

# Central Bank Digital Currency Adoption: A Two-Sided Model\*

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## Abstract

For central bank digital currencies (CBDCs) to accomplish their intended objectives, it is necessary for both consumers to use them and for merchants to accept them. This paper develops a dynamic two-sided payments model with both heterogeneous households and merchants/firms to study: (1) The adoption of CBDC by households and firms, and (2) The impact of CBDC issuance on financial inclusion, informality, and disintermediation. Our model shows that there is a feedback loop where more households will adopt CBDC if more firms accept CBDC and vice versa – incentivizing *both* households and firms will result in greater levels of take-up. Households are more likely to adopt CBDC if it is low cost, provides an attractive savings vehicle, reduces the cost of remittances, improves the efficiency of government payments, and (if accepted by merchants) offers a valuable means of payment. Firms are more likely to accept CBDC if fees are low, if there are tax exemptions or subsidies for transactions made in CBDC, and if households who prefer to make payments with CBDC make up a large share of revenue. Upon CBDC issuance, an economy can get stuck at a steady state with low CBDC adoption and small welfare gains if the features of CBDC which do not rely on merchant acceptance (remuneration, efficiency of cross border and government payments) are not sufficiently attractive, or if the households benefiting from these features make up a small share of merchant revenue. Temporary subsidies and using CBDC for government payments can spur initial take-up to transition an economy to a welfare improving steady state with high(er) CBDC usage. Greater adoption of CBDC will result in greater financial inclusion and formalization, but potentially the disintermediation of banks and card payments. Thus, there is a trade-off in designing CBDC for greater adoption. However, the gains are more likely to outweigh the risks in lower income economies with larger unbanked populations and informal sectors.

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# 1 Introduction

Central banks around the world have begun to explore the issuance of central bank digital currencies (CBDCs). Policy objectives such as boosting financial inclusion, improving cross-border payments, reducing cash use, and improving payments efficiency – including in government payments – stand out as key objectives for emerging market and developing countries, and are the focus of this paper (Auer et al., 2020).<sup>1</sup>

For CBDCs to accomplish their intended objectives, it is necessary for both consumers to use them and for merchants to accept them. This has been and will continue to be a key challenge for countries who have issued or are planning to issue a CBDC.<sup>2</sup> This paper develops a dynamic two-sided payments model with both heterogeneous households and firms/merchants to study:

1. The adoption of CBDC by households and firms
2. The impact of CBDC issuance on financial inclusion, informality, and disintermediation.

The model economy is populated by overlapping generation households who consume a continuum of (low to high value) goods sold by firms, and save to maximize utility over time periods. Households receive income in wages, remittances, and government payments.<sup>3</sup> They have the option to own a bank account at a fixed cost to access card payments and a

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<sup>1</sup>Other objectives include monetary sovereignty, strengthening monetary policy pass-through, combating the illicit use of money, and strengthening competition for e-money payment providers.

<sup>2</sup>According to the Atlantic Council’s tracker, 17 countries currently have their CBDC in the pilot phase and 11 countries have rolled it out. Adoption in many of these countries has been slow and limited. eNaira’s adoption has stagnated close to 0.5% (Bloomberg). Only 0.1% of total currency in circulation in the Bahamas comprises Sand Dollar (IMF). The Bank of Jamaica says that there has been paucity in the use of JAM-DEX, as large merchants are yet to come on board. “If all of us have CBDC and there is no place for us to spend it, that’s a problem. We have to get the merchants on board,” noted Richard Byles, governor of the Bank of Jamaica.

<sup>3</sup>Government payments could include transfers, pensions, and government salaries.

deposit account, or own a CBDC wallet at a lower fixed cost,<sup>4</sup> otherwise they are financially excluded. Firms can choose to accept CBDC and/or card payments at their respective fixed costs to avoid variable costs associated with handling cash, or remain in the informal sector and evade taxes. Households are heterogeneous in income and firms are heterogeneous in the value of goods sold.

In our model, there is a feedback loop in that more households will adopt a payment instrument if more firms accept it and vice versa. Thus, incentivizing both households and firms to use CBDC will result in greater levels of take-up. Households are more likely to adopt CBDC if the fixed cost to own a CBDC wallet is low, and if CBDC provides an attractive savings vehicle (interest-bearing CBDC), reduces the cost of remittances (via cross-border CBDC), improves the efficiency of government payments, and (if accepted by merchants) offers a valuable means of payment.<sup>5</sup> Firms are more likely to accept CBDC if the fixed cost and variable fees are low, if there are tax exemptions or subsidies for transactions made in CBDC, and if households who prefer to make payments with CBDC make up a large share of revenue.

In an initial equilibrium without CBDC, rich households own bank accounts and use card payments, while poor households use cash. (Formal) firms who accept card payments sell higher value goods, and (informal) firm who only accept cash sell lower value goods.

Upon CBDC issuance, there are two margins of impact on households. The first margin is financial inclusion, where unbanked households open CBDC wallets. This margin is large when many firms/merchants accept CBDC as payment, CBDC is valuable as a means of payment, the costs associated with CBDC are low, CBDC remuneration is high, CBDC reduces the cost of remittances, and CBDC facilitates receiving government payments. The

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<sup>4</sup>We note that the extent to which CBDC can be designed such that the fixed costs associated with CBDC are lower than that of bank accounts and card payments depends on the barriers to financial inclusion in the country and whether CBDC can address them.

<sup>5</sup>CBDC's value as a means of payment could be derived from a range of possible features such as greater convenience, trust, accessibility, lower cost, programmability, anonymity, network effects, data for credit underwriting, or offline capabilities etc.

second margin is disintermediation, where banked households choose to use CBDC wallets instead of a bank account. This margin is large when a large number of firms choose to only accept CBDC and not card payments, CBDC remuneration is high relative to bank deposit rates, the costs associated with owning a bank account are high relative to that of a CBDC wallet, and CBDC's value as a means of payment is high relative to that of card payments.

Holding government payments and remittances constant, the lowest income households use cash, middle income households own CBDC wallets, and the highest income households own bank accounts. If lower income households receive more government payments (such as in transfers) and remittances, then designing CBDC to reduce the cost of cross-border payments and facilitate efficient government payments will be particularly effective in boosting CBDC adoption and financial inclusion among the (lower income) unbanked population while leading to less disintermediation among the (higher income) banked population.

On the firms/merchant side, are also two margins of impact. The first margin is formalization, where informal firms who only accepted cash choose to accept CBDC (or card) payments after CBDC issuance, entering the formal sector. The formalization impact is greater when (1) many households have bank accounts and CBDC wallets preferring to use CBDC over cash, (2) these households have high income and thus bring a lot of revenue to make it worthwhile for the firm, (3) the costs associated with CBDC payments are low, and (4) if the tax implications of adopting CBDC and formalization are not too large<sup>6</sup>. The second margin is displacement, where firms who accepted cards no longer accept cards and accept CBDC instead after CBDC issuance. Displacement is small (or zero) when the size and income of households who prefer to use CBDC over cards for payment is small, and the costs (and taxes) associated with card payments relative to CBDC payments incurred by the firm are small. Firms selling the lowest value goods stay in the informal sector and use cash, firms selling middle value goods accept CBDC, and firms selling high value goods

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<sup>6</sup>Some countries are considering targeted exemptions from taxes for transactions made by CBDC for targeted merchants.

accept card payments.

The model suggests that greater adoption of CBDC will result in greater financial inclusion and formalization, but potentially also the disintermediation of banks and card payments. Thus, there is a trade-off in designing CBDC for greater adoption. However, we find that the gains from financial inclusion and formalization are more likely to outweigh the risks of disintermediation in lower income economies with larger unbanked populations and informal sectors.

Finally, the model's dynamics reveal that upon the introduction of CBDC an economy may not transition to a steady state with a high(er) level CBDC adoption even if it is welfare improving. This is because households cannot benefit from CBDC's value as a payments instrument if merchants do not accept it, and merchants have no incentive to incur the costs to accept CBDC if households do not adopt it. This will be the case if the benefits from CBDC which do not rely on merchant acceptance, such as remuneration on CBDC, reducing the cost of remittances, and efficient government payments, are not sufficiently attractive, or if the households population benefiting from these features (in particular, remittances and government transfers) are too low income such that merchants do not find it worthwhile to accept CBDC for households who make up a small share of total revenue. We show that temporary subsidies (or tax exemptions)<sup>7</sup> can be used to spur initial adoption and transition the economy to a welfare improving steady state with high CBDC usage. Using CBDC for government payments, making it more cost effective (or mandatory) to receive government payments through CBDC rather than through other means, will similarly spur adoption.<sup>8</sup>

We calibrate the model to that of a representative developing economy with a large informal sector and unbanked population, to show our results numerically. In our baseline, there are large gains in financial inclusion and formalization with low levels of disintermediation and

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<sup>7</sup>In Morocco, the government introduced in 2020 for 5 years a total exemption from taxes for transactions made by mobile payment with small size merchants.

<sup>8</sup>For example, Egypt implemented a law requiring that salaries and fees out paid by public bodies be made electronically.

displacement.

We show that an economy can get stuck at a steady state with low CBDC adoption and a small welfare impact if there are no efficiency gains in cross-border and government payments (the features of CBDC which do not rely on merchant acceptance are not sufficiently attractive). However, by introducing temporary measures to spur initial take-up such as subsidies, tax exemptions for CBDC transactions, and using CBDC for government payments, the economy can transition to a steady state with a high level of adoption with significant gains to household welfare, financial inclusion, and formalization.

We also show that there are smaller financial inclusion and formalization gains, and greater disintermediation and displacements risks in higher income countries.

Interest-bearing CBDC can result in greater adoption with slightly greater financial inclusion and formality gains, but the disintermediation and displacement impact is large. There can be bank intermediation if the costs associated with owning a CBDC wallet are high relative to that of a bank account (as the previously unbanked may open a bank account to gain access to CBDC in a two-tier system instead of opening a CBDC wallet). Last, if CBDC doesn't address and lower the fixed cost barriers firms face in accepting card payments, overall adoption is low even though some households are willing to open CBDC wallets.

This paper contributes to the emerging literature on CBDCs (Infante et al., 2022; IMF, 2021; Soderberg et al., 2022; Adrian and Mancini-Griffoli, 2019; Adrian et al., 2022). Our paper is novel in our focus on CBDC adoption. We are the first to develop a (two-sided payment) model to study both households and firms together. On the household side, our paper is related to the strand of research focused on the disintermediation impact of CBDC (Andolfatto, 2021, Keister and Sanches, 2022, Chiu et al., 2022, Whited et al., 2022, Garratt et al., 2022, Piazzesi and Schneider, 2020, Agur et al., 2022, Chang et al., 2023, Tan, 2023).<sup>9</sup>

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<sup>9</sup>The potential risk of bank disintermediation and contraction in the overall supply of credit if the issuance of CBDC results in bank deposits flowing quickly into CBDC wallets is one of if not the most frequently raised concern in the CBDC discussion.

Existing work assumes that CBDC can be used as a means of payment. Our paper endogenizes CBDC's utility as a payments instrument, incorporating that CBDC can only be used for payments when it is accepted by merchants. We show that the disintermediation impact of CBDC depends on the degree of merchant acceptance. In addition to disintermediation, we also examine the implications of CBDC on formality, cash use, and financial inclusion, which are key policy objectives for emerging market and low income economies. We build on the nascent literature exploring CBDC and financial inclusion (Tan, 2023). On the firm side, we are the first paper to study the impact of CBDC on the formalization of the informal economy. Formalization is a key policy objective for CBDC in developing countries, as a larger formal sector would enable the spread of the tax burden over a larger base, reducing effective rates and its associated distortionary effects. Last, we incorporate into our model use cases of CBDC which are understudied such as cross-border payments and government payments, and novel government policies to encourage CBDC take-up.

Our paper is also related to work on two-sided markets focused on theoretical modelling of platform competition (see Rochet and Tirole, 2002; Schmalensee, 2002; Rochet, 2003; Wright, 2003; Rysman, 2009; Rochet and Tirole, 2011). Rysman (2007) shows that there is a feedback loop between consumer usage and merchant acceptance. We innovate on the literature by introducing both heterogeneous households (in income) and heterogeneous firms (in goods value), and by bringing in CBDC.

The rest of the paper is organized as follows. Section 2 presents the model. Section 3 discusses calibration and data. Section 4 discusses the simulation results. Section 5 concludes.

## 2 Model

### 2.1 Households

The model economy is populated by  $k$ -period-lived overlapping generations. Time is denoted by  $t = 1, 2, \dots, T$ .

