Predicting the Demand for Central Bank Digital Currency: A Structural Analysis with Survey Data

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Introduction

- CBDC is a digital form of central bank issued money that is available to the general public and can be used for retail payments.
- Many central banks are considering the issuance of a CBDC.
- To decide whether to issue a CBDC, a central bank needs to consider:
  - What would be the demand for CBDC?
  - How would the design attributes of CBDC affect its demand?

This Paper

Apply a structural demand model to a unique Canadian survey dataset to:

- Predict households' CBDC demand relative to cash and demand deposits
  - Households hold 4–52% of liquid assets in CBDC with a baseline design
  - Allowing banks to respond can constrain CBDC take-up to below 20%
- Identify important attributes in affecting CBDC demand:
  - Usefulness for budgeting
  - Anonymity
  - Bundling of financial advice service
  - Rate of return

Methodology

Given the lack of data on CBDC, the paper uses a structural demand model:

- View cash, deposits, and CBDC as product bundles of attributes

$$\Downarrow$$

- Estimate preferences for different product attributes
  e.g. budgeting usefulness, anonymity

  Design CBDC by choosing levels of budgeting usefulness, anonymity, etc

$$\Downarrow$$

- Predict CBDC demand using preference parameters and design attributes

Literature Review

Existing works on CBDC are mostly theoretical:

> e.g. Ahnert et al. (2022); Assenmacher et al. (2021); Garratt and Zhu (2021); Chiu et al. (2020); Fernández-Villaverde et al. (2020); Schilling et al. (2020); Williamson (2020); Agur et al. (2019); Brunnermeier and Niepelt (2019); Keister and Sanches (2019); Andolfatto (2018); Davoodalhosseini (2018); Barrdear and Kumholf (2016)

Very few empirical works on CBDC:

> Whited et al. (2022) quantify CBDC's impact on bank disintermediation and stability; Bijlsma et al. (2021) conduct a survey on adoption and usage intention for CBDC; Huynh et al. (2020) predict the adoption and usage of CBDC at point of sale

- This paper represents the first attempt to empirically quantify:
  - households' potential CBDC holdings relative to deposits and cash
  - impacts of different design attributes on CBDC holdings

Outline

- Model
- Estimation of preferences
- CBDC designs and demand
- Data
- Counterfactual analyses
- Conclusions

Model

For each dollar of endowment, household i decides whether to hold it in cash c or deposits d based on utility obtained for each product $j \in \{c, d\}$:

$$u_{i,j} = \text{modeled utility } V_{i,j} + \text{unmodeled factors } \epsilon_{i,j}$$

$$V_{i,j} = \sum_k \alpha^k \text{ product attribute}_{i,j}^k + \sum_h \gamma_j^h \text{ demographics}_i^h + \eta_j$$

- After CBDC issuance, preference parameters $\boldsymbol{\alpha}$ stay the same
- Parameters $\boldsymbol{\gamma}_j$ and η_j are unknown for CBDC

  $\rightarrow$ require assumptions on $\boldsymbol{\gamma}_{cbdc}$ and η_{cbdc}

Estimation of Preferences

- Assuming $\epsilon_{i,j}$ is i.i.d. Type I extreme value, the deposit-to-cash ratio is:

$$\ln \frac{q_{i,d}}{q_{i,c}} = V_{i,d} - V_{i,c} = \sum_k \alpha^k (\text{product attribute}^k_{i,d} - \text{product attribute}^k_{i,c}) + \sum_h (\gamma^h_d - \gamma^h_c)\ \text{demographics}^h_i + \eta_d - \eta_c$$

Product Attributes	Return	Cost	Ease	Security	Acceptance	Anonymity	Budgeting usefulness	Online capability	Bundling
Deposit	Deposit rate	Debit card rating	Debit card rating	Debit card rating	Card acceptance	0	0	1	1
Cash	0	Cash rating	Cash rating	Cash rating	1	1	1	0	0

- Estimate preference parameter α^k for each attribute k

  e.g. identify α for anonymity using perceptions for its importance

Equivalent Asset Allocation Model

Predicting CBDC Demand

After estimating preferences, calculate utility for CBDC with a given design:

$$V_{i,cbdc} = \sum_k \alpha^k \text{ CBDC attribute}_{i,j}^k + \sum_h \gamma_{cbdc}^h \text{ demographics}_i^h + \eta_{cbdc}$$

$$\Downarrow$$

Product Attributes	Return	Cost	Ease	Security	Acceptance	Anonymity	Budgeting usefulness	Online capability	Bundling
CBDC under baseline design	0	Cash rating	Cash rating	Cash rating	1	0.7	0.7	1	0

- Require assumptions on the CBDC-specific effects consisting of:
  - Demographics-related effects γ_{cbdc}

    range from cash-like $\gamma_{cbdc} = 0$ to deposit-like $\gamma_{cbdc} = \widehat{\gamma}_d$
  - Effects of unmodeled factors η_{cbdc}

    range from cash-like $\eta_{cbdc} = 0$ to deposit-like $\eta_{cbdc} = \widehat{\eta}_d$

CBDC Demand

Data

- Methods-of-Payment Survey MOP (2013)
  1. Survey questionnaire: individuals' ratings for different product features
     - Payment-specific ratings for **cost**, **ease**, **security**
     - Perceptions of importance towards **anonymity**, usefulness for **budgeting**
  2. Payment diary: 3-day shopping diary of individuals' transactions
     - **Online** transaction frequency, card **acceptance** frequency
- Canadian Financial Monitor CFM (2010–2017)
  - Attitudes towards **bundling** of financial planning advice service
  - Households' holdings of cash and deposit
- Cannex (2010–2017)
  - Deposit **interest rate**

