Central Bank Digital Currency Design: The Interest Rate-vs-Convenience Frontier

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Based on joint work with Rodney Garratt (UCSB) and Jiaheng Yu (MIT Sloan)
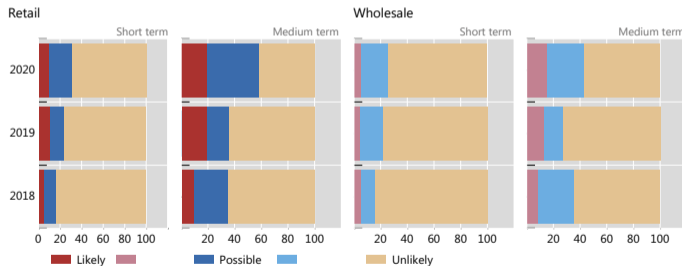
Central bank digital currency

A CBDC is "a digital payment instrument, denominated in the national unit of account, that is a direct liability of the central bank" (BIS 2020).

The likelihood of CBDC issuance continues to increase

Share of respondents   Graph 7

Short term: 1–3 years; Medium term: 1–6 years. "Likely" combines "very likely" and "somewhat likely". "Unlikely" combines "very unlikely" and "somewhat unlikely".
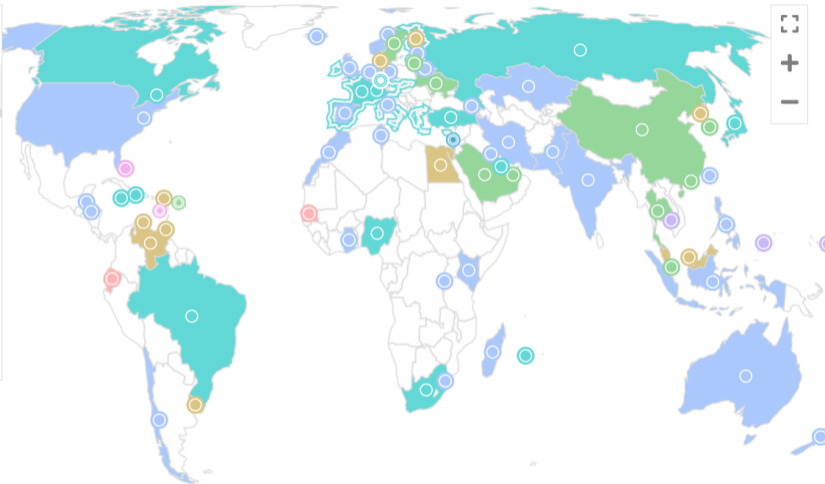
Source: BIS central bank survey on CBDCs.

83 Countries/Currency Unions Tracked

Click to filter

Status

- 5 Launched
- 14 Pilot
- 16 Development
- 32 Research
- 10 Inactive
- 2 Canceled
- 4 Other

Sources: Atlantic Council Research, Bank of International Settlements, International Monetary Fund, John Kiff Database
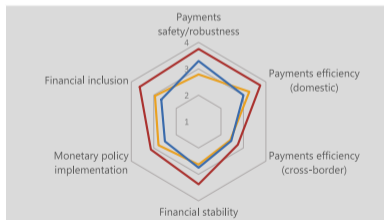
Objectives of CBDC

- Improving payment system – financial inclusion, financial stability
- Monetary policy implementation
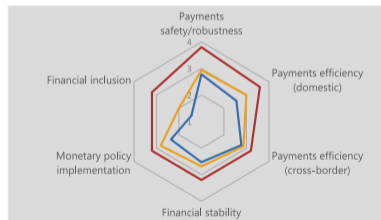
Main motivations of CBDC work by stage

Average importance   Graph 5

Retail CBDC — Wholesale CBDC

Research only — Research + Proof-of-concept — Research + Proof-of-concept + Pilot

(1) = "Not so important"; (2) = "Somewhat important"; (3) = "Important"; (4) = "Very important".

Source: BIS central bank survey on CBDCs.

How do we achieve these objectives?

If all a CBDC did was to substitute for cash – if it bore no interest and came without any of the extra services we get with bank accounts – people would probably still want to keep most of their money in commercial banks.

—Ben Broadbent, Deputy Governor for Monetary Policy of the Bank of England, 2016

- Interest-bearing is the "store of value" aspect of a currency.
- Payment service is the "medium of exchange" aspect of a currency.
- The "unit of account" property of a currency is automatically satisfied by CBDCs.

Swedish e-Krona pilot

The Swedish central bank (Sveriges Riksbank) just completed phrase one of its e-Krona pilot.

E-Krona is a token-based digital money on a private blockchain. The central bank owns the chain and controls who can participate. Participants (e.g. banks) get e-Krona from the central bank by debiting their account in the payment system. Then end users can get e-Krona by debiting their payment accounts.

Riksbank discussed the possibility of paying (negative) interest rate but has not tested interest-bearing e-Krona.