Households value the consumption of a continuum of goods indexed by  $j \in [0, 1]$ .

$$U_t = u \left( \min \left\{ \frac{c_t(j)}{(1-w)j^{-w}} \right\} \right), \quad w \in \mathbb{R}_- \quad (1)$$

where  $c_t(j)$  represents its consumption of good  $j$ .<sup>10</sup> The Leontief ordering of consumption goods above implies that:

$$\frac{c_t(j)}{(1-w)j^{-w}} = \bar{c}_t \quad (2)$$

Integrating from  $j = 0$  to 1 will verify that total consumption in period  $t$  is  $\bar{c}_t$ . It follows that  $j$  indexes the goods by value.

Households born in period  $T$  face the following maximization problem:

$$\max_{c_t(j), s_t} \sum_{t=T}^{T+k} \beta^{t-T} u(\bar{c}_t) \quad (3)$$

Households receive (non-government) wage income  $i_w$ , remittance income  $i_r$  and government payments<sup>11</sup>  $i_g$  in each period. In their last period  $k$ , households do not work and receive zero wage income; i.e.  $i_w = 0$  if  $t = T + k$ . They also save  $s_t$  in each period, starting with zero savings in their first period, i.e.  $s_t = 0$  if  $t = T$ .

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<sup>10</sup>Following Freeman and Kydland (2000).

<sup>11</sup>Government payments could include transfers, pensions, and government salaries.



### 2.1.1 No CBDC Scenario

Households choose between: (1) Using only cash, and (2) Owning a bank account with card payments.

In this scenario (as we will show in Subsection 2.2), firms  $j \geq j^{c,0}$  who sell high value goods accept card payments, while firms  $j < j^{c,0}$  who sell low value goods only accept cash (see Figure 4).

The budget constraint for households using only cash is:<sup>12</sup>

$$i_w + i_r(1 - e_0) + i_g(1 - \kappa_0) + s_{t-1}(1 - d) = \bar{c}_t + s_t \quad (4)$$

where  $e_0$  represents fees to receive remittance in cash (without a bank account),  $\kappa_0$  represents costs associated with receiving government payments in cash (without a bank account),<sup>13</sup>  $s_{t-1}$  represents households savings from the last period, and  $d$  represents the cost of storing cash.

The budget constraint for households with a bank account pre-CBDC issuance is

$$i_w + i_r(1 - e_b) + i_g(1 - \kappa_b) + s_{t-1}(1 + r_b) = \underbrace{\int_0^{j^{b,0}} c_t(j) dj}_{\text{Cash payments}} + (1 - v_b) \underbrace{\int_{j^{b,0}}^1 c_t(j) dj}_{\text{Card payments}} + F_b + s_t \quad (5)$$

where  $e_b$  represents fees to receive remittance with a bank account,  $\kappa_b$  represents costs associated with receiving government payments with a bank account,  $r_b$  represents the interest

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<sup>12</sup>Note that  $i_w = 0$  if  $t = T + k$  and  $s_t = 0$  if  $t = T$ . The budget constraint can also be written as:

$$\begin{aligned} i_w + i_r(1 - e_0) + i_g(1 - \kappa_0) &= \bar{c}_t + s_t && \text{if } t = T \\ i_w + i_r(1 - e_0) + i_g(1 - \kappa_0) + s_{t-1}(1 - d) &= \bar{c}_t + s_t && \text{if } T < t < T + k \\ i_r(1 - e_0) + i_g(1 - \kappa_0) + s_{t-1}(1 - d) &= \bar{c}_t && \text{if } t = T + k \end{aligned}$$

The same follows for rest of the household constraints presented in this section.

<sup>13</sup>This includes costs from fees, missed payments, inconvenience etc.

on bank deposits/savings,<sup>14</sup>  $v_b$  represents the (convenience) value of card payments relative to cash, and  $F_b$  is the fixed cost associated with owning a bank account.<sup>15</sup>  $\{e_b, \kappa_b\}$  are likely of similar magnitude as (or only slightly less costly than)  $\{e_0, \kappa_0\}$ . We assume  $v_b > 0$  as card payments are convenient and digital, and its value can be inferred from revealed preference as households with bank accounts widely use card payments.<sup>16</sup>  $r_b \geq 0$  as banks need to attract deposits.

Households decide on whether it is worth paying the fixed cost,  $F_b$ , to own a bank account to access a saving vehicle / deposits account ( $r_b > -d$ ) and a better means of payment ( $v_b > 0$ ) than cash. Households only benefit from the value of card payments if it is accepted by merchants.

We find that holding all else fixed, households with greater wage income  $i_w$  will open a bank account while those with lower wage income will not. This is because the returns from saving in a deposit accounts over cash and the value from card payments increase with wage income (greater wage income implies more savings and more consumption), while the cost to own a bank account is fixed. So, there exists a income threshold  $i_w^{b,0}$  below which the poor use cash ( $i_w < i_w^{b,0}$ ), and above which the rich own bank accounts ( $i_w \geq i_w^{b,0}$ ); see Figure 1.

We find the value of having a bank account increases as more firms accept card payments, i.e.  $j^{b,0}$  decreases. As a result, more households open bank accounts ( $i_w^{b,0}$  decreases) as more firms accept card payments.

More households open bank accounts ( $i_w^{b,0}$  decreases) if the deposit interest rate  $r_b$  is high, the value of card payments  $v_b$  is high (if  $j^{b,0} < 1$ ), and the fixed cost of owning a bank account  $F_b$  is low.

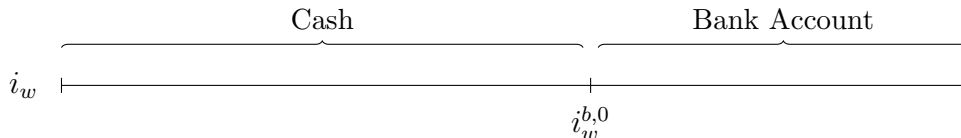
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<sup>14</sup>We abstract away from savings (or investments) outside bank accounts, e.g. in bonds.

<sup>15</sup> $F_b$  includes both monetary and non-monetary barriers/costs associated with owning a bank account.

<sup>16</sup> $v_b$  incorporates any card transaction fees that merchants pass to households.

Figure 1: Household Bank Account Ownership: No CBDC



*Notes: Holding all other variables fixed.*

### 2.1.2 CBDC Issuance Scenario

Households choose between: (1) Using only cash, (2) Owning a CBDC wallet,<sup>17</sup> and (3) Owning a bank account with card payments and access to CBDC.<sup>18</sup>

In this scenario (as we will show in Subsection 2.2), firms  $j \in [0, j^c]$  only accept cash payments, firms  $j \in [j^c, j^b]$  accept cash and CBDC payments, firms  $j \in [j^b, j^{c,b}]$  accept cash and card payments, and firms  $j \in [j^{c,b}, 1]$  accept cash, CBDC and card payments (see Figure 5).

The budget constraint for households using cash only is:

$$i_w + i_r(1 - e_0) + i_g(1 - \kappa_0) + s_{t-1}(1 - d) = \bar{c}_t + s_t \quad (6)$$

where  $e_0$  represents fees to receive remittance in cash (without CBDC or a bank account),  $\kappa_0$  represents costs associated with receiving government payments in cash (without CBDC or a bank account),  $s_{t-1}$  represents households savings from the last period, and  $d$  represents the cost of storing cash.

<sup>17</sup>Either directly provided by the central bank, or through a non-bank payment service provider in a two-tier system

<sup>18</sup>We assume that bank account holders also have access to a CBDC wallet, as most countries are considering a two-tier system where central banks issue CBDC to commercial banks (and non-bank payment service providers that provide CBDC wallets) who then distribute CBDC.

The budget constraint for households with a CBDC wallet is

$$\begin{aligned}
& i_w + i_r(1 - e_c) + i_g(1 - \kappa_c) + s_{t-1}(1 + r_c) \\
& = \underbrace{\int_0^{j^c} c_t(j) dj + \int_{j^b}^{j^{c,b}} c_t(j) dj}_{\text{Cash payments}} + (1 - v_c) \underbrace{\left( \int_{j^c}^{j^b} c_t(j) dj + \int_{j^{c,b}}^1 c_t(j) dj \right)}_{\text{CBDC payments}} + F_c + s_t \quad (7)
\end{aligned}$$

where  $e_c$  represents fees to receive remittance with CBDC,  $\kappa_c$  represents costs associated with receiving government payments with CBDC,  $r_c$  represents CBDC remuneration,  $v_c$  represents the value of CBDC as a means of payments relative to cash, and  $F_c$  is the fixed cost associated with owning a CBDC wallet.<sup>19</sup> We assume  $e_c \leq e_0$ , as reducing the cost of remittances via cross-border CBDC is a policy objective. We assume  $\kappa_c \leq \kappa_0$ , as improving the efficiency of government payments is a key use case for CBDC. CBDC's value as a means of payment relative to cash,  $v_c$ , depends on a range of possible features such as trust, convenience/accessibility, digitalization, transaction costs/fees,<sup>20</sup> programmability, data collection for credit underwriting, anonymity, and offline capabilities etc. We assume  $v_c > 0$ , as this is a design objective of CBDC.  $r_c$  is positive if CBDC is interest bearing, and zero if CBDC is non-interest bearing as most governments are considering. Note that  $r_c \geq 0 > -d$ , as storing cash is costly.

Households decide whether it is worth paying the fixed cost to own a CBDC wallet to access a higher return savings vehicle ( $r_c > -d$ ), a valuable means of payment ( $v_c > 0$ ), cheaper remittance costs ( $e_c \leq e_0$ ), and more efficient government payments ( $\kappa_c \leq \kappa_0$ ). Households only benefit from the value of CBDC payments if it is accepted by merchants.

We find that holding all else fixed, households with greater wage income  $i_w$  will open a CBDC wallet while those with lower wage income will not. This is because the returns from saving in CBDC over cash and the value from CBDC payments increase with wage income

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<sup>19</sup> $F_c$  includes both monetary and non-monetary barriers/costs associated with owning a CBDC wallet.

<sup>20</sup>Merchants can pass on CBDC transaction fees to households.

(greater wage income implies more savings and more consumption), while the cost to own a CBDC wallet is fixed. Also, those receiving more government payments (likely lower income households) and remittances are also more likely to own a CBDC wallet. Last, the value of having a CBDC wallet for payments increases as more firms accept CBDC payments, i.e.  $j^c$  and  $j^{c,b}$  decreases. As a result, more households open CBDC wallets as more firms accept CBDC payments.

The budget constraint for households with a bank account post-CBDC issuance is

$$\begin{aligned}
& i_w + i_r(1 - \max\{e_b, e_c\}) + i_g(1 - \max\{\kappa_b, \kappa_c\}) + s_{t-1}(1 + \max\{r_b, r_c\}) \\
= & \underbrace{\int_0^{j^c} c_t(j) dj}_{\text{Cash payments}} + (1-v_c) \underbrace{\int_{j^c}^{j^b} c_t(j) dj}_{\text{CBDC payments}} + (1-v_b) \underbrace{\int_{j^b}^{j^{c,b}} c_t(j) dj}_{\text{Card payments}} + (1-\max\{v_b, v_c\}) \underbrace{\int_{j^{c,b}}^1 c_t(j) dj}_{\text{CBDC or Card}} + F_b + s_t
\end{aligned} \tag{8}$$

where  $e_b$  represents fees to receive remittance with a bank account,  $\kappa_b$  represents costs associated with receiving government payments with a bank account,  $r_b$  represents the interest on bank deposits,  $v_b$  represents the value of card payments relative to cash, and  $F_b$  is the fixed cost associated with owning a bank account.  $e_c$  is likely less than  $e_b$ , as reducing the cost of remittances via cross-border CBDC is a policy objective.  $\kappa_c$  may be less than  $\kappa_b$ , as efficient government payments is a key use case for CBDC. We assume  $v_b > 0$ , as card payments are convenient and digital, and its value can be inferred from revealed preference as households with bank accounts widely use card payments.  $v_c$  may or may not be greater than  $v_b$ .  $r_b \geq r_c$  and  $r_b \geq 0$  as banks need to attract deposits. We assume  $F_b > F_c$ , as an objective of CBDC is accessibility and low cost.<sup>21</sup>

Households decide whether it is worth paying a higher fixed cost to own a bank account (while preserving access to CBDC) to access a higher return saving vehicle / deposits account

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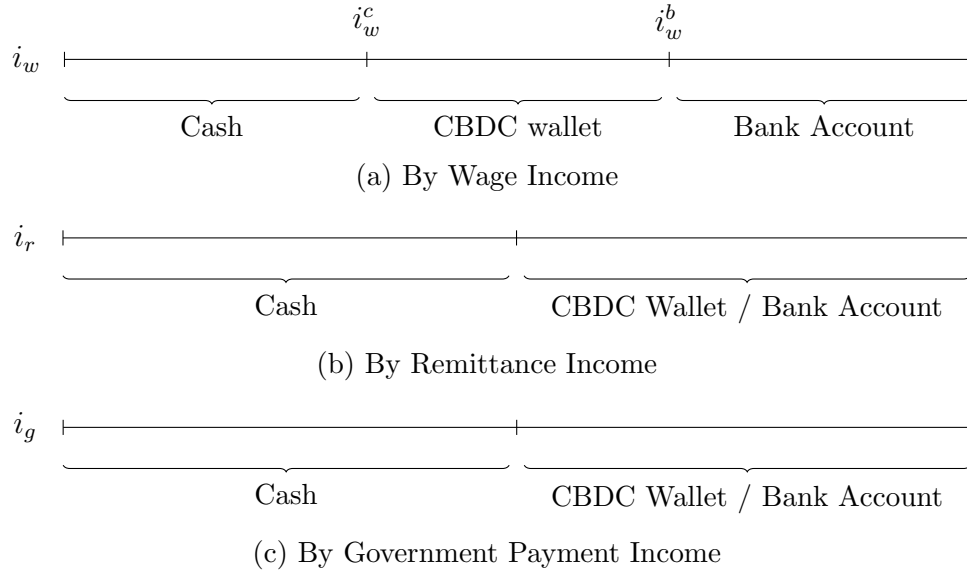
<sup>21</sup>The extent to which CBDC can be designed such that  $F_c$  is lower than  $F_b$  depends on the barriers to financial inclusion in the country and whether CBDC can address them. Cost is also a policy choice.