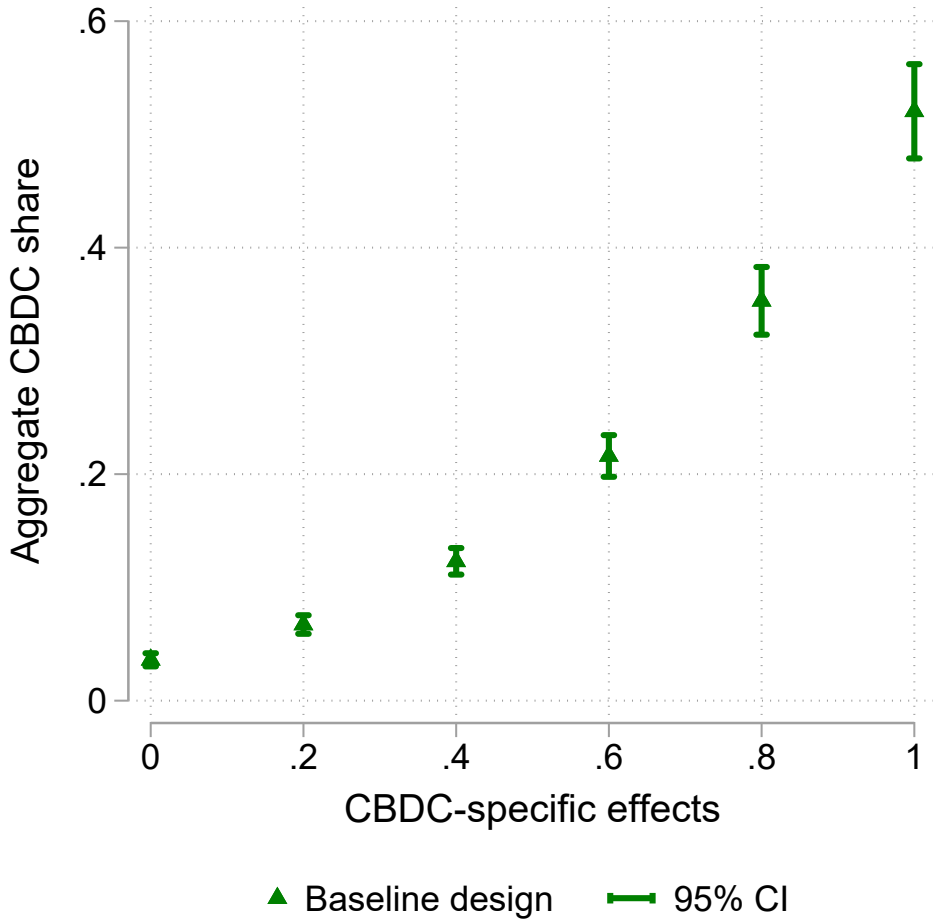
Data Details | Estimated Parameters

Counterfactual Analyses

- To what extent would CBDC demand depend on
  - designs of CBDC?
  - assumptions for the CBDC-specific effects?
- What are the impacts of different attributes on CBDC demand?

Demand for CBDC

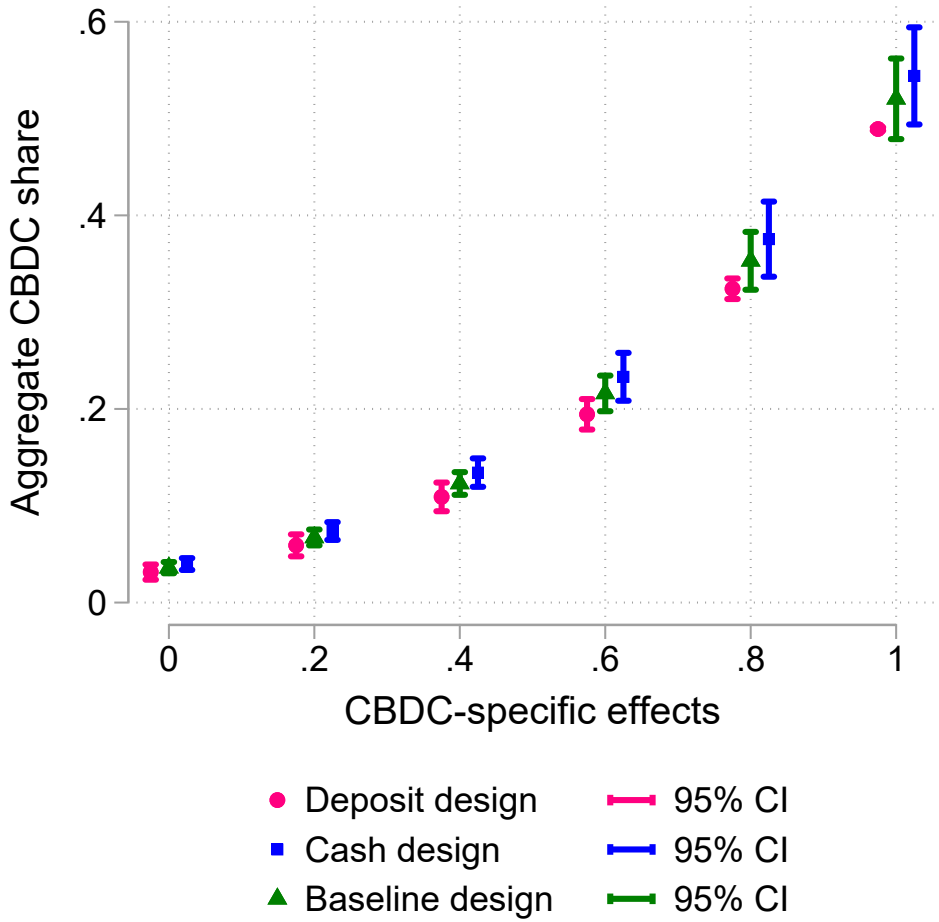
Under a baseline CBDC design, households hold 4–52% of liquid assets in CBDC