CBDC in China

China has started field experiments RMB CBDC (DC/EP). It aims to be an alternative to cash and third-party payment providers. It pays zero interest.
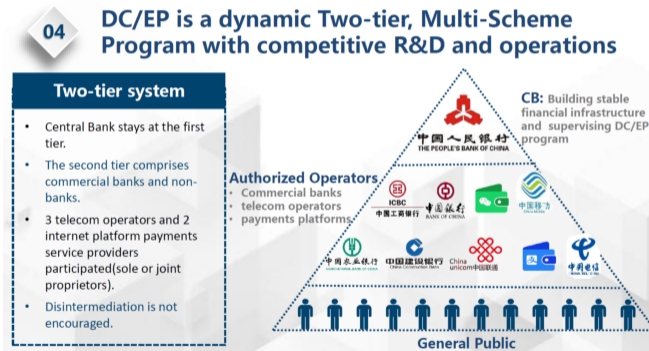
Source: Zhou Xiaochuan

Banking for All Act of U.S. Congress

This design incorporates payment service and interest-bearing.

Section 5 (c) Terms Of Digital Dollar Wallets
(1) shall not be subject to any account fees, minimum balances, or maximum balances, and shall pay interest at a rate not below the greater of the rate of interest on required reserves and the rate of interest on excess reserves;
(2) shall provide debit cards, online account access, automatic bill-pay, mobile banking, customer service and other such services as the Board of Governors of the Federal Reserve System determines appropriate in the public interest, provided that digital dollar wallets shall not include overdraft coverage;
(3) shall provide, in conjunction with the Postal Service, access to automatic teller machines
(4) shall be branded in all account statements, marketing materials, and other communications as "FedAccounts"
(5) may not be closed or restricted on the basis of profitability considerations
(6) shall provide account holders with reasonable protection against losses caused by fraud or security breaches.

What do we do this paper?

- We study the design of CBDC in two dimensions: interest-bearing and payment convenience. CBDC is offered via commercial banks (thus no difference in privacy).
- We provide a tractable model of deposit and lending with large and small banks.
- An interest-bearing CBDC puts a lower bound on deposit interest rates. It speeds up monetary policy transmission, but further reduces market share of small banks.
- A convenient CBDC raises the market share of the small bank, "leveling the playing field." If CBDC convenience value is high enough, it also increase monetary policy transmission.
- Banks and households have opposite preference about the interest-bearing feature, but they agree on the convenience feature (to a point).
- We construct a CBDC frontier—"Pareto optimal" combinations of interest rate and convenience value in CBDC design. The exact design depends on central bank objectives.

CBDC frontier
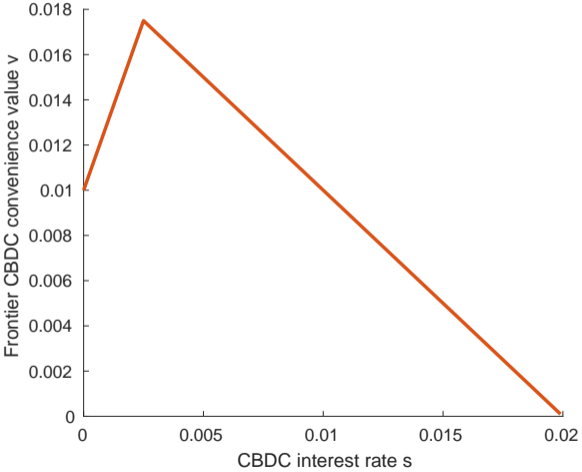
CBDC Literature

Agur, Ari and Dell'Ariccia (2019); Keister and Sanches (2019); Chiu, Davoodalhosseini, Jiang and Zhu (2019); Andolfatto (2020); Fernández-Villaverde, Sanches, Schilling and Uhlig (2020); Piazzesi and Schneider (2020); Fernández-Villaverde, Schilling and Uhlig (2021)

Conclusions vary and depend upon the level of competition, the interest rate on the CBDC, and other features (e.g., liquidity properties of CBDC and reserve requirements)

Some derive conditions under which the addition of a CBDC does not affect equilibrium outcomes, e.g., Brunnermeier and Niepelt (2019) and Fernández-Villaverde et al. (2020).

Why do we need an economic model?

- Adding a CBDC changes incentives and behavior of stakeholders, e.g., large financial institutions and households. It also changes outcomes of policy relevance, e.g., financial inclusion and monetary policy transmission.
- The model predicts who wins and who loses under what circumstances—and if there is any common ground among stakeholders. The CBDC frontier is the set of common grounds.

Model

- A large bank (L) and a small bank (S)
- Bank assets are reserves X_L and X_S, exogenous and large (Total reserves = X).
- Bank liabilities are existing deposits.

Asset	Liability
Reserves X_L	Deposits X_L

- Central bank pays interest on reserves (IOR) f to banks.
- Banks set deposit interest rates r_L and r_S.