( $r_b \geq r_c$ ) and a potentially better means of payment ( $v_b > v_c$ ) than CBDC. Households only benefit from the value of card and CBDC payments if they are accepted by merchants.

We find that holding all else fixed, households with greater wage income  $i_w$  will open a bank account while those with lower wage income will not. This is because the returns from saving in a deposit account over CBDC and the potential value from card payments increase with wage income (greater wage income implies more savings and more consumption), while the difference in cost to own a bank account versus a CBDC wallet is fixed. We also find that the value of having a bank account increases as more firms accept card payments, i.e.  $j^b$  decreases. As a result, more households open bank accounts as more firms accept card payments.

So together, we get two income thresholds  $i_w^c, i_w^b$  (holding all else fixed). The poorest use cash ( $i_w < i_w^c$ ), the richest own bank accounts ( $i_w \geq i_w^b$ ), and those in between own a CBDC wallet ( $i_w^c \leq i_w < i_w^b$ ), see Figure 2a. More households open CBDC wallets ( $i_w^c$  decreases) when CBDC remuneration  $r_c$  is high, the CBDC cost of remittance  $e_c$  is low, the value of CBDC for payments  $v_c$  is high (if  $j^c < 1$ ), the cost of receiving government payments via CBDC  $\kappa_c$  is low, the fixed cost of owning a CBDC wallet  $F_c$  is low, and many firms accept CBDC payments; i.e.  $j^c$  (and  $j^{c,b}$  if  $v_c > v_b$ ) is low. More households open bank accounts ( $i_w^b$  decreases) when the bank deposit interest rate  $r_b$  is high, the value of cards for payments  $v_b$  is high, the fixed cost of owning a bank account  $F_b$  is low, and many firms accept card payments; i.e.  $j^b$  (and  $j^{c,b}$  if  $v_b > v_c$ ) is low.

Figure 2: Household CBDC Wallet and Bank Account Ownership: CBDC Scenario



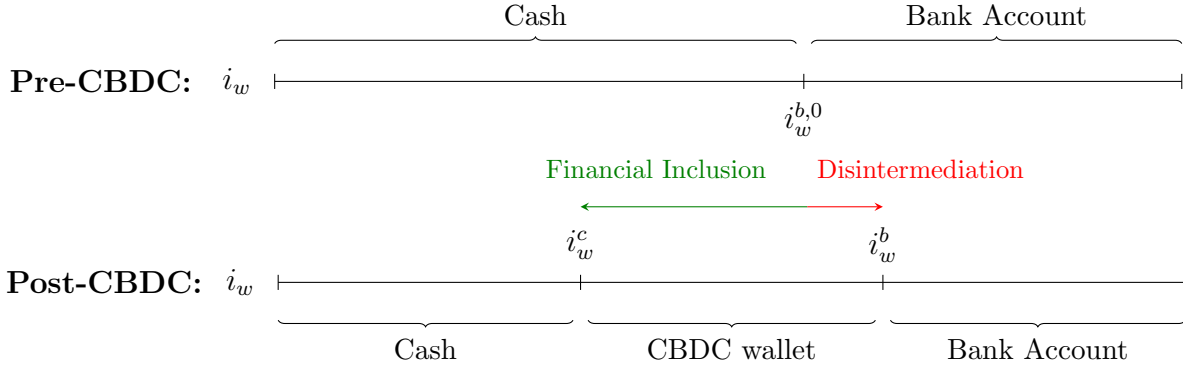
*Notes: Holding all other variables fixed in each subfigure.*

### 2.1.3 Impact of CBDC on Households

In Figure 3, we illustrate the impact of CBDC issuance on households. There are two margins of impact:

1. Financial Inclusion: households switch from using cash to owning CBDC wallets (or bank accounts)
2. Disintermediation: households with bank accounts open CBDC wallets instead

Figure 3: Impact of CBDC on Households



Notes: Holding all other variables fixed in each subfigure.

The model implies that upon issuance of CBDC more households switch from using cash to owning CBDC wallets (greater financial inclusion) if: (1) CBDC reduces the cost of remittances (more so for households with high remittance income), i.e.  $e_c$  is small; (2) Households can receive government payments much more cheaply/efficiently with CBDC, i.e.  $\kappa_c$  is small; (3) CBDC remuneration is high, i.e.  $r_c$  is large; (4) CBDC is a valuable means of payment, i.e.  $v_c$  is large; (5) The fixed cost of owning a CBDC wallet is low, i.e.  $F_c$  is small; and (6) Many firms accept CBDC as payment, i.e.  $j^c$  and  $j^{c,b}$  are small (and  $j^b$  is high).

We note that intermediation, where previously unbanked households open bank accounts, is also possible. Since bank account holders have access to and receive the benefits of CBDC, holding a bank account becomes more attractive.

However, if the fixed cost associated with CBDC is lower than that of a bank account and if a bank account doesn't provide a sufficiently higher savings rate or payments value from cards, then households with bank accounts will open CBDC wallets instead upon CBDC issuance (bank disintermediation). This is the case when: (1) CBDC remuneration is high relative to the bank deposit interest rate, i.e.  $r_c - r_b$  is large; (2) The fixed cost of owning a bank account is high relative to that of owning a CBDC wallet, i.e.  $F_b - F_c$  is large; (3)



CBDC's value as a means of payment is high relative to that of card payments, i.e.  $v_c - v_b$  is large; and (4) A large number of firms accept only CBDC as payment, i.e.  $j^b - j^c$  is large.

At the economy level, the size of the financial inclusion margin depends on the density of households at lower income levels who were previously unbanked and adopt CBDC after issuance. Similarly, the size of the disintermediation margin depends on the density of households at higher income levels who were banked and switch to a using CBDC wallet after issuance. Thus, the financial inclusion margin is larger (smaller) and the disintermediation margin is smaller (larger) in lower (higher) income economies.

Last, we note that if low income (unbanked) households receive more government payments (e.g. in transfers) and remittances than high income households, then designing CBDC to reduce the cost of remittances and to facilitate efficient government payments will be more effective in boosting financial inclusion with less disintermediation.

## 2.2 Firms

There exists a continuum of firms selling each good indexed by  $j \in [0, 1]$ . As shown in Subsection 2.1,  $j$  indexes the goods by value. Households in the economy indexed by  $i$  receive wage income  $i_w(i)$ , remittance income  $i_r(i)$  and government payments  $i_g(i)$ .

### 2.2.1 No CBDC Scenario

In each period, firms  $j$  maximize revenue and choose to accept either:

1. Only Cash (Informal firms)
2. Cash and Card payments (Formal Firms)

There are two groups of households following from household optimization from the last

Subsection 2.1. Households that only pay in cash (group  $g_{0,0}$ ), and households that pay in card payments if accepted and pay in cash otherwise (group  $g_{b,0}$ ).

If firm  $j$  only accepts cash, then its revenue in period  $t$  is:

$$(1 - f_0) \sum_i c_{t,i}(j) \quad (9)$$

where  $f_0$  is the cost of transacting in and handling cash.<sup>22</sup> “Only Cash” firms are informal and can evade taxes.

If firm  $j$  accepts cash and card, then its revenue in period  $t$  is:

$$(1 - f_b - \tau_b) \sum_{i \in g_{b,0}} c_{t,i}(j) + (1 - f_0) \sum_{i \in g_{0,0}} c_{t,i}(j) - K_b \quad (10)$$

where  $f_b$  represents fees associated with transacting in cards (which are incurred by the firm and not passed on to households),<sup>23</sup> and  $\tau_b$  represents taxes on card transactions.  $K_b$  is the fixed cost incurred by the firm in order to accept card payments.<sup>24</sup>

In the firms’ decision on which payment modes to accept, they are trading off the difference in the cost of handling cash and the fees and taxes associated with card payment acceptance, with the fixed cost of adopting card payment  $K_b$ . The former is variable and increases in revenue from households who prefers card payments,  $\sum_{i \in g_{b,0}} c_{t,i}(j)$ , while the latter is fixed in revenue. If no households prefer to use cards for payments, then there are no benefits to accepting cards.

We note that  $\sum_{i \in g_{b,0}} c_{t,i}(j)$  is large when: (1) Many households prefer to use cards for payments, i.e.  $|g_{b,0}|$  is large (or the size of set/group  $g_{b,0}$  is large); (2) Households who use cards for payment are high income (higher income implies higher  $c_{t,i}(j)$ ); and (3)  $j$  is large,

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<sup>22</sup>This can also include lost revenue from not accepting other payment modes.

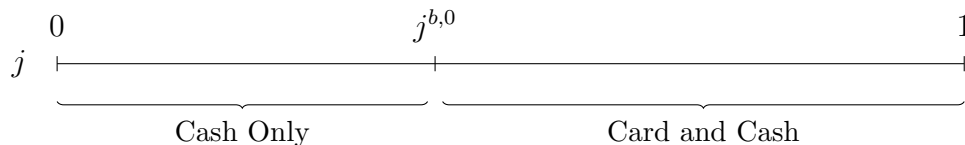
<sup>23</sup>Firms can pass on fees to households reducing that incurred by the firm. Households then are sharing their surplus from making payments in cards with firms, reflected in a lower  $v_b$ .

<sup>24</sup> $K_b$  includes both monetary and non-monetary barriers/costs associated with accepting card payments.

i.e. the firm sells a higher value good.

We get that firms  $j \in [0, j^{b,0}]$  only accept cash payments, and firms  $j \in [j^{b,0}, 1]$  accept cash and card payments (see Figure 4).

Figure 4: Firm Payment Mode Acceptance by Goods Value  $j$ : Pre-CBDC



Note that if  $f_0 < f_b + \tau_b$ , then all firms will only accept cash because there is no benefit to accepting card payments and incurring a fixed cost to do so. So,  $j^{b,0} = 1$ .

The model implies that more firms adopt cards, or  $j^{b,0}$  is low, when: (1) Many households have bank accounts and prefer to use card payments, (2) These households have high income and thus bring in a lot of revenue to make it worthwhile for the firm, (3) The costs associated with card payments are low, both in variable fees and fixed costs, and (4) The costs of handling cash are high.

### 2.2.2 CBDC Issuance Scenario

In each period, firms  $j$  maximize revenue and choose to accept either:

1. Only Cash (Informal)
2. Cash and CBDC payments (Formal)
3. Cash and Card payments (Formal)
4. Cash, CBDC, and Card payments (Formal)

There are three groups of households following from household optimization from the last Subsection 2.1. Households that only pay in cash (group  $g_0$ ), households that pay in CBDC

if accepted and pay in cash otherwise (group  $g_c$ ), and households that pay in card payments if accepted, if not pay in CBDC if accepted, and pay in cash otherwise (group  $g_b$ ). Group  $g_0$  is made up of all households who use cash only if  $v_c > 0$  and  $v_b > 0$ , all households who use cash only and have a CBDC wallet if  $v_c < 0 < v_b$ , or all households if  $v_c < 0$  and  $v_b < 0$ . Group  $g_c$  is made up of all households with a CBDC wallet and households with a bank account if  $v_c > v_b$  and  $v_c > 0$ , all households with a CBDC wallet if  $v_b > v_c > 0$ , or is empty otherwise. Group  $g_b$  is made up of all households with a bank account if  $v_b > v_c$  and  $v_b > 0$ , or is empty otherwise.