Note: Zero (one) on the x-axis refers to the case where CBDC-specific effects are cash-like (deposit-like)

CBDC Demand under Different Designs

CBDC demand relies on the assumptions for the CBDC-specific effects a lot



Note: Zero (one) on the x-axis refers to the case where CBDC-specific effects are cash-like (deposit-like)

Nested Logit Predictions Crowding-out Effects

The Impacts of Design Attributes

CBDC design attributes	Changing a given attribute, while keeping the other attributes the same as in baseline design	Percentage change in aggregate CBDC share relative to baseline share
Budgeting usefulness	70% of cash usefulness $\rightarrow$ 0%	Drops by 7–14%
Anonymity	70% of cash anonymity $\rightarrow$ 0%	Drops by 5–10%
Bundling of financial advice service	unbundled with service $\rightarrow$ bundled	Increases by 4–8%
Rate of return	0% interest rate $\rightarrow$ 0.1%	Increases by 10–23%

Extension 1: Nested Logit Model

Relax Type I extreme value assumption on the unmodeled factors $\epsilon_{i,cbdc}$

This presentation has focused on predictions based on logit model. Results are largely robust to the nested logit model.

Logit Model	Nested Logit Model
$\epsilon_{i,cbdc}$ is uncorrelated with $\epsilon_{i,d}$ or $\epsilon_{i,c}$	$\epsilon_{i,cbdc}$ is correlated with $\epsilon_{i,d}$ or $\epsilon_{i,c}$
cash and deposit $\downarrow$ by same %	$\rho_{d\_cbdc} > 0$: deposit $\downarrow$ by more

- Level of CBDC demand robust to a wide range of correlation coefficients
- The impacts of design attributes are larger under nested logit model
- Crowding-out effects on cash more sensitive to the correlation

Extension 2: Incorporating Banks' Responses

- So far, focused on households' demand perspective only. When allowing banks to respond to CBDC, the demand for CBDC is likely to be lower.
- Assume N identical banks compete *à la* Cournot in deposit market
- Bank j takes $\boldsymbol{D}_{-j}$ as given and chooses D_j to maximize profit:

$$\pi_j(D_j, \boldsymbol{D}_{-j}) = \left[r^l - r^d \left(D_j + \sum_{k \neq j} D_k \right) - c \right] D_j$$

  - r^l: exogenous return on loans
  - $r^d(.)$: endogenously determined deposit rate
  - c: marginal cost

Calibration and Estimate Bank's Marginal Cost

First-order condition wrt D_j gives:

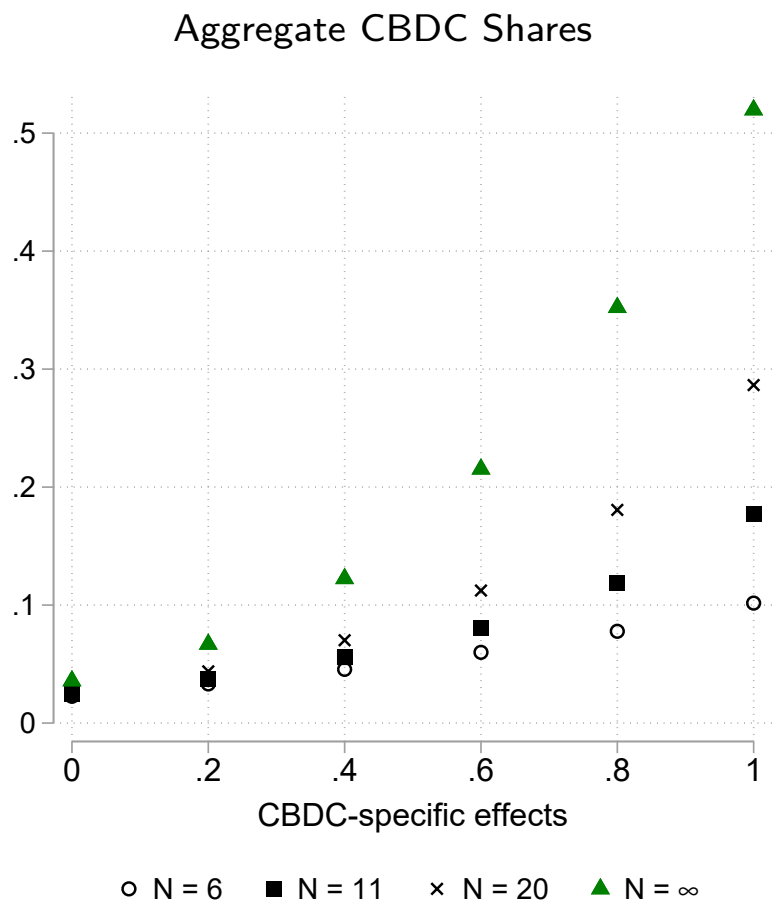
$$\underbrace{r^l - r^d - c}_{\text{profit margin}} = \left(\frac{\partial D}{\partial r^d}\frac{N}{D}\right)^{-1}$$