Payment convenience

- Each depositor has a convenience value $\delta \geq 0$ for large bank deposit, independent draws from G. Small bank deposit has convenience value 0.
  - Convenience value: extensive bank branches, better Apps, other services, etc.
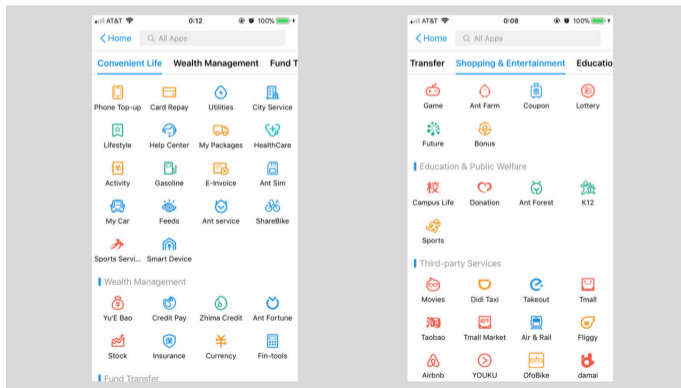
CBDC

- CBDC is the central bank's liability, but offered through commercial banks to depositors.
- CBDC offers its own convenience value $v \geq 0$.
   - Better mobile App, lower fees, available in all ATMs...
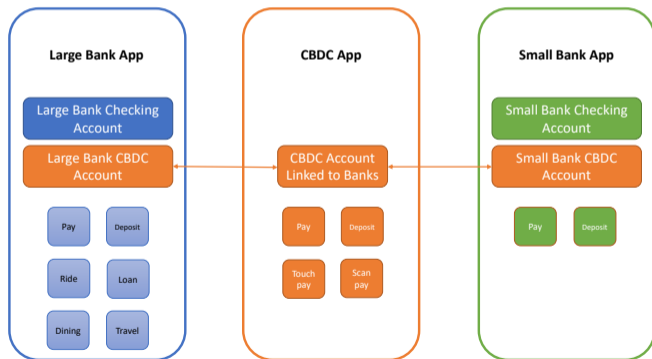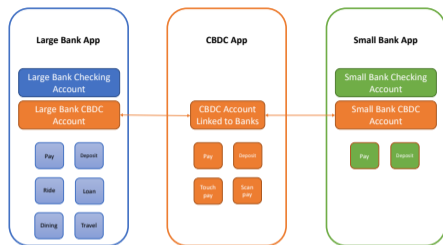
- A depositor's total convenience value for using the large bank is $\max(\delta, v)$, and small bank $\max(v, 0) = v$.

- Within each bank, deposits in checking account and CBDC account receive the same services.

- CBDC pays interest rate $s \in [0, f]$, and s is a lower bound of bank deposit interest rates. Thus, $r_L \geq s$, $r_S \geq s$.

CBCD with and without payment convenience

Convenience CBDC ($v > 0$)
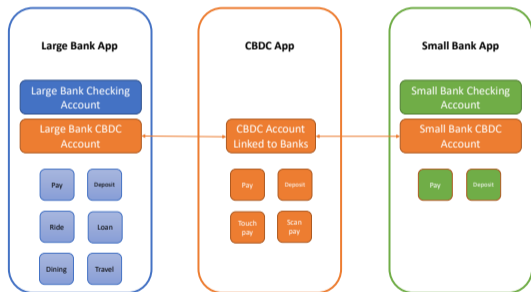
Inconvenience CBDC ($v = 0$)
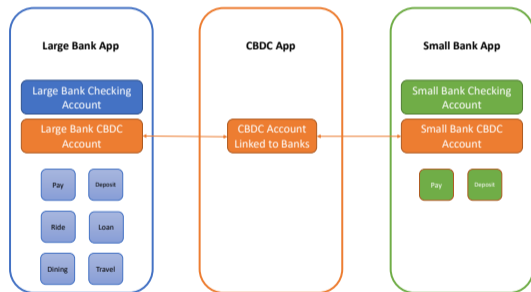
Timeline

A unit mass of agents play three roles: entrepreneurs, workers, depositors.

$t = 0$ Banks set deposit interest rates r_L and r_S. Central bank sets IOR f, CBDC interest rate s, and CBDC convenience v. Each agent already has an account with a commercial bank.

$t = 1$ Each agent is endowed with a project and goes to their bank to borrow \$1. Project i pays $A > 1$ if successful, which happens with probability q_i, cdf Q. Failed projects pay zero. Agent i can only borrow from her current deposit bank, which prices the loan as a monopolist. If a loan is granted, a funded entrepreneur pays a randomly matched agent (worker) \$1 as wage.

$t = 2$ Worker chooses a bank to deposit the wage, based on interest rate and convenience value.

$t = 3$ Projects payoff realized. Banks receive interests on reserves and pay interests to depositors.

Bank deposit creation (e.g., large bank)

1. Before lending, the large bank starts with X_L reserves.

Asset	Liability
Reserves X_L	Deposits X_L

2. If the large bank makes a loan of \$1, it immediately creates a deposit of \$1 in the name of the entrepreneur.

Reserves X_L	Deposits X_L
Loans 1	New Deposits 1

3. Eventually, the entrepreneur pays a worker \$1. With probability α_S, the worker deposits at the small bank and her deposit leaves the large bank. With probability $\alpha_L = 1 - \alpha_S$, the deposit stays.

