBDC is non-interest-bearing or pays a low interest rate, high-income households would hold less CBDC as they are less willing to move liquid wealth away from interest-bearing bank deposits. Their consumer surplus gains are not necessarily lower, however, because they benefit more from banks' higher equilibrium deposit rates in response to CBDC issuance. Detailed results are shown in Online Appendix E.1.

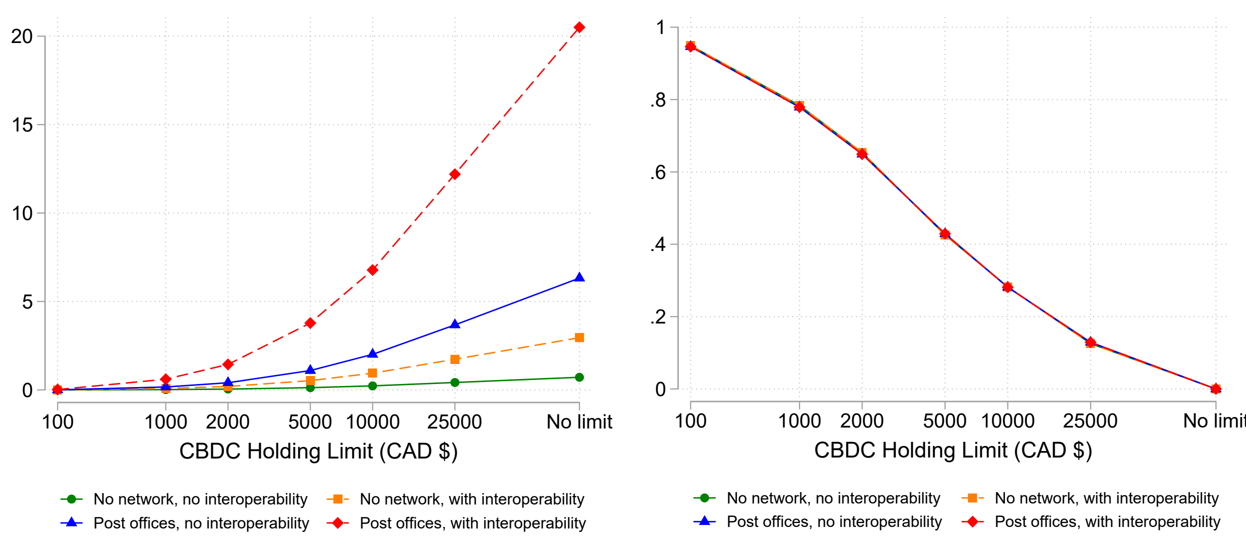
Young vs Old Households: Heterogeneous Tastes for Service Locations. The baseline model assumes that households of different ages value CBDC service locations or bank branches equally. To capture age-specific heterogeneity in tastes for branches, we re-estimate the model allowing preferences for branch networks to vary with age groups. As expected, older groups tend to have stronger preferences for branch network when choosing their deposit banks. As a result, older households hold more CBDC and gain more consumer surplus when CBDC provides service locations. Conversely, younger households hold more and gain more when CBDC has no service locations because they are less affected by the absence of a service network. Detailed results are shown in Online Appendix E.2.[23]

4.3 Impact of Imposing Limits on CBDC Holdings

Recently, several central banks are considering imposing a limit on CBDC holdings to avoid excessive crowding out of bank deposits. For example, the proposed digital euro legislation suggests that the ECB should establish a limit on CBDC holdings.[24] To study this policy in the Canadian context, we add a holding limit to the same four CBDC designs studied in the previous section and vary the limit from \$100 to \$25,000. Using the estimated parameters and the calibrated σ,[25] we solve the model subject to the additional holding limit.

Figure 7: Imposing Different Limits on CBDC Holdings

(a) Aggregate CBDC share (b) Fraction of constrained households



Data sources: CFM 2017, FCAC 2017, Canada Post 2021, Government of Canada website, Statistics Canada
Note: This figure varies CBDC holding limits for the same four designs as Figure 4. The x-axis is log-scaled, and "No limit" is the unconstrained case. CBDC is non-interest-bearing, with the big five fixed effect and $\sigma = 0.5$.