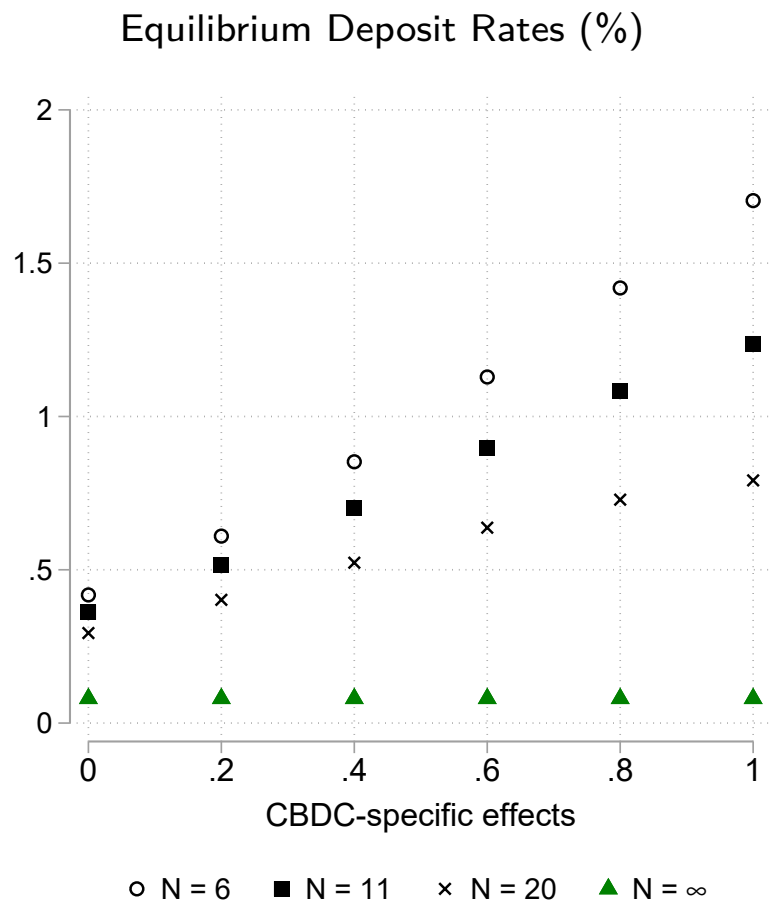
where $D = \sum_j D_j$.

- Calibrate $N = 11$ to match weighted average net interest income to total assets ratio of 1.5% in 2017.
- Using the estimated demand and calibrated N, calculate marginal cost c
- Treat c as exogenous and unchanged after CBDC issuance
- CBDC tends to make deposit demand more elastic, inducing banks to make deposits more attractive through a higher r^d

Bank Market Power and Equilibrium Outcomes

The upper bound estimate can be reduced to below 20% with banks' responses





Note: Zero (one) on the x-axis refers to the case where CBDC-specific effects are cash-like (deposit-like).
$N = 11$: calibration that matches the bank profit margin
$N = \infty$: identical to baseline predictions based on demand side only

Conclusions

This paper applies a structural demand model to Canadian survey data to:

- Quantify CBDC demand relative to deposits and cash
  - ⇒ Households hold around 4–52% of liquid assets in a baseline CBDC

    Level of CBDC demand depends on assumptions of CBDC-specific effects
  - ⇒ Allowing banks to respond to CBDC would greatly constrain the take up
- Provide important insights on which CBDC attributes matter
  - ⇒ Budgeting usefulness, anonymity, bundling of bank service, rate of return

Portfolio Asset Allocation Problem

Each household i maximizes the following CES utility:

$$u_i(q_{i,c}, q_{i,d}, \boldsymbol{x_{i,c}}, \boldsymbol{x_{i,d}}, \boldsymbol{z_i}) = \left[\alpha_{i,c} q_{i,c}^{\rho} + \alpha_{i,d} q_{i,d}^{\rho}\right]^{\frac{1}{\rho}}$$

subject to a budget constraint:

$$q_{i,c} + q_{i,d} = w_i$$

where $\rho \in (0, 1]$ is a substitution parameter and $\alpha_{i,j}$ is a function of product attributes $\boldsymbol{x_{i,j}}$ and household characteristics $\boldsymbol{z_i}$ for $j \in \{c, d\}$.

Take FOCs wrt asset $q_{i,j}$:

$$\frac{1}{\rho}\left[\alpha_{i,c} q_{i,c}^{\rho} + \alpha_{i,d} q_{i,d}^{\rho}\right]^{\frac{1}{\rho}-1} \alpha_{i,j} \rho q_{i,j}^{\rho-1} = \lambda$$

where λ is the Lagrange multiplier associated with the budget constraint.

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Divide FOCs wrt $q_{i,d}$ and $q_{i,c}$ to give:

$$\frac{q_{i,d}}{q_{i,c}} = \left(\frac{\alpha_{i,d}}{\alpha_{i,c}}\right)^{\frac{1}{1-\rho}}$$

Assume $\alpha_{i,j} = \exp(V_{i,j})$ and take logs of the deposit-to-cash ratio:

$$\ln \frac{q_{i,d}}{q_{i,c}} = \frac{1}{1-\rho}\left(V_{i,d} - V_{i,c}\right)$$

which is equivalent to the estimation equation from the logit demand model.