Reserves $X_L - \alpha_S$	Deposits X_L
Loans 1	New Deposits α_L

Marginal profit of lending

- If the large bank lends \$1 and charges interest rate R_i, its total expected profit is

$$\underbrace{(X_L - \alpha_S)f}_{\text{Interest on reserves}} + \underbrace{[q_i(1 + R_i) - 1]}_{\text{Gross profit on the loan}} - \underbrace{(X_L + \alpha_L)r_L}_{\text{Cost of deposits}}.$$

- If the large bank does not make the loan, its total profit is
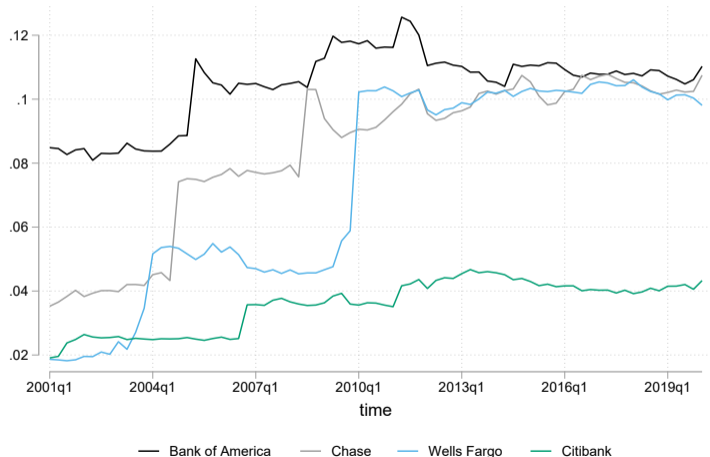
$$X_L(f - r_L).$$

- The large bank's marginal profit from making the loan is

$$\pi_i = \underbrace{q_i(1 + R_i) - (1 + f)}_{\text{Net profit on the loan}} + \underbrace{\alpha_L(f - r_L)}_{\text{Profit on retained deposit}}.$$

- Each \$1 lent out earns a profit on the loan and a part of IOR-deposit rate spread.

Concentration of deposits in U.S. banks (call reports)

Large bank concentration $\implies$ Part of lent money comes back to large banks as deposit

Equilibrium

Deposit market at $t = 2$

Depositor choices	Large bank		Small bank	
	Deposit	CBDC	Deposit	CBDC
Convenience value	$\max(\delta, v)$	$\max(\delta, v)$	v	v
Interest rate	r_L	s	r_S	s

- We look for equilibrium with $r_S > r_L$, so depositor with $\delta \leq v$ chooses small bank.
- Depositor chooses large bank if and only if $\delta > r_S - r_L + v$.
- The eventual market shares of the banks are

$$\alpha_L = 1 - G(r_S - r_L + v)$$
$$\alpha_S = G(r_S - r_L + v)$$

Loan market at $t = 1$

$$\pi_i = \underbrace{q_i(1 + R_i) - (1 + f)}_{\text{Net profit on the loan}} + \underbrace{\alpha_L(f - r_L)}_{\text{Profit on retained deposit}} .$$

- The large bank makes the loan if and only if

$$q_i A - (1 + f) + \alpha_L(f - r_L) > 0 \quad \implies \quad q_i > q_L^* = \frac{1 + f - \alpha_L(f - r_L)}{A}.$$

- The small bank's lending standard is

$$q_S^* = \frac{1 + f - \alpha_S(f - r_S)}{A}.$$

- Banks' lending criteria have nothing to do with existing deposit level.
- A nonbank would use a lending standard $\frac{1+f}{A}$.

Choice of deposit rates at $t = 0$

- Let m_L and $m_S = 1 - m_L$ be initial deposit market shares and X is initial total reserves. The large bank's profit from choosing r_L given r_S is

$$\Pi_L = \underbrace{m_L \int_{q_L^*}^{1} [qA - (1+f) + \alpha_L(f - r_L)]dQ(q)}_{\text{Profit from loans}} + \underbrace{[X + m_S(1 - Q(q_S^*))]\alpha_L(f - r_L)}_{\text{Profit from other reserves}}.$$

(1)

- For simplicity, let $Q(\cdot)$ be the uniform distribution.
- Further impose the stationarity condition $\alpha_j = m_j$.

If CBDC interest rate is not binding, $r_L > s$

First-order condition:

$$0 = \frac{d\Pi_L}{dr_L} = [X + \alpha_L(1 - q_L^*) + \alpha_S(1 - q_S^*)] \cdot [(f - r_L)G'(r_S - r_L + v) - 1 + G(r_S - r_L + v)]$$
$$- \frac{1}{A}\alpha_S\alpha_L(f - r_L)(f - r_S)G'(r_S - r_L + v), \tag{2}$$

$$0 = \frac{d\Pi_S}{dr_S} = [X + \alpha_L(1 - q_L^*) + \alpha_S(1 - q_S^*)] \cdot [(f - r_S)G'(r_S - r_L + v) - G(r_S - r_L + v)]$$
$$- \frac{1}{A}\alpha_L\alpha_S(f - r_L)(f - r_S)G'(r_S - r_L + v). \tag{3}$$