If firm  $j$  only accepts cash, then its revenue in period  $t$  is:

$$(1 - f_0) \sum_i c_{t,i}(j) \quad (11)$$

where  $f_0$  is the cost of transacting in and handling cash. “Only Cash” firms are informal and evade taxes.

If firm  $j$  only accepts cash and card, then its revenue in period  $t$  is:

$$(1 - f_b - \tau_b) \sum_{i \in g_b} c_{t,i}(j) + (1 - f_0) \sum_{i \in g_0, g_c} c_{t,i}(j) - K_b \quad (12)$$

where  $f_b$  represents fees associated with transacting in cards, and  $\tau_b$  represents taxes on card transactions.  $K_b$  is the fixed cost incurred by the firm in order to accept card payments.

If firm  $j$  only accepts cash and CBDC, then its revenue in period  $t$  is:

$$(1 - f_c - \tau_c) \sum_{i \in g_c} c_{t,i}(j) + (1 - f_0) \sum_{i \in g_0, g_b} c_{t,i}(j) - K_c \quad (13)$$

where  $f_c$  represents fees associated with transacting in CBDC (which are incurred by the firm and not passed on to households),<sup>25</sup> and  $\tau_c$  represents taxes on CBDC transactions.

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<sup>25</sup>Firms can pass on fees to households reducing that incurred by the firm. Households then are sharing

Note, the government can exempt (targeted/small) firms from taxes for transactions made by CBDC, so  $\tau_c \leq \tau_b$ .<sup>26</sup>  $K_c$  is the fixed cost incurred by the firm in order to accept CBDC payments.<sup>27</sup> We assume  $K_c < K_b$ , as low cost is a policy objective of CBDC.

If firm  $j$  accepts cash, CBDC and card payments, then its revenue in period  $t$  is:

$$(1 - f_b - \tau_b) \sum_{i \in g_b} c_{t,i}(j) + (1 - f_c - \tau_c) \sum_{i \in g_c} c_{t,i}(j) + (1 - f_0) \sum_{i \in g_0} c_{t,i}(j) - K_{c,b} \quad (14)$$

$K_{b,c}$  is the fixed cost incurred by the firm in order to accept both CBDC and card payments. We assume  $K_{c,b} > K_b$ , as firms need to incur a greater cost to accept both CBDC and card payments than only cards, and  $K_{b,c} \leq K_b + K_c$ .

In the firms' decision on which payment modes to accept, they are trading off the differences in taxes, fees, and cash handling which increase in revenue from the group  $g_x \in \{g_0, g_c, g_b\}$  who prefers that payment mode,  $\sum_{i \in g_x} c_{t,i}(j)$ , with the cost of adopting each mode of payment which is fixed in revenue. If no households prefer to use CBDC (cards) for payments, then there are no benefits to accepting CBDC (cards).

We note that  $\sum_{i \in g_x} c_{t,i}(j)$  is large when: (1) Many households prefer to use payment mode  $x$  for payments, i.e.  $|g_x|$  is large (or the size of set/group  $g_x$  is large); (2) Households who use payment mode  $x$  are high income (higher income implies higher  $c_{t,i}(j)$ ); (3)  $j$  is large, i.e. the firm sells a higher value good.

We get that firms  $j \in [0, j^c]$  only accept cash payments, firms  $j \in [j^c, j^b]$  accept cash and CBDC payments, firms  $j \in [j^b, j^{c,b}]$  accept cash and card payments, and firms  $j \in [j^{c,b}, 1]$  accept cash, CBDC, and card payments (see Figure 5).

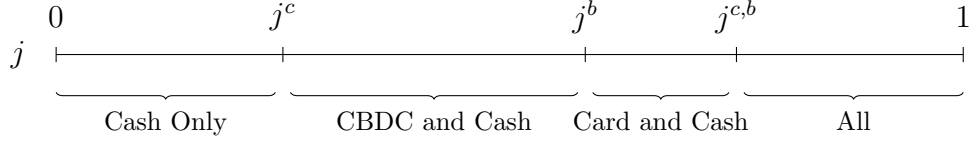
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their surplus from making payments in CBDC with firms, reflected in a lower  $v_c$ .

<sup>26</sup>In Morocco, the government introduced in 2020 for 5 years a total exemption from taxes for transactions made by mobile payment with small size merchants.

<sup>27</sup> $K_c$  includes both monetary and non-monetary barriers/costs associated with accepting CBDC.

Figure 5: Firm Payment Mode Acceptance by Goods Value  $j$



If  $f_0 < f_b + \tau_b$  and  $f_0 < f_c + \tau_c$ , then all firms will only accept cash because there is no benefit to accepting CBDC or card payments and incurring a fixed cost to do so. So,  $j^c, j^b, j^{c,b} = 1$ .

If  $f_0 > f_b + \tau_b > f_c + \tau_c$ , then there is no benefit to accepting card payments over CBDC and incurring a greater fixed cost to do so. There is a benefit to accepting CBDC and paying its associated fees and taxes over the cost of handling cash for high value goods. So,  $0 < j^c \leq 1 = j^b, j^{c,b}$ .

In this scenario, firms selling higher value goods ( $j^c \leq j \leq 1$ ) will accept CBDC and firms selling lower value goods ( $0 \leq j < j^c$ ) will only accept cash. No firms will accept card payments.  $j^c$  is lower (more firms accept CBDC) if many households have CBDC wallets or bank accounts and prefer to use CBDC, and if these households are high income (and thus bringing in a lot of revenue).  $j^c$  also decreases (more firms accept CBDC) as the fixed cost to accept CBDC  $K_c$  (and  $K_{c,b}$ ) decreases, and the fees/taxes associated with CBDC  $f_c + \tau_c$  decreases.

If  $f_0 > f_c + \tau_c > f_b + \tau_b$ , then there is a benefit to accepting card payments over CBDC and incurring a greater fixed cost to do so.

In this scenario, there are two cases:

Case 1:  $(1 - f_b - \tau_b) \sum_{i \in g_b} c_{t,i}(j) + (1 - f_0) \sum_{i \in g_c} c_{t,i}(j) < (1 - f_c - \tau_c) \sum_{i \in g_b} c_{t,i}(j) + (1 - f_c - \tau_c) \sum_{i \in g_c} c_{t,i}(j)$ . In this case, firms always prefer to accept only CBDC and cash payments over accepting only card and cash payments (since  $K_b > K_c$ ). So,  $0 < j^c < j^b = j^{c,b} < 1$ , i.e. firms  $j \in [0, j^c]$  only accept cash payments, firms  $j \in [j^c, j^{c,b}]$  accept cash and CBDC

payments, and firms  $j \in [j^{c,b}, 1]$  accept cash, CBDC and card payments.

Case 2:  $(1 - f_b - \tau_b) \sum_{i \in g_b} c_{t,i}(j) + (1 - f_0) \sum_{i \in g_c} c_{t,i}(j) \geq (1 - f_c - \tau_c) \sum_{i \in g_b} c_{t,i}(j) + (1 - f_c - \tau_c) \sum_{i \in g_c} c_{t,i}(j)$ . In this case, firms may prefer to accept only card and cash payments over accepting only CBDC and cash payments. So,  $0 < j^c \leq j^b \leq j^{c,b} < 1$ . We note that it is possible that CBDC is not adopted by firms in this scenario if  $j^c = j^b$ .

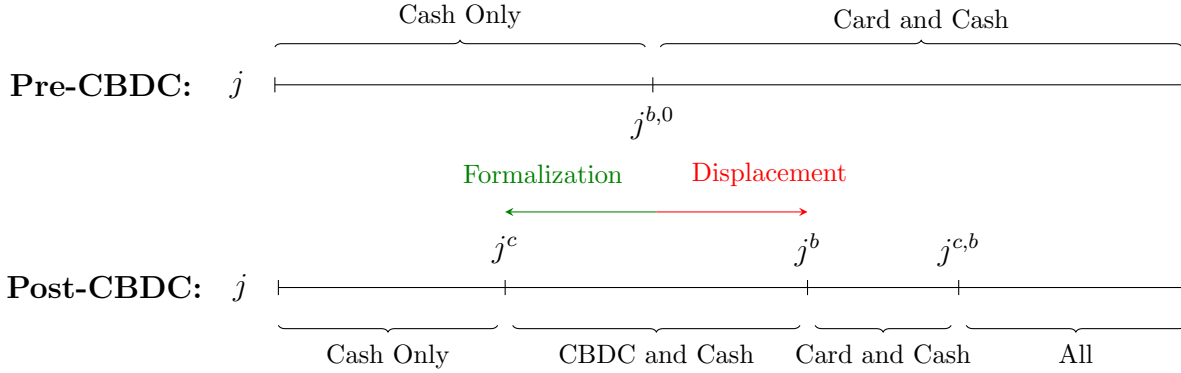
Here,  $j^b$  and  $j^{c,b}$  are lower (more firms accept card payments) if many households have bank accounts and prefer to use card payments, and if these households are high income (and thus bringing in a lot of revenue).  $j^b$  and  $j^{c,b}$  also decrease (more firms accept card payments) as the fixed cost to accept card payments  $K_b$  (and  $K_{c,b}$ ) decreases, and the fees/taxes associated with card payments  $f_b + \tau_b$  decreases.

### 2.2.3 Impact of CBDC on Firms

In Figure 6, we illustrate the impact of CBDC issuance on firms. There are two potential margins of impact:

1. Formalization: Informal firms who only accepted cash choose to accept CBDC (or card) payments after CBDC issuance.
2. Displacement: Firms who accepted card payments no longer accept cards and accept CBDC instead after CBDC issuance.

Figure 6: Firm Payment Mode Acceptance by Goods Value  $j$ : Pre-CBDC



There are greater levels of formalization (more firms move from the informal to formal sector) when: (1) Many households have bank accounts and CBDC wallets and prefer to use CBDC payments over cash, (2) These households have high income and thus bring in a lot of revenue to make it worthwhile for the firm, (3) The fixed cost associated with accepting CBDC payments is low, (4) The fees associated with CBDC payments are low relative to that of handling cash, and (5) There are tax exemptions or subsidies for payments made in CBDC.

CBDC's displacement of card payments is small and could be zero if: (1) The size and income of households who prefer to use CBDC over cards for payment (choose to own a CBDC wallet instead of a bank account or  $v_c > v_b$ ) is small, (2) The fixed and variable costs associated with card payments relative to CBDC payments incurred by the firm are small, and (3) The size of the tax exemptions or subsidies for payments made in CBDC (which do not exist for cards) are small.

We note that more firms could accept card payments (opposite of displacement) after CBDC issuance if firms incur the fixed cost to accept CBDC and find that accepting the marginal fixed cost to accept cards ( $K_{c,b} - K_c$ ) is small, making it worthwhile to accept both.



## 2.3 Dynamics and Timing

We begin in a steady state “no CBDC” scenario at  $t = 0$ . We then introduce CBDC from  $t = 1$  onwards. In each period  $t$ , firms make their payment acceptance decisions based on household bank account or CBDC wallet ownership choices in the last period  $t - 1$ , then households make their new bank account or CBDC wallet ownership choices after observing those firm decisions.<sup>28</sup> The economy then converges towards a new steady state.<sup>29</sup>

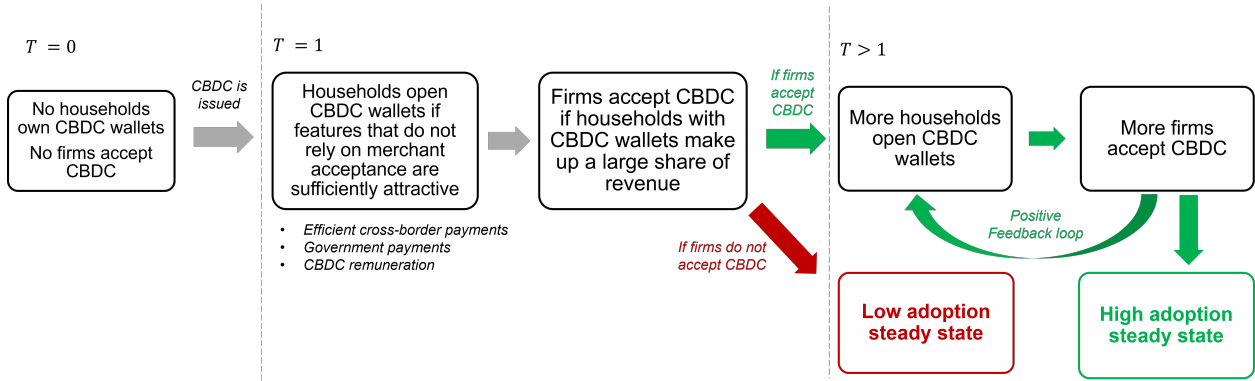
Upon introduction of CBDC, an economy may not transition to a steady state with a high(er) level of CBDC adoption even if it is welfare improving. This is because households cannot benefit from CBDC’s value as a payments instrument ( $v_c$ ) if merchants do not accept it, and merchants have no incentive to incur the fixed cost ( $K_c$ ) to accept CBDC if households do not adopt it. This will be the case if the benefits from CBDC which do not rely on merchant acceptance are not sufficiently attractive (remuneration on CBDC  $r_c$  is low/zero, costs associated with remittances and government payments via CBDC  $e_c, \kappa_c$  are high and close to  $e_0, \kappa_0$ ), or if the households populations benefiting from these features (in particular, remittances and government payments) are too low income such that merchants do not find it worthwhile to accept CBDC for households who make up a small share of total revenue. Thus, the positive feedback loop of adoption between firms and households never starts and the economy is stuck at a low adoption steady state.