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CBDC Demand

under logit and nested logit models

- This presentation focuses on the logit model predictions.
  - $\Rightarrow$ Assume $\epsilon_{i,cbdc}$ is uncorrelated with $\epsilon_{i,d}$ or $\epsilon_{i,c}$
  - $\Rightarrow$ CBDC share out of liquid assets is:

$$s_{i,cbdc} = \exp(V_{i,cbdc})/(\exp(V_{i,c}) + \exp(V_{i,d}) + \exp(V_{i,cbdc}))$$

  - $\Rightarrow$ Demand for CBDC draws proportionally from cash and deposit

- The paper also looks at the nested logit model predictions.
  - $\Rightarrow$ Assume $\epsilon_{i,cbdc}$ is correlated with $\epsilon_{i,d}$ or $\epsilon_{i,c}$
  - $\Rightarrow$ When CBDC and deposit (cash) are closer substitutes, demand for CBDC draws more than proportionally from deposit (cash)

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Data on Product Attributes

Attributes	Data	Source	Description
Return	Net deposit rate after tax Data	Cannex, Government website 2010–2017	Match bank-specific deposit rates from Cannex with each household's main FI
Cost	Payment-specific ratings Data	MOP 2013	How costly do you think it is (or would be) to use each payment instrument?
Ease	Payment-specific ratings	MOP 2013	How easy or hard do you think...?
Security	Payment-specific ratings	MOP 2013	How risky or secure do you think...?
Anonymity	Perceptions of importance	MOP 2013	Rate the attribute importance when considering how to pay
Budgeting	Perceptions of importance	MOP 2013	Rate the attribute importance ...
Bundling of bank service	Attitudes towards bundling of financial advice service	CFM 2010–2017	Level of agreement with statement: "I would go to my bank for any financial planning advice"
Online	Online transaction frequency	MOP 2013 diary	Fraction of online transactions
Acceptance	Card acceptance frequency	MOP 2013 diary	Fraction of transactions where cards are accepted

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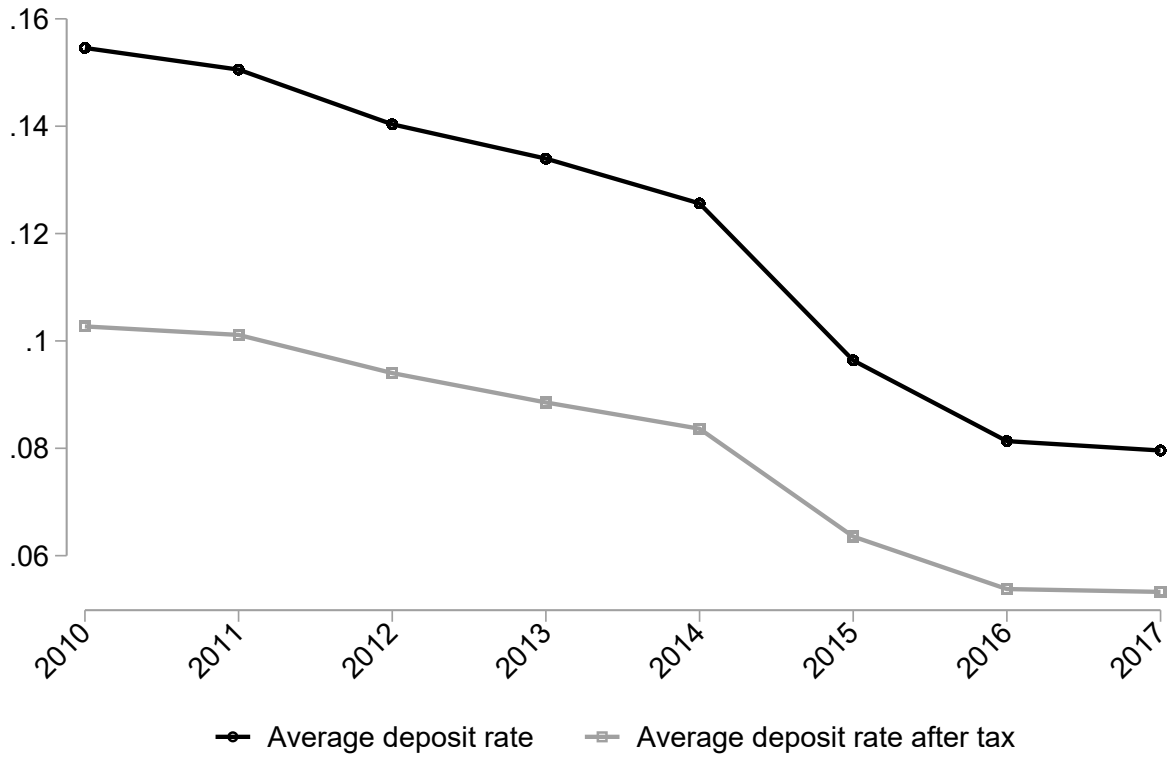
Household-specific Deposit Rate

Average deposit rates before and after taxes across households



Data sources: CFM 2010–2017, Cannex 2010–2017, Government of Canada website

Note: Households face different deposit rates (after taxes) as they save at different banks (and they have different marginal income tax rates).