Unconstrained equilibrium

Proposition

Suppose that the profit function Π_j is quasi-concave in r_j. Let r_L and r_S solve first-order conditions (2)–(3). If $r_L > s$ and $r_S > s$, then it is an unconstrained equilibrium that the banks set r_L and r_S as their deposit interest rates. In this equilibrium:

- *The large bank sets a lower deposit interest rate ($r_L < r_S$) and has a larger market share ($\alpha_L > \alpha_S$) than the small bank.*
- *The large bank uses a looser lending standard than the small bank does ($q_L^* < q_S^*$).*

If CBDC interest rate becomes binding

- The lower bound of deposit interest rates is the CBDC interest rate s.
- Since $r_L < r_S$ in the unconstrained equilibrium, by continuity, the large bank's deposit interest rate will hit the lower bound first.
- We look for an equilibrium in which Π_S attains an interior optimum but Π_L attains its maximum at the corner $r_L = s$, i.e.,

$$0 = [X + \alpha_L(1 - q_L^*) + \alpha_S(1 - q_S^*)] \cdot [(f - r_S)G'(r_S - s + v) - G(r_S - s + v)]$$
$$- \frac{1}{A}\alpha_L\alpha_S(f - s)(f - r_S)G'(r_S - s + v), \tag{4}$$
$$0 > [X + \alpha_L(1 - q_L^*) + \alpha_S(1 - q_S^*)] \cdot [(f - s)G'(r_S - s + v) - 1 + G(r_S - s + v)]$$
$$- \frac{1}{A}\alpha_L\alpha_S(f - s)(f - r_S)G'(r_S - s + v). \tag{5}$$

Constrained equilibrium

Proposition

Suppose that the profit function Π_j is quasi-concave in r_j. Let r_S solve equation (4). If, at r_S, equation (5) also holds, then it is a constrained equilibrium that the large bank sets s and the small bank sets r_S as their deposit interest rates. In this equilibrium:

- *The large bank sets a lower deposit interest rate ($s < r_S$) and has a larger market share ($\alpha_L > \alpha_S$) than the small bank.*
- *The large bank uses a looser lending standard than the small bank does ($q_L^* < q_S^*$).*

Long-run framework

Our model is a contribution to the study of deposit and lending markets in the current regime of large excess reserves.

- Reserves are abundant, lending is determined by the opportunity cost of funds, and banks have monopoly power in lending market. See also Martin, McAndrews and Skeie (2013) and Andolfatto (2020).
- A loan is made if its return exceeds the marginal opportunity cost of reserves.

We have multiple banks and hence lent money may return to the same bank as new deposits, so opportunity cost of lending is related to deposit market share and hence differs across banks.

- This allows us to look at the differential impact of the CBDC interest rate on banks of different sizes.

1. Model and Equilibrium

2. Impact of CBDC Interest Rate and Convenience Value

3. A CBDC Frontier

4. Takeaways

Impact of CBDC interest rate s

- Obviously, the CBDC interest rate matters only in the constrained equilibrium.
- Holding f and v fixed, a higher CBDC interest rate enhances monetary policy transmission by raising deposit interest rates.
- But a higher s also reduces $f - s$ and reduces the small bank's ability to compete in price. Deposit and lending activities shift toward the large bank.

Impact of the CBDC interest rate s on the deposit market
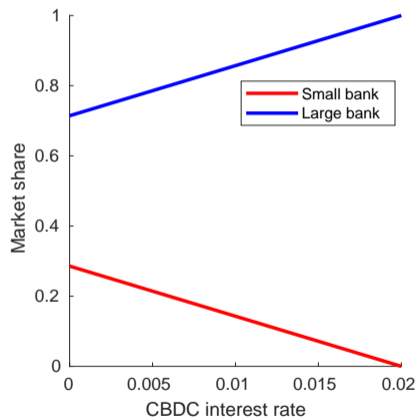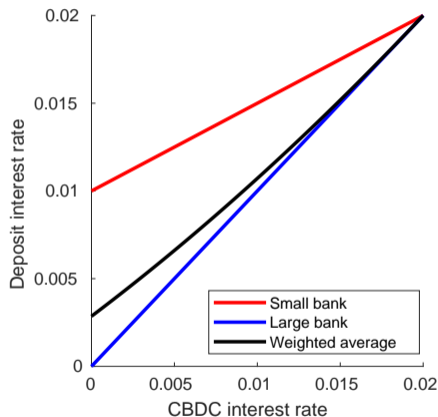
Parameters: $G(\delta) = \delta/0.035$, $A = 1.5$, $X = 10$, $f = 0.02$, $v = 0$.