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<sup>28</sup>In the baseline, we assume  $r_b$  is fixed. In Appendix Section B.1, we allow banks to have market power and raise interest rates in response to an outflow of deposits from CBDC issuance. As a result, fewer households choose to switch from owning a bank account to owning a CBDC wallet instead (less disintermediation).

<sup>29</sup>The results are robust to introducing switching frictions/costs  $\delta^h$  which are incurred by households every time they choose to change their bank or CBDC wallet ownership choice in a new period, and  $\delta^f$  which are incurred by firms every time they choose to change their payment acceptance choices in a new period.

Figure 7: CBDC Adoption Dynamics



Temporary subsidies can be used to spur initial adoption and the transition the economy to a welfare improving steady state with high CBDC usage.<sup>30</sup> Similarly, temporary tax exemptions for transactions in CBDC for targeted firms can be used.<sup>31</sup> Using CBDC for government payments, or making it more cost effective (or mandatory) to receive government payments through CBDC rather than through other means (increasing  $\kappa_0$  and decreasing  $\kappa_c$ ), will similarly spur adoption.<sup>32</sup>

### 3 Data and Calibration

We calibrate our model to that of a representative developing country with a large informal sector and unbanked population.

We populate the economy with households receiving wage income  $i_w$ , remittances income  $i_r$ , and government payments  $i_g$  (public sector salaries and social transfers) using administrative

<sup>30</sup>For example, the Jamaican government launched a “Small/Micro Merchant Incentive Program”, which will reward the first 10,000 merchants who sign up for their JAM-DEX CBDC platform as of April 1 2023, with a J\$25,000 (about \$164 USD) deposit.

<sup>31</sup>In Morocco, the government introduced in 2020 for 5 years a total exemption from taxes for transactions made by mobile payment with small size merchants.

<sup>32</sup>For example, Egypt implemented a law requiring that salaries and fees out paid by public bodies be made electronically.

household survey data from a large emerging market economy.<sup>33</sup> Overlapping generations are two-period-lived ( $k = 2$ ) and constant in population for simplicity. Utility is logarithmic, i.e.  $u(x) = \log(x)$ .

We calibrate other parameters following Table A1. We assume a banked population share of 57% (World Bank data) and back out the fixed cost of owning a bank account  $F_b$  in the “no CBDC” equilibrium. We assume 80% of the lowest-value goods selling firms are in the informal sector (or  $j^{b,0} = 0.2$ ). This corresponds to the informal sector representing 30% of total output (Quarterly Informal Economy Survey). Then, we back out the fixed cost  $K_b$  of accepting card payments in the “no CBDC” equilibrium.

Our assumed baseline parameters for CBDC are presented in Table A2. We assume that CBDC improves the efficiency of cross-border and government payments, is a more valuable means of payment than cash but less than cards, is non-remunerated, has no tax exemptions, has lower fees (than cards), and has lower fixed costs (than owning a bank account).

## 4 Simulation Results

We present our numerical simulation results in this section. First, we present the baseline results. Second, we show that an economy can get stuck at a steady state with low CBDC adoption if the benefits from CBDC that do not rely on merchant acceptance are not sufficiently attractive. We also show that by introducing temporary measures to spur initial take-up the economy can transition to a steady state with a high(er) level of adoption with significant gains to household welfare, financial inclusion, and formalization. Third, we show that there are smaller financial inclusion and formalization gains and greater disintermediation and displacements risks in higher income countries. Fourth, we show that interest-bearing CBDC can result in greater adoption with slightly greater financial inclu-

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<sup>33</sup>Household Income Sources Survey (2019).

sion and formality gains, but the disintermediation and displacement impact is large. Fifth, we show that there can be bank intermediation if the fixed cost associated with owning a CBDC wallet are high relative to that of a bank account (as the previously unbanked may open a bank account to gain access to CBDC in a two-tier system instead of opening a CBDC wallet). Last, if CBDC doesn't address and lower the fixed cost barriers firms face in accepting card payments, overall adoption is low even though some households are willing to open CBDC wallets.

## 4.1 Baseline results

We present our baseline results in Figure 8 and Table 1.

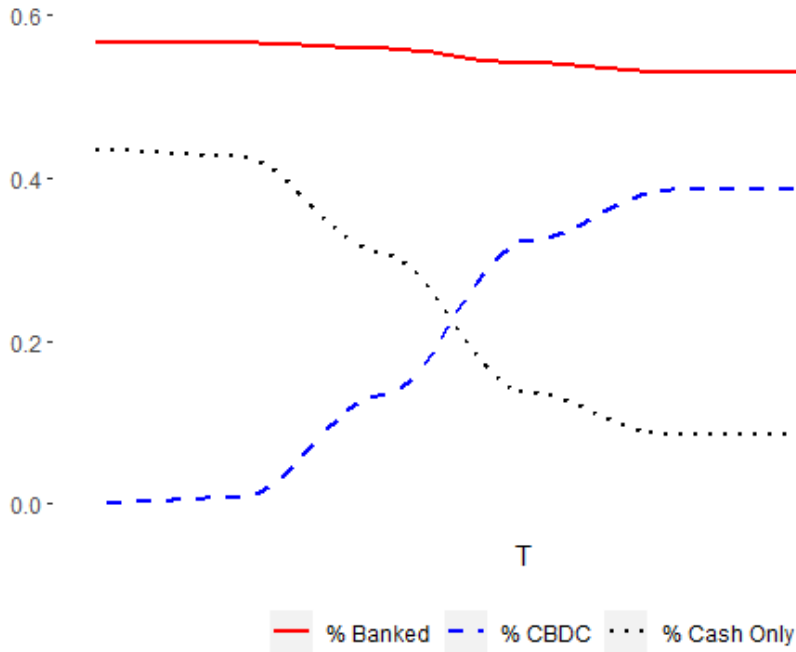
Table 1: Impact of CBDC – Baseline Results

	Pre-CBDC	Post-CBDC
<b>Households (%)</b>		
Cash only	43%	8%
CBDC wallet	0%	39%
Bank account	57%	53%
Financial Inclusion (CBDC or Bank)	57%	92%
% Change in welfare	-	0.39%
<b>Firms (%)</b>		
Cash only (Informal)	80%	26%
Accept CBDC	0%	55%
Accept Card	20%	19%
Formal (CBDC and/or Card)	20%	74%
<b>Savings (%)</b>		
Cash	13%	<1%
CBDC wallet	0%	14%
Bank deposits	87%	86%

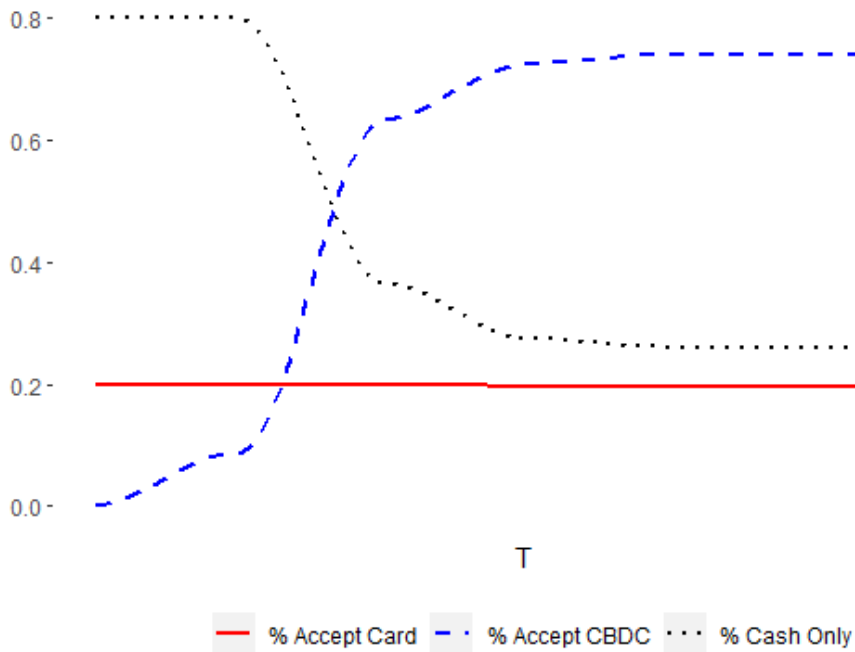
Notes: This table presents the impact of CBDC issuance. The second column reports the initial equilibrium without CBDC, and the third column reports the steady state equilibrium with CBDC.

We find that the economy transitions from the “no CBDC” initial equilibrium to a steady state with a high level of adoption at 39% of households and 55% of firms. Household welfare

Figure 8: Impact of CBDC – Baseline Results



(a) Households



(b) Firms

Notes: This figure presents the impact of CBDC issuance over time. Figure (a) reports the share of households who own a bank account, own a CBDC wallet, or use only cash. Figure (b) reports the share of firms who accept card payments, CBDC payments, and cash only.

increases by 0.39%.<sup>34</sup> Financial inclusion increases 35 p.p. from 57% of population owning a bank account pre-CBDC to 92% owning a CBDC wallet or bank account post-CBDC. The share of informal firms drops by 54 p.p., from 80% to 26%. We find relatively low levels of disintermediation (1 p.p. decrease in the share of total savings and 4 p.p. decrease in bank account ownership). There is also small displacement of card payments at a 1 p.p. decrease in firms accepting card payments.

## 4.2 Low adoption steady state and temporary measures

We consider the issuance of a CBDC with no improvements to cross-border and government payments ( $e_c = e_0$  and  $\kappa_c = \kappa_0$ ). CBDC only offers a non-remunerated savings vehicle and a valuable means of payment. We present the results in Table 2 and Figure A1.

We find that CBDC wallet adoption remains persistently low at 1% of households. As a result, there is near zero take-up of CBDC by firms, and near zero impact on household welfare, financial inclusion and formalization. This is because the benefits from CBDC that do not rely on merchant acceptance are not sufficiently attractive to incentivize enough early adoption by households such that merchants will then find it worthwhile to accept CBDC. Thus, the positive feedback loop of adoption between firms and households never starts and the economy is stuck at a low adoption steady state.

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<sup>34</sup>We note that the household welfare gains measured do not include potential gains from tax revenues through greater formalization.

Table 2: Impact of CBDC – Low adoption steady state and temporary incentives

	Pre-CBDC	Post-CBDC <i>w/o incentives</i>	Post-CBDC <i>w/ incentives</i>
<b>Households (%)</b>			
Cash only	43%	42%	21%
CBDC wallet	0%	1%	23%
Bank account	57%	57%	56%
Financial Inclusion (CBDC or Bank)	57%	58%	79%
% Change in welfare	-	0.01%	0.25%
<b>Firms (%)</b>			
Cash only (Informal)	80%	80%	31%
Accept CBDC	0%	<1%	49%
Accept Card	20%	20%	20%
Formal (CBDC and/or Card)	20%	20%	69%
<b>Savings (%)</b>			
Cash	13%	13%	4%
CBDC wallet	0%	0%	9%
Bank deposits	87%	87%	87%

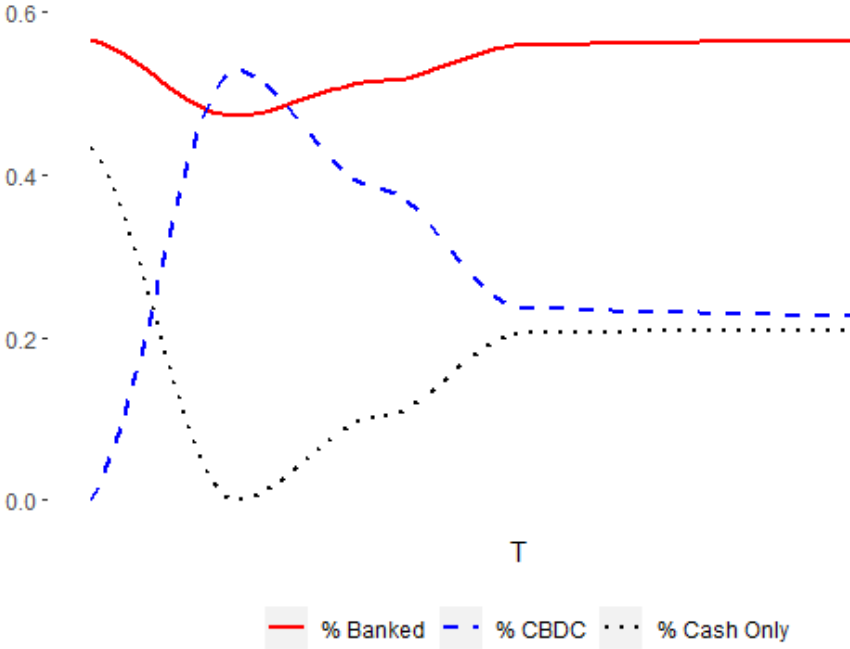
Notes: This table presents the impact of CBDC issuance when  $e_c = e_0$  and  $\kappa_c = \kappa_0$ . The second column reports the initial equilibrium without CBDC, the third column reports the steady state equilibrium with CBDC and no temporary incentives, the fourth column reports the steady state equilibrium with CBDC and temporary incentives in the first period: 20% decrease in  $F_c$  for below median income households,  $\tau_c = 0$ , 1 p.p increase in  $\kappa_0$  and 0.5 p.p. decrease in  $\kappa_c$ .