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Ratings for Payment-specific Features

Ratings	1	2	3	4	5
Cost of use	Very low cost				Very high cost
Cash	0.74	0.14	0.10	0.02	0.00
Debit card	0.27	0.37	0.20	0.12	0.02
Credit card	0.17	0.22	0.17	0.29	0.14
Mobile payment app	0.05	0.10	0.71	0.10	0.02
Prepaid card	0.12	0.17	0.49	0.15	0.05
Ease/Convenience	Very hard to use				Very easy to use
Cash	0.00	0.01	0.04	0.17	0.76
Debit card	0.00	0.01	0.10	0.29	0.59
Credit card	0.01	0.01	0.07	0.31	0.60
Mobile payment app	0.04	0.13	0.63	0.13	0.04
Prepaid card	0.02	0.06	0.45	0.28	0.18
Security/Risk	Very risky				Very secure
Cash	0.01	0.07	0.11	0.26	0.54
Debit card	0.01	0.11	0.16	0.53	0.18
Credit card	0.02	0.13	0.16	0.53	0.15
Mobile payment app	0.09	0.22	0.54	0.11	0.02
Prepaid card	0.02	0.09	0.41	0.32	0.15

Data source: MOP 2013

Note: The table summarises the weighted fraction of households choosing each rating (from a scale of one to five) for each feature of a given payment instrument, where the sample weights are applied.

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Estimated Preference Parameters

Dependent variable: ln(deposit/cash)

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Deposit rate	2.114**	2.175**	2.208**	2.176**	2.167**	2.098**	2.263**	2.297**	2.191**
	(1.035)	(1.033)	(1.035)	(1.035)	(1.036)	(1.034)	(1.033)	(1.034)	(1.036)
Bank service		0.052***	0.051***	0.050***	0.050***	0.054***	0.060***	0.060***	0.059***
		(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)	(0.018)
Cost of use			-0.204	-0.150	-0.080	-0.087	-0.087	-0.102	-0.101
			(0.189)	(0.195)	(0.201)	(0.201)	(0.201)	(0.202)	(0.202)
Ease/Convenience				0.490	0.371	0.402	0.437	0.423	0.374
				(0.460)	(0.466)	(0.466)	(0.465)	(0.465)	(0.466)
Security					0.402	0.366	0.453*	0.444*	0.457*
					(0.256)	(0.256)	(0.256)	(0.256)	(0.256)
Anonymity						-0.058***	-0.039**	-0.038**	-0.038**
						(0.018)	(0.018)	(0.018)	(0.018)
Budgeting							-0.063***	-0.063***	-0.062***
							(0.018)	(0.017)	(0.017)
Online payment								0.425	0.439
								(0.312)	(0.314)
Card unacceptance									-0.282
									(0.181)
Constant	1.372***	1.318***	1.348***	1.391***	1.385***	1.594***	1.690***	1.672***	1.695***
	(0.381)	(0.380)	(0.382)	(0.384)	(0.384)	(0.389)	(0.387)	(0.388)	(0.388)
Observations	4,352	4,352	4,352	4,352	4,352	4,352	4,352	4,352	4,352
Adjusted R^2	0.062	0.064	0.064	0.064	0.064	0.067	0.069	0.069	0.070

Robust standard errors in parentheses
* $p < 0.1$, ** $p < 0.05$, *** $p < 0.01$

Data sources: CFM 2010–2017, MOP 2013, Cannex 2010–2017, Government of Canada website

Note: Bank, region, and year fixed effects are included in each regression. Household characteristics included in each regression consist of household income, household head age, female head indicator, household head education, home ownership, household size, rural area indicator, internet access at work, attitudes towards stock market investment, feeling difficulty in paying off debt, and the indicator of being behind debt obligations in the past year.