Impact of the CBDC interest rate s on the loan market
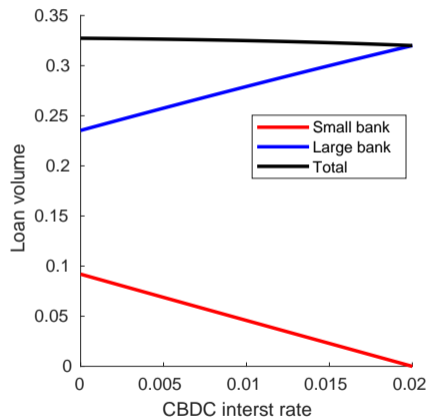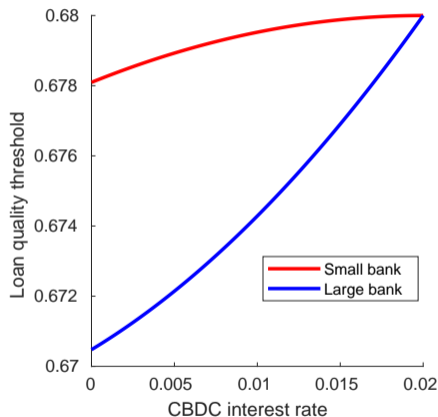
Parameters: $G(\delta) = \delta/0.035$, $A = 1.5$, $X = 10$, $f = 0.02$.

Proposition

Suppose that $G''(\delta) < G'(\delta)/f$ for any $\delta \in [0, f]$. Then, in the constrained equilibrium, for a sufficiently large X, an increasing CBDC interest rate has the following impact:

| As s increases	Constrained equilibrium	
	Large	*Small*
Deposit interest rates r_L and r_S	↑	↑
Deposit market shares α_L and α_S	↑	↓
Weighted average deposit interest rate	↑	
Loan quality thresholds q_L^* and q_S^*	↑	↑
Loan volume $\alpha_L(1 - q_L^*)$ and $\alpha_S(1 - q_S^*)$	*unclear*	↓
Total loan volume, i.e., total deposit created	↓ if $G'' \leq 0$	

Impact of CBDC convenience value

- The key advantage of the large bank is its convenience value of deposits, which spill over to lending market.
- A convenience CBDC narrows the convenience gap ($\max(\delta, v) - v < \delta$) and "levels the playing field" between large and small banks.
- Passthrough of monetary policy can be positive or negative, depending on v.

Impact of CBDC convenience value v on deposit market

Weighted average interest rate is decreasing in constrained equilibrium and increasing in unconstrained one $\implies$ Total bank profit has the approximate opposite pattern.
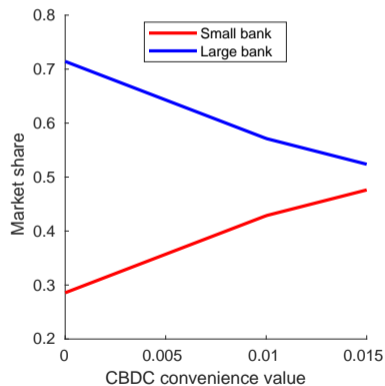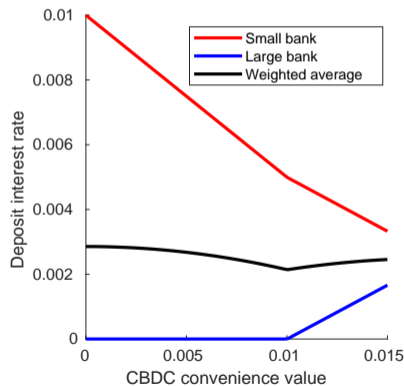
Parameters: $G(\delta) = \delta/0.035$, $A = 1.5$, $X = 10$, $f = 0.02$, $s = 0$.

Impact of CBDC convenience value *v* on loan market
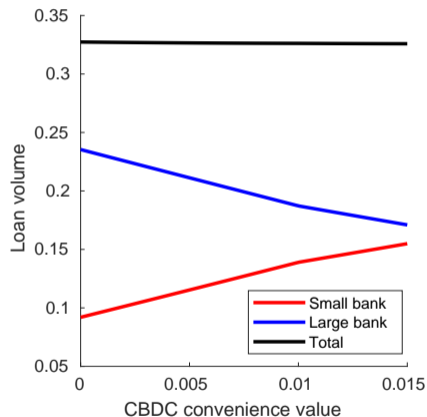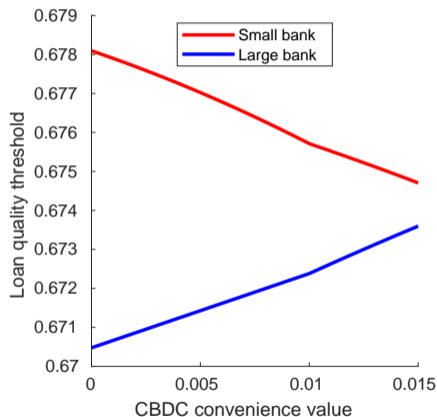
Parameters: $G(\delta) = \delta/0.035$, $A = 1.5$, $X = 10$, $f = 0.02$, $s = 0$.