Figure 7a shows that even a large holding limit can effectively reduce the impact of a CBDC. The large impact is most visible when CBDC is attractive. With post offices as service locations and interoperability with big five banks, the aggregate CBDC share falls from 20.6% without a limit to 11.7% with a \$25,000 limit. With post offices as service locations but no interoperability,

[23] Online Appendix E.2 also considers a forward-looking scenario in which all households are assigned the branch-network preferences of the youngest group (under 35 years old). In that case, the impact of the CBDC service network is smaller.

[24] See https://perma.cc/36VB-QLGE.

[25] As discussed in Section 3.2, σ is not separately identified. We set $\sigma = 0.5$ here but results are robust for $\sigma \in [0.1, 0.9]$, as shown in Figure C11 in the Online Appendix C.4.4.

the corresponding share falls from 6.4% without a limit to 3.5% with a $25,000 limit. In both cases, a large holding limit of $25,000 reduces the aggregate CBDC share by more than 40%.

Figure 7b reports the share of households for whom the CBDC holding limit would bind, defined as households whose unconstrained desired CBDC holdings would exceed the limit conditional on choosing CBDC. In the model, each household is endowed with an observed amount of liquid assets, which it allocates between CBDC and cash conditional on choosing CBDC. The binding status is therefore closely tied to the observed distribution of household liquid assets: households with larger liquid asset endowments are more likely to desire CBDC holdings above the cap. This explains why the share of constrained households varies little across CBDC designs.

Although the $25,000 limit binds for only slightly more than 10% of households, these households hold large liquid balances. Figure A4 in Online Appendix A.5 shows that households in the top decile of the liquid asset distribution hold roughly 51% of total liquid assets. As a result, a holding limit can substantially reduce aggregate CBDC holdings. At the same time, because the cap affects only a small fraction of households, its effect on consumer surplus is more limited, as shown in Figure C12 in Online Appendix C.4.4.

5 Extensions

This section presents two extensions. Section 5.1 discusses how the model mechanisms apply to stablecoins. Section 5.2 extends the baseline model by allowing a household to hold both the CBDC and bank deposits.

5.1 Stablecoins

Fiat-backed stablecoins, privately issued digital tokens designed to maintain a one-to-one peg with fiat money, have recently become increasingly prominent in policy debates. Several jurisdictions have adopted regulatory frameworks for stablecoins, including the GENIUS Act in the United States and MiCA in the European Union. These developments have also raised broader questions about whether stablecoin issuers should be allowed to pay interest and how stablecoin adoption may affect the banking sector (e.g., Cong, 2025). This section shows how our model can be applied to study stablecoins. Details of this counterfactual exercise are shown in Online Appendix E.7.

From households' perspective, a stablecoin is another digital money with its own set of features, so the demand side is similar to CBDC. The main differences from CBDC are on the supply side. First, a stablecoin issuer is a private, profit-maximizing entity that can choose the stablecoin interest rate, subject to regulatory restrictions. Second, stablecoins are private liabilities backed by a regulated reserve asset portfolio. Since bank deposits are one type of eligible reserve asset, part of the funds flowing into stablecoins can return to banks as issuer reserve deposits. As a result, the impact on bank funding is smaller when stablecoin issuers hold a larger share of reserves as bank deposits. This differs from CBDC, which is a central bank liability and does not create reserve deposits at commercial banks. For example, the GENIUS Act prohibits stablecoin issuers from paying interest on stablecoins and requires 100% reserve backing in eligible U.S. dollar assets, including short-term government securities and bank deposits.

We conduct new counterfactuals that use the estimated model to study entry of a Canadian Dollar stablecoin, rather than a CBDC, and to evaluate how stablecoin yield and reserve backing affect banks. In these counterfactuals, households choose among bank deposits and a stablecoin for digital money. The stablecoin has no service location network or interoperability with incumbent banks, and its fixed effect is set equal to that of the online banks. On the supply side, the stablecoin issuer maximizes profit subject to an interest rate cap. The issuer must back outstanding stablecoins with a reserve portfolio in which a fraction ρ^D is held as bank deposits, earning a deposit rate, and the rest is held as short-term government securities. We vary both the interest rate cap and ρ^D.