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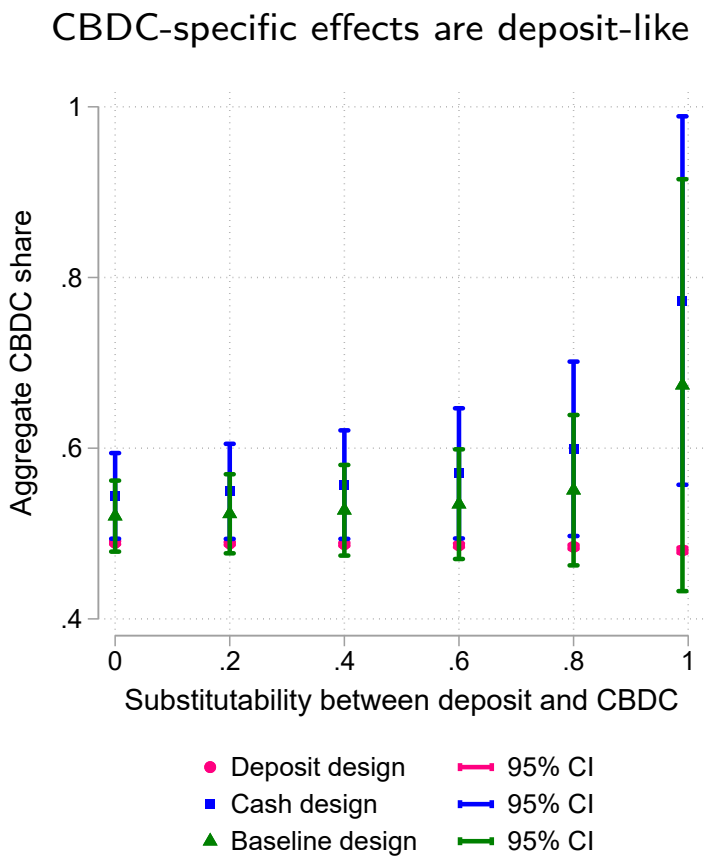
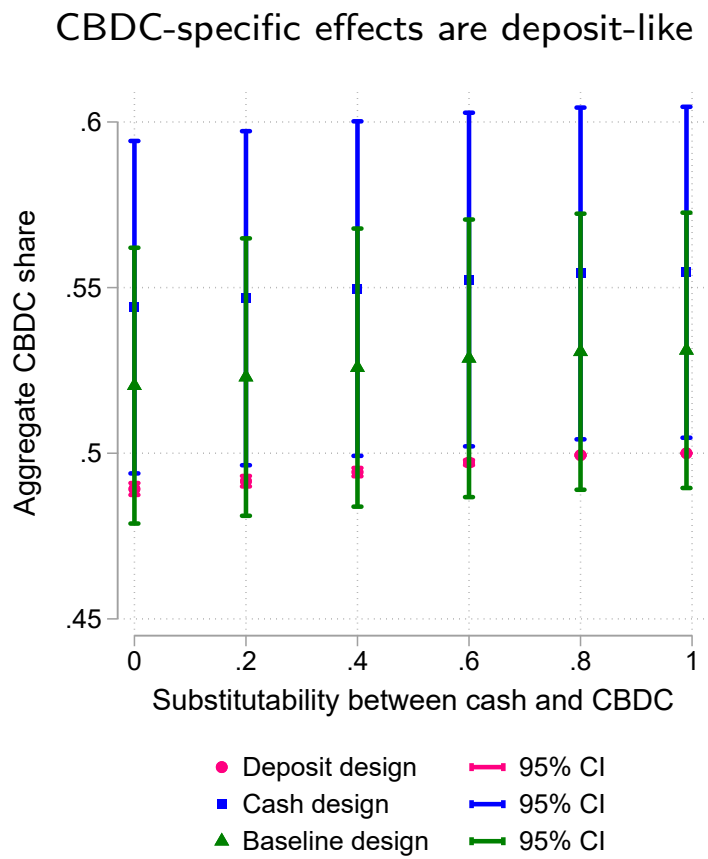
CBDC Demand under Nested Logit Model

Predictions under logit model are robust to changing degrees of substitutability





x-axis: correlation between the unobserved utilities of CBDC and deposit (cash) on LHS (RHS)

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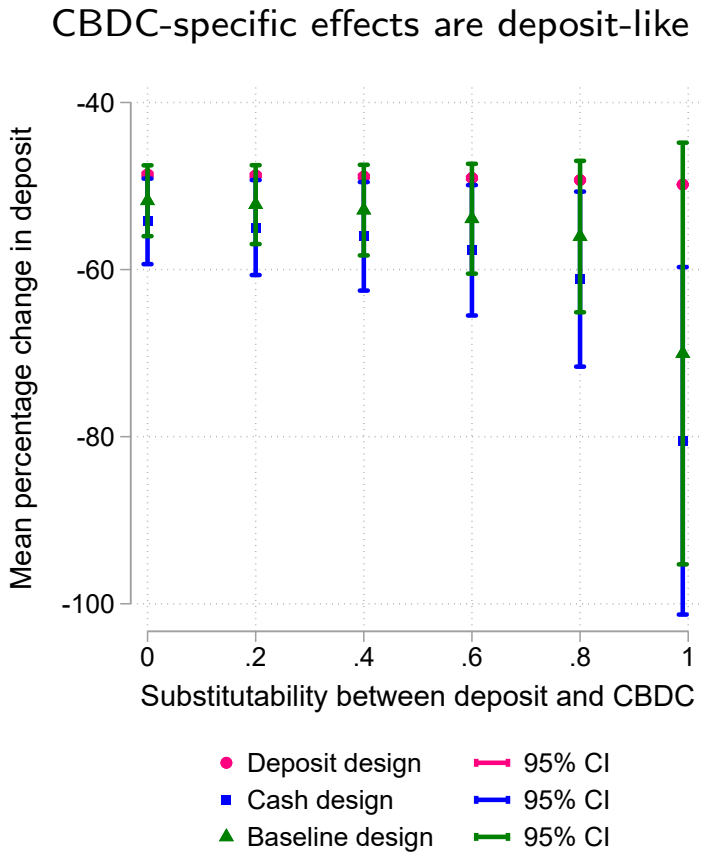
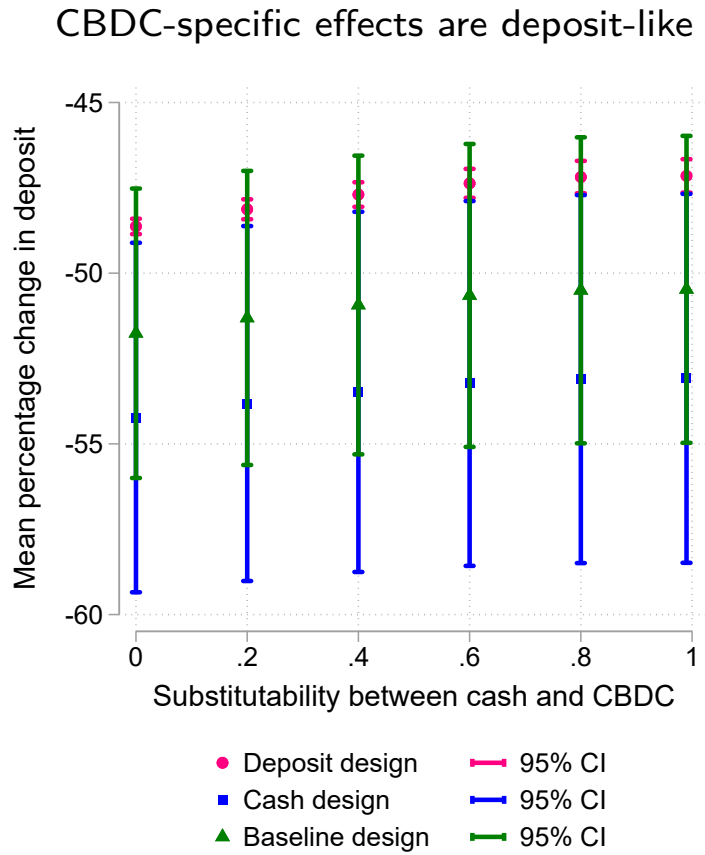
Crowding-out Effects on Deposit Demand