Next, we put into place three temporary policies to spur initial take up in the first period after CBDC issuance. First, a temporary 20% subsidy on the fixed cost of owning a CBDC wallet for households ( $F_c$ ) below median income. Second, CBDC transactions are exempt from taxes ( $\tau_c = 0$ ).<sup>35</sup> Last, governments payments are administered through CBDC, making it more cost effective to receive government payments through CBDC rather than through other means – increasing  $\kappa_0$  by 1 p.p. and decreasing  $\kappa_c$  by 0.5 p.p..<sup>36</sup> These policies are all actively being considered by countries designing CBDC. We present the results in Table 2 and Figure 9.

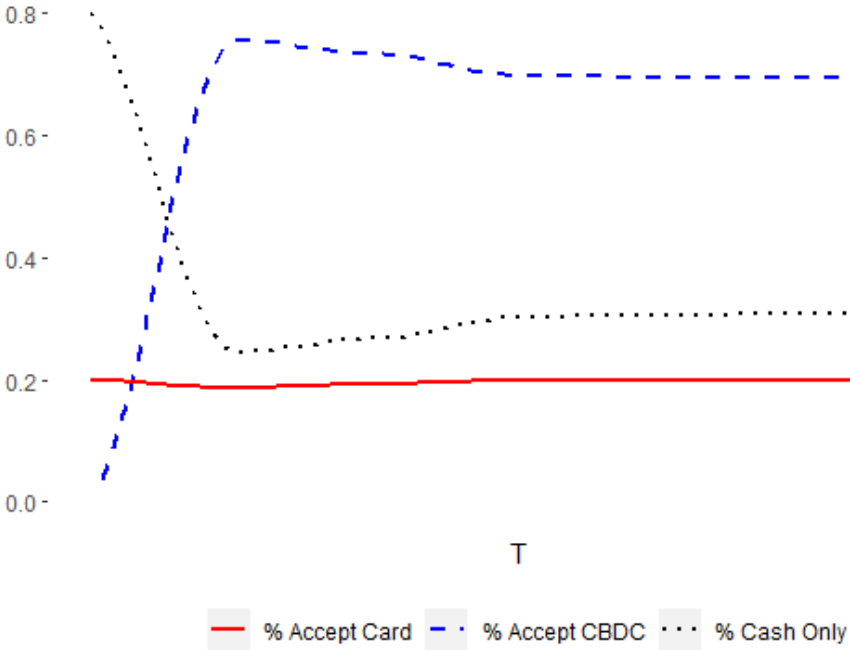
<sup>35</sup>In Morocco, the government introduced in 2020 for 5 years a total exemption from taxes for transactions made by mobile payment with small size merchants.

<sup>36</sup>Egypt implemented a law requiring that salaries and fees out paid by public bodies be made electronically.

Figure 9: Impact of CBDC – High adoption steady state with temporary policy measures



(a) Households



(b) Firms

Notes: This figure presents the impact of CBDC issuance over time when  $e_c = e_0$  and  $\kappa_c = \kappa_0$  but with temporary incentives in the first periods: 20% decrease in  $F_c$  for low median income households,  $\tau_c = 0$ , 1 p.p increase in  $\kappa_0$  and 0.5 p.p. decrease in  $\kappa_c$ . Figure (a) reports the share of households who are own a bank account, own a CBDC wallet, or use only cash. Figure (b) reports the share of firms who accept card payments, CBDC payments, and cash only.



We find that the temporary incentive measures encourage high levels of initial take up of CBDC, which then reduce slightly over time after the measures expire. However, these incentive measures are successful in pushing the economy (out of the low adoption steady state) to a steady state with a much higher level of CBDC adoption at 23% of households and 49% of firms. Household welfare increases by 0.25%. Financial inclusion increases 22 p.p. from 57% of population owning a bank account pre-CBDC to 79% owning a CBDC wallet or bank account post-CBDC. The share of informal firms drops by 49 p.p., from 80% to 31%. Disintermediation of banks is small (<1 p.p. decrease in savings and 1 p.p. decrease in bank account ownership) and there is no displacement of card payments.

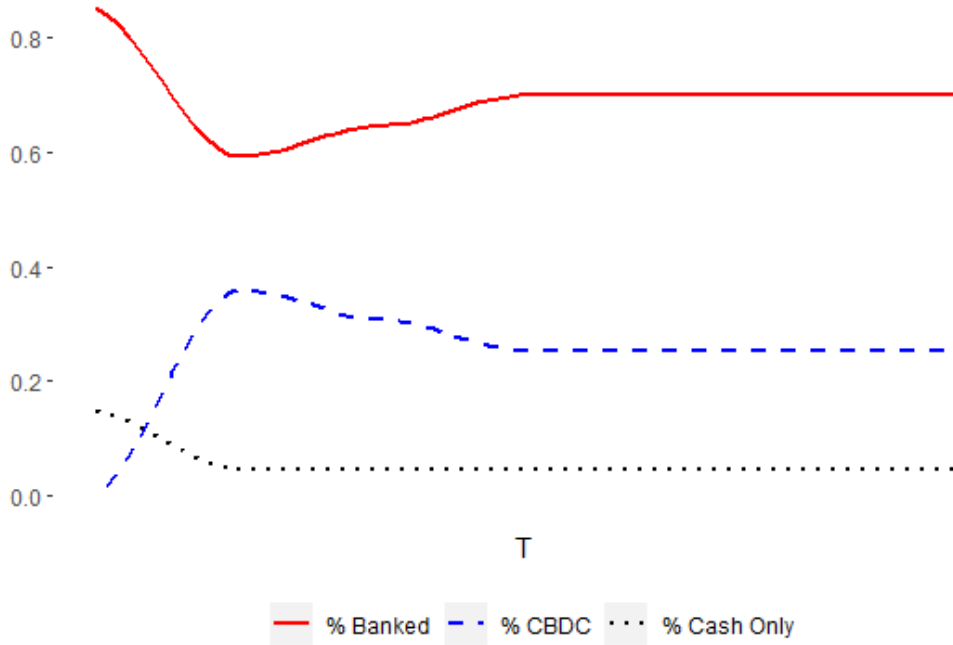
### 4.3 Country income level

Next, we show that the financial inclusion and formalization gains are smaller, and the disintermediation and displacement risks are greater in higher income economies.

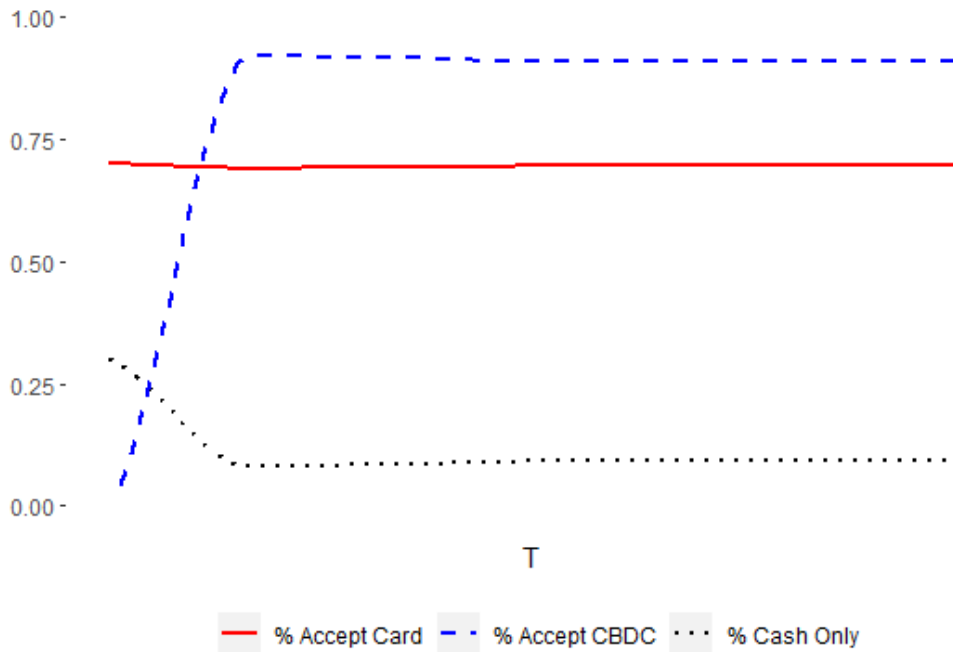
We increase the incomes  $i_w$  of all households by 10%, giving us a higher income population with a smaller unbanked population (18%) and smaller informal sector ( $j^{b,0} = 0.3$ ) in the “no CBDC” equilibrium. We report the results in Table 3 and Figure 10.

We find that there is a smaller margin for gains in financial inclusion and formality (compared to the lower-income country baseline), at 13 p.p. (vs 35 p.p.) and 21 p.p. (vs 54 p.p.) respectively. Additionally, there is a much larger disintermediation impact with a 22 p.p. decrease in the share of households with a bank account (who switch to owning a CBDC wallet), and a 6 p.p. decrease in the share of savings in bank deposit accounts (compared to 4 p.p. and 1 p.p. respectively). The displacement of cards payment impact is 1 p.p..

Figure 10: Impact of CBDC – Higher income country



(a) Households



(b) Firms

Notes: This figure presents the impact of CBDC issuance over time in a higher income country (10% higher income and smaller informal sector  $j^{b,0} = 0.3$ ). Figure (a) reports the share of households who own a bank account, own a CBDC wallet, or use only cash. Figure (b) reports the share of firms who accept card payments, CBDC payments, and cash only.

Table 3: Impact of CBDC – Higher income country

	Pre-CBDC	Post-CBDC
<b>Households (%)</b>		
Cash only	18%	5%
CBDC wallet	0%	25%
Bank account	82%	60%
Financial Inclusion (CBDC or Bank)	82%	95%
% Change in welfare	-	0.25%
<b>Firms (%)</b>		
Cash only (Informal)	30%	9%
Accept CBDC	0%	91%
Accept Card	70%	69%
Formal (CBDC and/or Card)	70%	91%
<b>Savings (%)</b>		
Cash	3%	<1%
CBDC wallet	0%	8%
Bank deposits	97%	91%

Notes: This table presents the impact of CBDC issuance in a higher income country (10% higher income and smaller informal sector  $j^{b,0} = 0.3$ ). The second column reports the initial equilibrium without CBDC, and the third column reports the steady state equilibrium with CBDC.

#### 4.4 Remunerated CBDC

Interest-bearing CBDC results in greater adoption with slightly greater financial inclusion and formality gains, but the disintermediation and displacement impact is large.

We allow CBDC to be interest-bearing at half the bank deposit interest rate, i.e. setting  $r_c = 1.5\%$ . We find CBDC adoption is greater at 63% of households and 79% of firms (vs 39% and 55% in the baseline respectively). CBDC is more attractive to households, increasing adoption which also results in higher take-up from firms. The financial inclusion and formality impact is slightly larger at 37 p.p. and 59 p.p. (vs 35 p.p. and 54 p.p. in the baseline), respectively. However, with remunerated CBDC, disintermediation is much greater than in the baseline with the share of households with a bank account decreasing by 27 p.p., and with the share of savings held in bank account decreasing by 14 p.p. (vs 4 p.p. and 1 p.p. in the baseline). Displacement also is greater with the share of firms accepting

card payments decreasing at 5% (vs 1% in the baseline). The results are reported in Table 4 and Figure A2.