Figure E32 in Online Appendix E.7 highlights two supply-side channels. First, stablecoin yield matters: when the issuer faces a zero-yield cap, stablecoin adoption and deposit crowding out are limited; when the issuer faces no yield cap, it optimally offers a yield above 1%, leading to higher stablecoin adoption and larger deposit outflows. Second, reserve backing dampens the crowding-out impact on bank deposits. With $\rho^D = 0.15$, the issuer offers a lower yield because part of its reserves earns the deposit rate rather than the higher government security return, which reduces stablecoin demand. In addition, 15% of stablecoin balances flow back to banks as issuer reserve deposits. Interestingly, a zero-interest stablecoin without service locations or interoperability with banks takes about 1.4% of the market, which is close to the U.S. dollar fiat-backed stablecoin share in total liquid assets, defined as U.S. dollar fiat-backed stablecoins plus U.S. M1. This share was 1.43% as of June 30, 2026.[26]

5.2 Holding Both the CBDC and Deposits

In this extension, we relax the baseline assumption that households must choose either a CBDC or bank deposits. Here, a household can also choose a bundle that combines the CBDC with a deposit account at an incumbent bank. Figure 8 illustrates the expanded choice set for the case with two banks. When a household chooses such a bundle, it keeps the bank's complementarity with other financial products, uses the better service location network of the bank and the CBDC, and allocates digital balances to the instrument with the higher per-dollar liquidity value. Online Appendix E.8 provides the formal setup.

Figure 8: Household Choice Set Allowing for Holdings of Both Deposits and CBDC

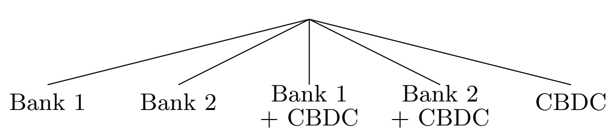


Figure E33 in Online Appendix E.8 shows that the multiple-holdings extension does not always reduce CBDC demand. The key lesson is that CBDC demand depends on the incremental value

[26]U.S. dollar fiat-backed stablecoin market capitalization was $286.97 billion from DeFiLlama's Stablecoins dataset; U.S. liquid deposits are measured as M1, equal to $19,750.9 billion FRED series `M1SL`.

of CBDC when households can keep their bank relationship. For example, post offices provide an additional service network outside the household's existing bank relationship, so households can keep their bank relationship while using CBDC for broader service access, which is why the post office design generates higher CBDC holdings in this multiple holdings extension. By giving households access to a common service network that is not tied to a particular bank, this channel can also reduce the service location advantage of large banks and improve the effective service network available to smaller-bank customers, echoing the mechanism of leveling the playing field in (e.g., Garratt, Yu and Zhu, 2022; Sarkisyan, 2024).

6 Conclusions

This paper develops and estimates a structural model using unique Canadian household data to study how retail CBDC design affects adoption and the crowding out of bank deposits. We highlight the importance of CBDC interoperability and service locations in driving the CBDC adoption and the resulting crowding out of bank deposits. We also study how these attributes interact with CBDC remuneration and holding limits, all of which are central to current CBDC design debates. Holding limits can meaningfully reduce this crowding-out effect while preserving CBDC access for most households. We also document heterogeneous effects of CBDC across banks and households and show that CBDC designs can have distributional implications.

Although our analysis uses the Canadian data, the framework can be applied to inform CBDC designs in other jurisdictions. The parameter values may differ across countries, but several economic mechanisms are likely to be more general. For example, we find that high-income households are more likely to adopt and benefit from a CBDC when it is interest-bearing because they are more rate sensitive. A similar mechanism may operate in Europe, where high-income households are also found to be more rate sensitive (e.g., Albertazzi et al., 2026). Interoperability and service locations may also matter beyond Canada. As discussed in the introduction, U.S. households appear to value interoperability across financial products. In addition, Ritzberger-Grünwald and Stix (2018) find that 43% of the Austrian population still visits a bank desk at least monthly, suggesting that service access may remain relevant in Europe as well. Finally, the framework can also be used to study the impact of stablecoins on the banking sector, a question that has become increasingly relevant as stablecoin regulation has emerged as a policy priority across jurisdictions.

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