A baseline CBDC with deposit-like unidentified effects could reduce deposit by 52–70%





x-axis: correlation between the unobserved utilities of CBDC and deposit (cash) on LHS (RHS)

y-axis: mean percentage change in deposit relative to the deposit holding before CBDC issuance

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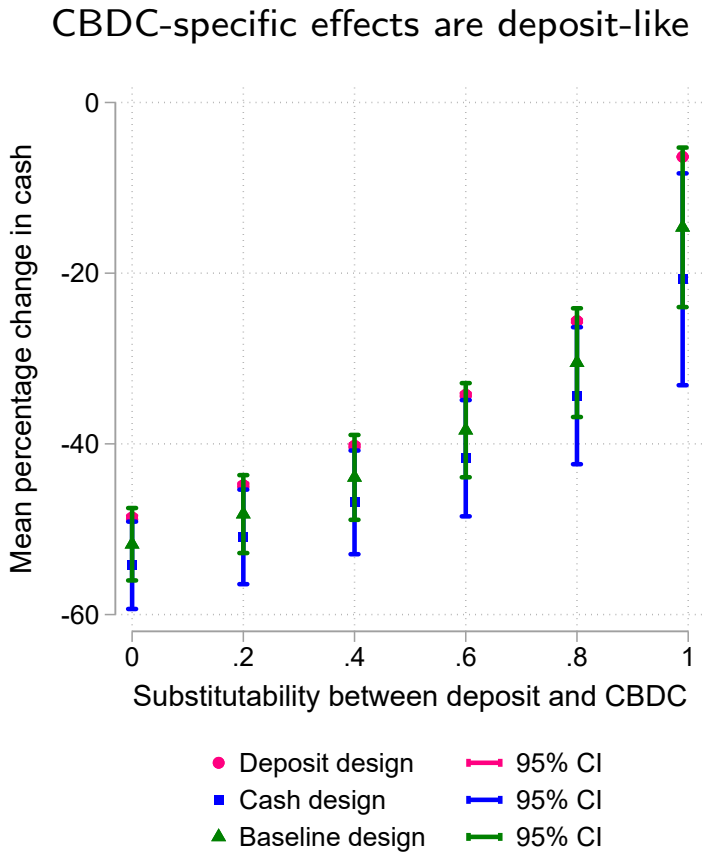
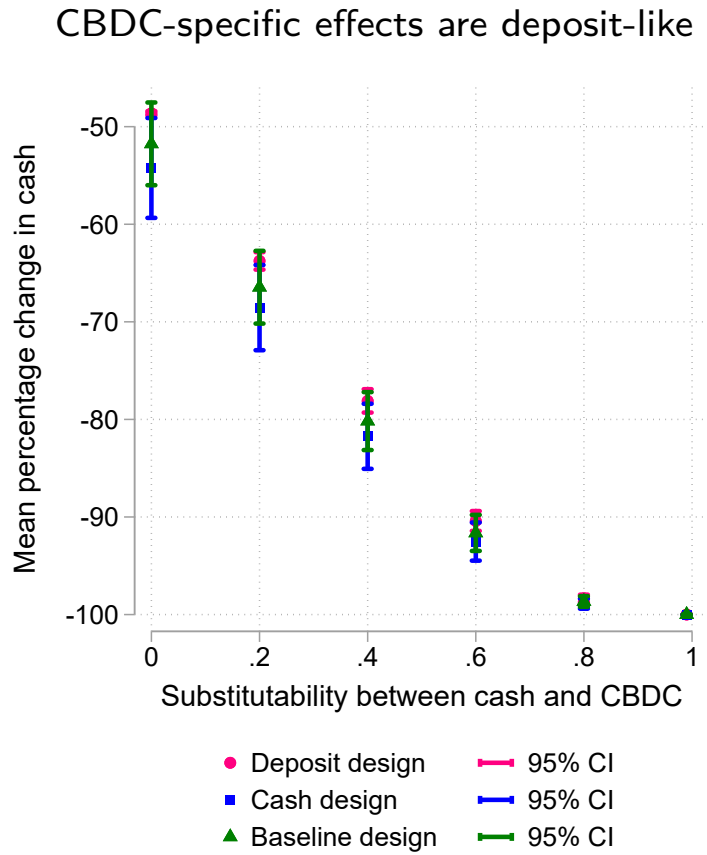
Crowding-out Effects on Cash Demand

The effects on cash are sensitive to model assumptions





x-axis: correlation between the unobserved utilities of CBDC and deposit (cash) on LHS (RHS)

y-axis: mean percentage change in cash relative to the cash holding before CBDC issuance

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