Table 4: Impact of CBDC – Additional Results

	Pre-CBDC	Post-CBDC <i>Baseline</i>	Post-CBDC $r_c = 1.5\%$	Post-CBDC $F_c = F_b$	Post-CBDC $K_c = K_b$
<b>Households (%)</b>					
Cash only	43%	8%	6%	42%	42%
CBDC wallet	0%	39%	63%	0%	1%
Bank account	57%	53%	30%	58%	57%
Financial Inclusion	57%	92%	94%	58%	58%
<b>Firms (%)</b>					
Cash only (Informal)	80%	26%	21%	80%	80%
Accept CBDC	0%	55%	79%	<1%	0%
Accept Card	20%	19%	15%	20%	20%
Formal	20%	74%	79%	20%	20%
<b>Savings (%)</b>					
Cash	13%	<1%	<1%	12%	12%
CBDC wallet	0%	14%	26%	0%	<1%
Bank deposits	87%	86%	73%	88%	87%

Notes: This table presents the impact of CBDC issuance. The second column reports the initial equilibrium without CBDC, the third column reports the baseline steady state equilibrium with CBDC, the fourth column reports the steady state equilibrium with interest-bearing CBDC at  $r_c = 1.5\%$ , the fifth column reports the steady state equilibrium with CBDC when the fixed cost to own a CBDC wallet is the same as that of a bank account  $F_b = F_c$ , and the last column reports the steady state equilibrium with CBDC when the fixed cost to accept CBDC is the same as that of a bank account  $K_b = K_c$ .

## 4.5 Household CBDC wallet fixed cost

We show that there can be bank intermediation if the costs associated with owning a CBDC wallet are high relative to that of a bank account, as the previously unbanked may open a bank account to gain access to CBDC in a two-tier system instead of opening a CBDC wallet.

If the fixed cost to own a CBDC wallet is not lower than that of a bank account, i.e. setting  $F_c = F_b$ , it is never worth it for households to open just a CBDC wallet instead of a bank account (since bank account owners have access to CBDC in a two-tier system). Unbanked

households are incentivized to open a bank account to access CBDC, and there is the intermediation of banks (though small), with savings in bank deposit accounts increasing by 1 p.p. and the share of households owning a bank account increasing by 1 p.p.. However, there is no adoption of CBDC by households and near zero acceptance by merchants. Thus, the positive feedback loop of adoption between firms and households never starts. The financial inclusion gain is 1 p.p., and the formality gain is less than 1%. There is no displacement of card payments. The results are reported in Table 4 and Figure A3.

This scenario is equivalent to one where CBDCs are only distributed by banks (and cannot be distributed by non-bank payment service providers) in a two-tier system.

#### **4.6 Firm CBDC acceptance fixed cost**

Last, we consider a scenario where CBDC doesn't address and lower the fixed cost barriers firms face in accepting card payments.

If the fixed cost to accept CBDC is the same as that of cards, i.e. setting  $K_c = K_b$ , then firms are not sufficiently incentivized to accept CBDC even if a small number of households have adopted it. Thus, the positive feedback loop of adoption between firms and households never starts. CBDC adoption remains low at 1% of households and 0% of firms accept CBDC. There is a 1 p.p. financial inclusion gain (the share of households using only cash drops by 1 p.p.) and no formalization impact. There is no displacement, and the disintermediation impact is very small and near zero. The results are reported in Table 4 and Figure A4.

## **5 Conclusion**

This paper develops a dynamic two-sided payments model with heterogeneous households and merchants/firms to study: (1) The adoption of CBDC by households and firms, and (2)

The impact of CBDC issuance on financial inclusion, formality, and disintermediation.

Our model shows that more households will adopt CBDC if more firms accept CBDC (and vice versa) – incentivizing *both* households and firms will result in greater levels of take-up. Households are more likely to adopt CBDC if it is low cost, provides an attractive savings vehicle, reduces the cost of remittances, improves the efficiency of government payments, and (if accepted by merchants) offers a valuable means of payment. Firms are more likely to accept CBDC if the fixed cost and variable fees are low, if there are tax exemptions or subsidies for transactions made in CBDC, and if households who prefer to make payments with CBDC make up a large share of revenue.

An economy can get stuck at a steady state with low CBDC adoption and small welfare gains if the features of CBDC which do not rely on merchant acceptance (remuneration, efficiency of cross border and government payments) are not sufficiently attractive, or if the households benefiting from these features make up a small share of merchant revenue. Temporary subsidies and using CBDC for government payments can spur initial take-up to transition an economy to a welfare improving steady state with high(er) CBDC usage.

Greater adoption of CBDC will result in greater financial inclusion and formalization, but potentially the disintermediation of banks and card payments. Thus, there is a trade-off in designing CBDC for greater adoption.

However, the gains from financial inclusion and formalization are more likely to outweigh the risks of disintermediation in lower income economies with larger unbanked populations and informal sectors.

We calibrate the model to that of a representative developing economy with a large informal sector and unbanked population, to show our results numerically. We show that an economy can get stuck at a steady state with low CBDC adoption and a small welfare impact if there are no gains in the efficiency of cross-border and government payments. However, by introducing

temporary measures to spur initial take-up such as subsidies, tax exemptions for CBDC transactions, and using CBDC for government payments, the economy can transition to a steady state with a high level of adoption with significant gains to household welfare, financial inclusion, and formalization. We find limited disintermediation in this developing economy setting, compared to that of a higher-income economy (with a small informal sector and unbanked population).

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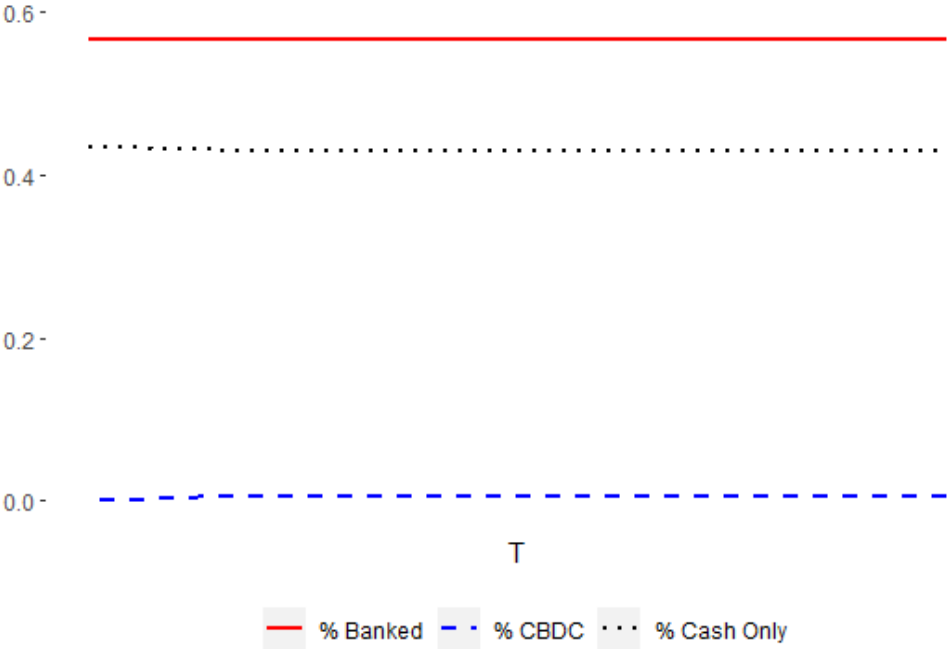


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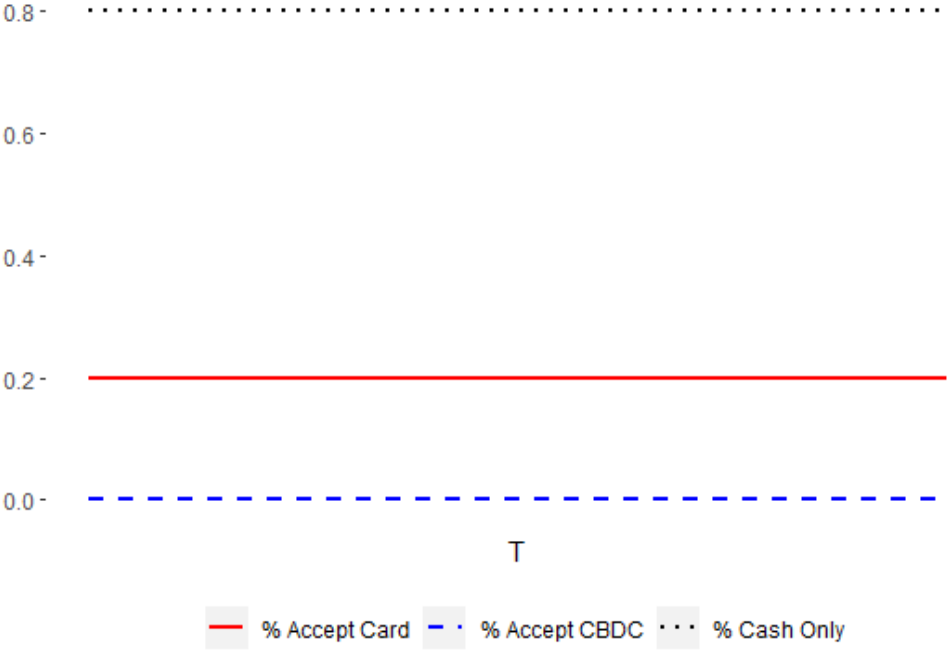
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# A Appendix Tables and Figures

Figure A1: Impact of CBDC – Low adoption steady state



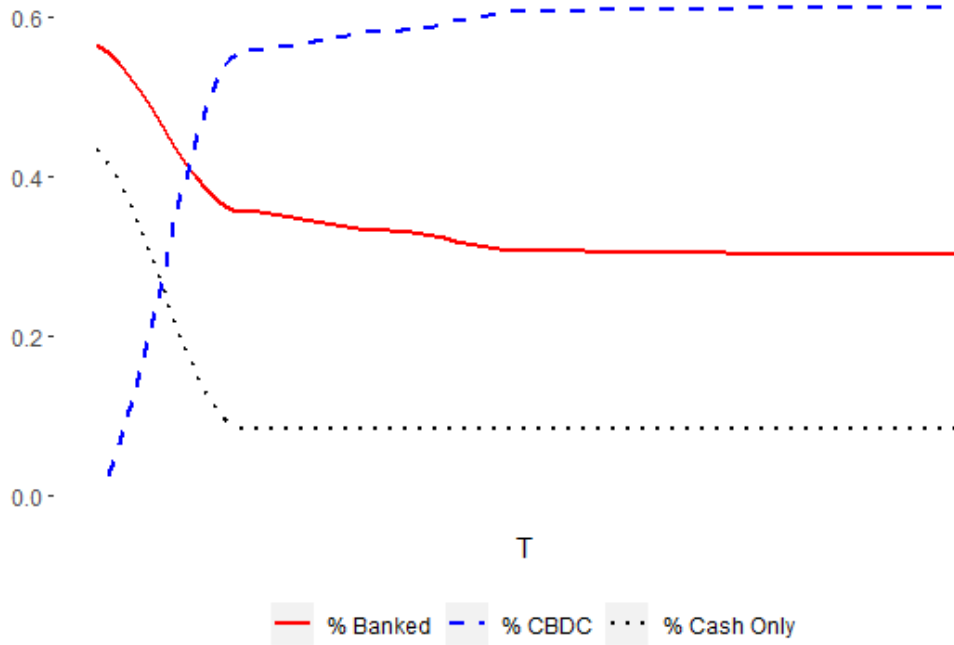
(a) Households



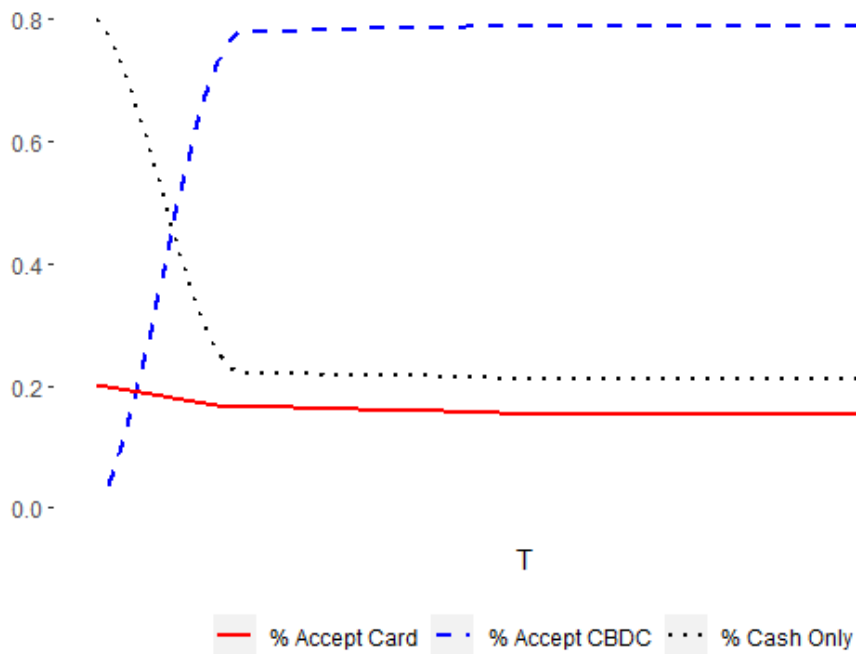
(b) Firms

Notes: This figure presents the impact of CBDC issuance over time for the low adoption steady where  $e_c = e_0$  and  $\kappa_c = \kappa_0$ . Figure (a) reports the share of households who are own a bank account, own a CBDC wallet, or use only cash. Figure (b) reports the share of firms who accept card payments, CBDC payments, and cash only.