Proposition

Suppose that G satisfies $-G'(\delta)/f < G''(\delta) < G'(\delta)/f$ for any $\delta \in [0, f - s + v]$. For sufficiently large X, the impacts of increasing v are given in the following table:

As v increases	Constrained		Unconstrained	
	Large	*Small*	*Large*	*Small*
Deposit interest rates r_L and r_S	*Flat(=s)*	$\downarrow$	$\uparrow$	$\downarrow$
Deposit market shares α_L and α_S	$\downarrow$	$\uparrow$	$\downarrow$	$\uparrow$
Weighted average deposit interest rate	*unclear*		$\uparrow$ if $0 \leq G''(\delta) < \frac{G'(\delta)}{f}$	
Loan quality thresholds q_L^* and q_S^*	$\uparrow$	$\downarrow$	$\uparrow$	$\downarrow$
Loan volume $\alpha_L(1 - q_L^*)$ and $\alpha_S(1 - q_S^*)$	$\downarrow$	$\uparrow$	$\downarrow$	$\uparrow$
Total loan volume, i.e., total deposit created	*unclear*		$\downarrow$ if $0 \leq G''(\delta) < \frac{G'(\delta)}{f}$	

Depositor welfare

Depositors receive interest rates and convenience value. Per dollar deposit, they add up to
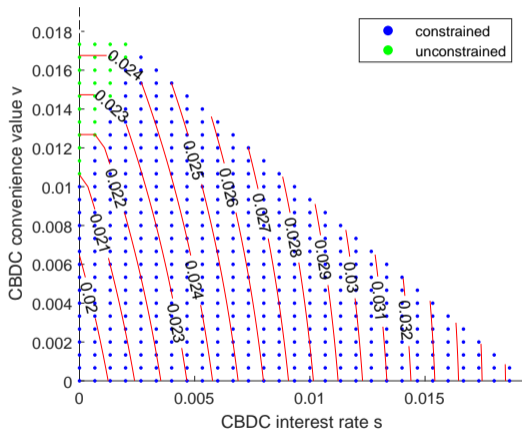
$$W = \alpha_S r_S + \alpha_L r_L + \alpha_S v + \int_{\delta = r_S - r_L + v}^{\infty} \delta dG(\delta). \qquad (6)$$

Proposition

For a sufficiently large X, depositor welfare W:

1. *increases in s in the constrained equilibrium if $-G'(\delta)/f < G''(\delta) < G'(\delta)/f$,*
2. *increases in v in the constrained equilibrium if $-G'(\delta)/f < G''(\delta) < G'(\delta)/f$, and*
3. *increases in v in the unconstrained equilibrium if $0 \leq G''(\delta) < G'(\delta)/f$.*

The interest rate-convenience trade-off for depositors

Parameters: $G(\delta) = \delta/0.0035$, $A = 1.5$, $X = 10$, $f = 0.02$.

Bank profit

$$\Pi_L = \alpha_L \left[\frac{A}{2}(1 - q_L^{*2}) - (1 + f)(1 - q_L^*) \right] + [X + \alpha_L(1 - q_L^*) + \alpha_S(1 - q_S^*)] \alpha_L(f - r_L),$$

$$\Pi_S = \alpha_S \left[\frac{A}{2}(1 - q_S^{*2}) - (1 + f)(1 - q_S^*) \right] + [X + \alpha_L(1 - q_L^*) + \alpha_S(1 - q_S^*)] \alpha_S(f - r_S).$$

Proposition

Under technical conditions, for a sufficiently large X, total bank profit $\Pi_L + \Pi_S$:

- *increases in v in the constrained equilibrium,*
- *decreases in v in the unconstrained equilibrium, and*
- *decreases in s in the constrained equilibrium.*

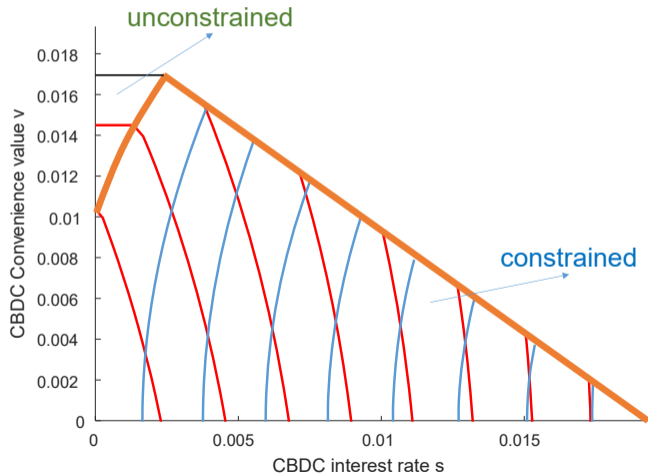*Moreover, a higher v increases $\min(\Pi_L, \Pi_S)$.*