Figure A2: Impact of CBDC – Interest-bearing CBDC



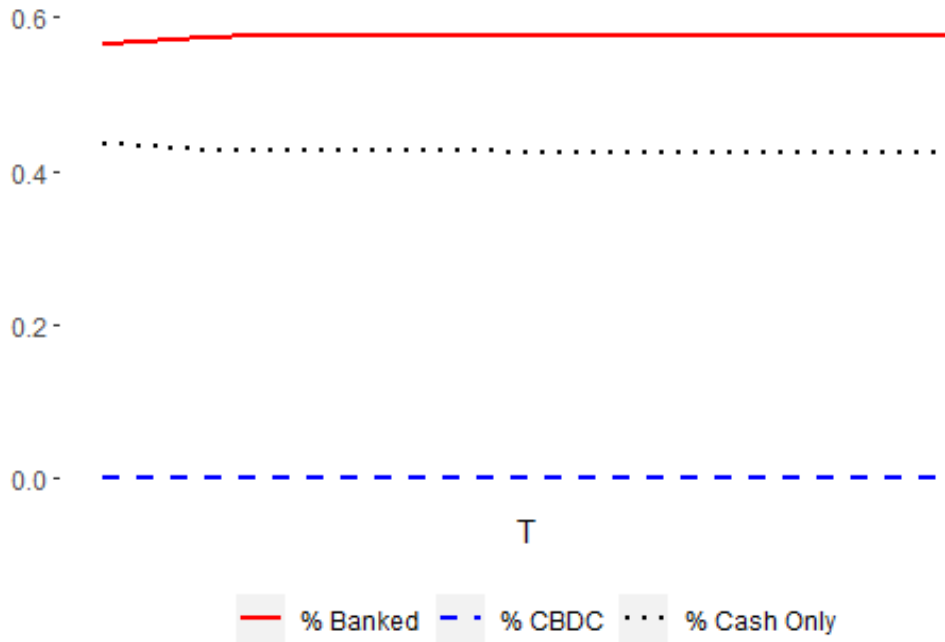
(a) Households



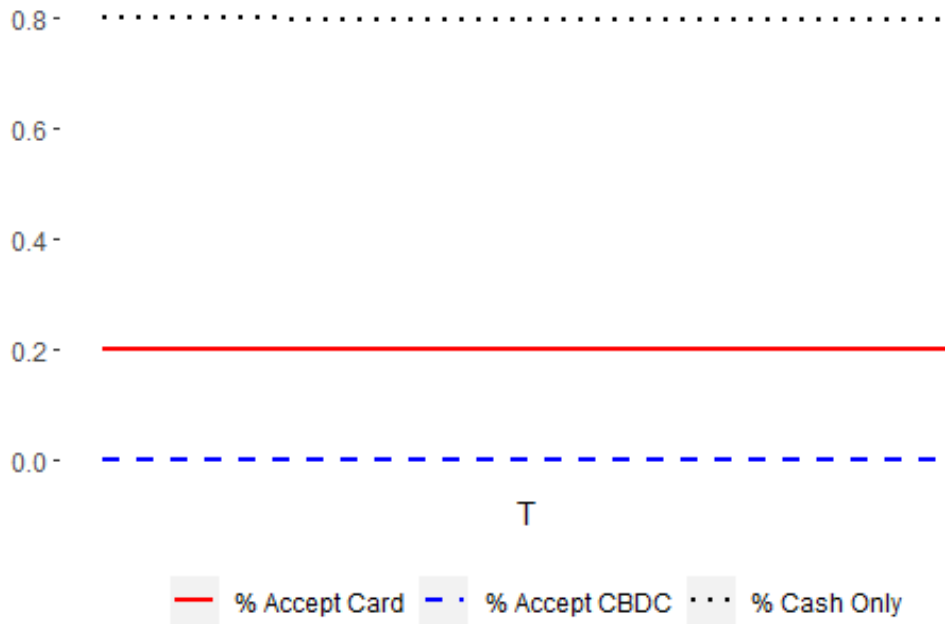
(b) Firms

Notes: This figure presents the impact of CBDC issuance over time when CBDC is interest-bearing at  $r_c = 1.5\%$ . Figure (a) reports the share of households who own a bank account, own a CBDC wallet, or use only cash. Figure (b) reports the share of firms who accept card payments, CBDC payments, and cash only.

Figure A3: Impact of CBDC – High fixed cost for households own a CBDC wallet



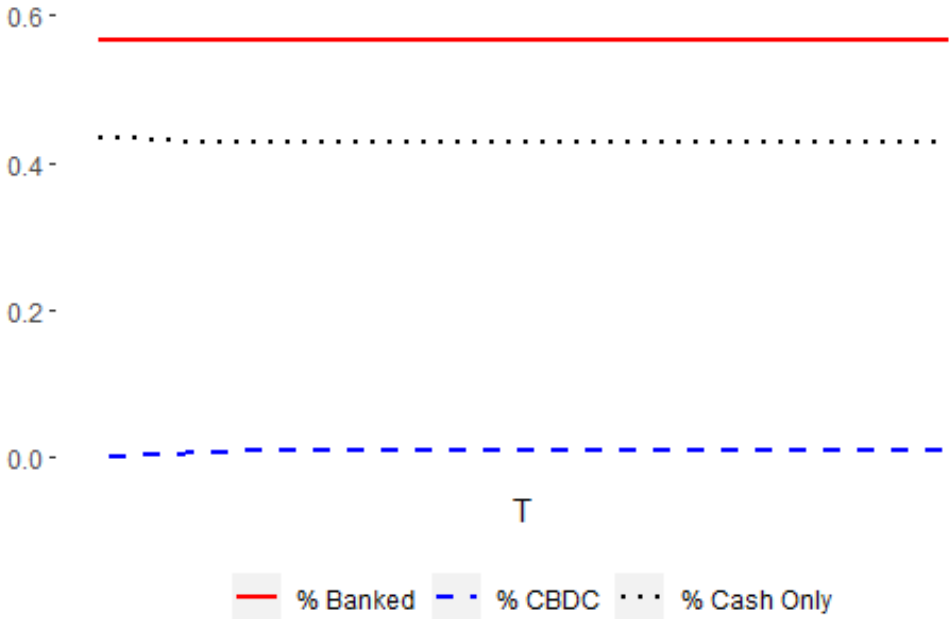
(a) Households



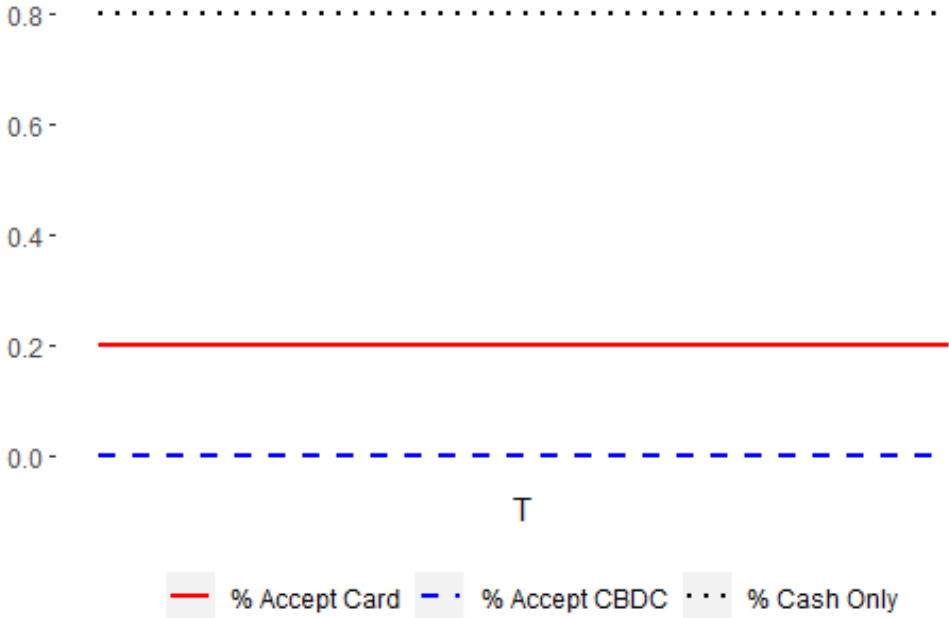
(b) Firms

Notes: This figure presents the impact of CBDC issuance over time when the fixed cost to own a CBDC wallet is the same as that of a bank account  $F_b = F_c$ . Figure (a) reports the share of households who are own a bank account, own a CBDC wallet, or use only cash. Figure (b) reports the share of firms who accept card payments, CBDC payments, and cash only.

Figure A4: Impact of CBDC – High fixed cost for firms to accept CBDC



(a) Households



(b) Firms

Notes: This figure presents the impact of CBDC issuance over time when the fixed cost to accept CBDC is the same as that of a bank account  $K_b = K_c$ . Figure (a) reports the share of households who are own a bank account, own a CBDC wallet, or use only cash. Figure (b) reports the share of firms who accept card payments, CBDC payments, and cash only.

Table A1: Calibration Parameters

Variable	Value	Source
$e_0, e_b$	6%	World Bank - Remittance Prices Worldwide
$\kappa_0, \kappa_b$	3%	Ortiz et al. (2017)
$v_b$	1%	Lam and Ossolinski (2015)
$r_b$	3%	IMF - Deposit interest rates
$\tau_b, \tau_0$	7%	World Bank - Taxes on goods and services
$f_0$	10%	IHL Group (2018)
$f_b$	2%	Hayashi (2009)
$\beta$	0.85	Assumption
$d$	0.5%	Assumption
$w$	-3	Assumption

Table A2: CBDC Parameters

Variable	Value
$e_c$	5.8%
$\kappa_c$	2.5%
$v_c$	0.2%
$r_c$	0%
$\tau_c$	7%
$f_c$	1.9%
$F_c$	$\frac{F_b}{5}$
$K_c$	$\frac{K_b}{10}$
$K_{b,c}$	$K_b + K_c$

## B Additional Results and Extensions

### B.1 Imperfectly Competitive Banking Sector

If banks have market power, they can raise the bank deposit interest rate  $r_b$  in response to any outflow of deposits upon CBDC issuance to make deposits more attractive.

We assume banks set interest rates at the beginning of each period based on household deposits from the last period. Let the elasticity of the interest rate  $r_b$  with respect to household deposits be  $-2$ .<sup>37</sup> We present the results in Table A3.

Table A3: Impact of CBDC – Imperfectly Competitive Banking Sector

	Pre-CBDC	Post-CBDC
<b>Households (%)</b>		
Cash only	43%	8%
CBDC wallet	0%	37%
Bank account	57%	55%
Financial Inclusion (CBDC or Bank)	57%	92%
<b>Firms (%)</b>		
Cash only (Informal)	80%	26%
Accept CBDC	0%	55%
Accept Card	20%	19%
Formal (CBDC and/or Card)	20%	74%
<b>Savings (%)</b>		
Cash	13%	<1%
CBDC wallet	0%	13%
Bank deposits	87%	87%

Notes: This table presents the impact of CBDC issuance when the elasticity of the interest rate  $r_b$  with respect to household deposits is  $-2$ . The second column reports the initial equilibrium without CBDC, and the third column reports the steady state equilibrium with CBDC.

We find that the financial inclusion and formalization gains are just as strong as in our baseline results, with financial inclusion increasing by 35 p.p. and informality dropping by 54 p.p.. However, the disintermediation impact is smaller than in our baseline results. There

<sup>37</sup>Estimated from Chang et al., 2023.



is only a 2 p.p. decrease in bank account ownership (vs 4 p.p. in the baseline), and near zero decrease in the share of total savings (vs a 1 p.p. decrease in the baseline).