The interest-convenience trade-off for banks

Total bank profit goes up in v in constrained equilibrium!
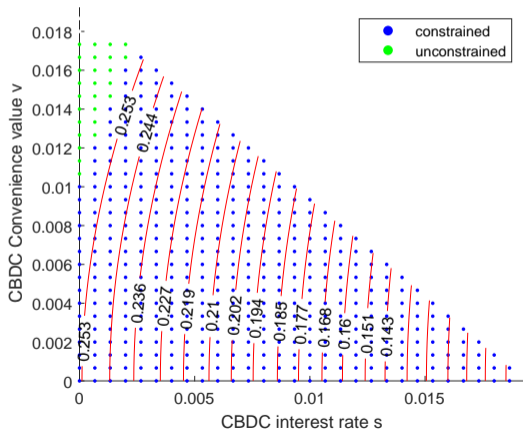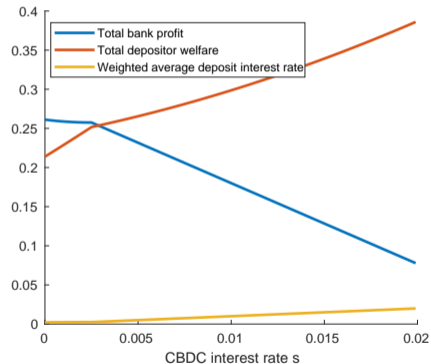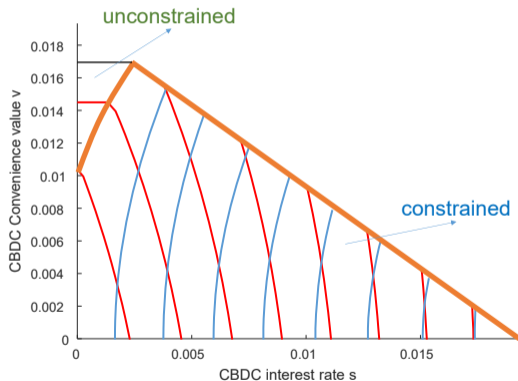
CBDC frontier

Any point below the frontier is dominated by a point on the frontier for banks <u>and</u> households.

- For every CBDC interest rate $s < f$, the CBDC frontier gives the "Pareto optimal" convenience value v. Higher v will raise objections from depositors or banks or both.
- The constrained equilibrium is likely more relevant in the near future.
- But which point should the central bank pick on that frontier? It depends on central bank's mix of objectives.
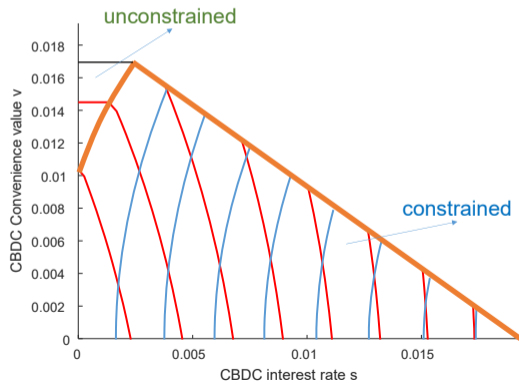
- Monetary policy passthrough and depositor welfare: highest CBDC interest rate s
- Bank profitability: lowest CBDC interest rate s

- Leveling playing yield and financial stability favor the interior optimum.
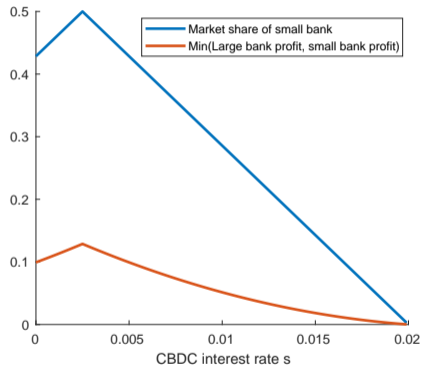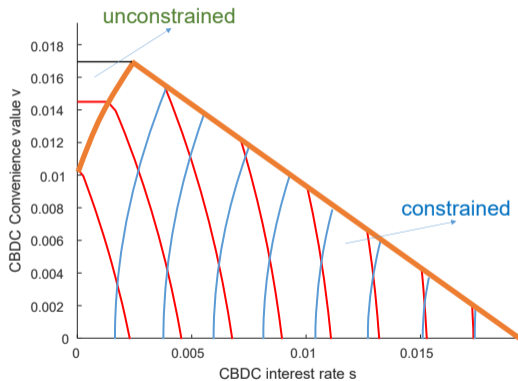
Model highlights

- A model of deposit and lending with heterogeneous banks; attention to competition and composition of the banking sector
- Large bank's advantage comes from its convenience value of deposits.
- Banks have ample reserves that earn interests from central bank.
- Lent money may come back to the bank and (still) earn interest on reserves from central bank, so the large bank's advantage in deposits spills over to lending: lower opportunity cost of lending and lower lending standards.

Conclusions on CBDCs

- CBDC interest rate puts a lower bound on banks' deposit interest rates, particularly binding for large bank. A higher CBDC interest rate enhances passthrough of monetary policy but reduces small bank's market share.
- A higher CBDC convenience value levels the playing field between large and small banks; it can also enhance monetary policy transmission if the convenience value is large enough to lift the large bank's interest rate from the lower bound.
- CBDC need not disintermediate banks (in deposit or lending) to have these effects.

A CBDC Frontier

For each CBDC interest rate s, the CBDC frontier gives the highest v that is "Pareto optimal." The best (s, v) combination depends on central bank objectives.