Working Papers in Economics & Finance
2020-11

Central bank digital currency and informal economy

Eun Young Oh, University of Portsmouth

Shuonan Zhang, University of Portsmouth

Portsmouth Business School
https://www.port.ac.uk/about-us/structure-and-governance/organisational-structure/our-academic-structure/faculty-of-business-and-law/portsmouth-business-school

Central bank digital currency and informal economy

Eun Young Oh, Shuonan Zhang*, †

University of Portsmouth, Economics and Finance, Portsmouth, UK, PO1 2UP

Abstract

The central bank digital currency (CBDC) attracts discussions on its merits and risks but much less attention is paid to the adoption of a CBDC. In this paper, we show that the CBDC may not be widely accepted in the presence of a sizeable informal economy. Based on a two-sector monetary model, we show an L-shaped relationship between the informal economy and CBDC. The CBDC can formalize the informal economy but this effect becomes marginally significant in countries with significantly large informal economies. In order to promote CBDC adoption and improve its effectiveness, tax reduction and the positive CBDC interest rate can be useful tools. We further show that CBDC policy rate adjustment triggers a reallocation effect between formal and informal sectors, through which improves the effectiveness of both conventional monetary policy and fiscal policy.

JEL classification: E26, E40, E42, E58

Keywords: Central Bank Digital Currency, Informal Economy, Quantitative Analysis

*Corresponding Author: Dr. Shuonan Zhang, University House, Winston Churchill Avenue, Portsmouth, Hampshire, PO1 2UP, shuonan.zhang@port.ac.uk

†This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

1 Introduction

The technological advances such as the distributed ledger technology (DLT) opened the possibility for central banks to issue digital fiat currency–*Central Bank Digital Currency* (CBDC).[1] The ongoing research spurs a broad discussion about whether central banks should issue CBDC. The proponents argue that CBDC has lower transaction costs than cash (Griffoli et al. 2018), could avoid potential instability caused by private money creation (Brunnermeier & Niepelt 2019) and improve macroeconomic management as well as control of money[2] (Bindseil 2020). The opponents, on the other hand, are concerned with the potential disintermediation consequences which could threaten both economic growth and financial stability (Keister & Sanches 2019). Despite the disagreement, their discussions are commonly from issuer or banking perspectives with less attention paid to user sides. To date, there is a lack of investigations to what extent CBDC can be accepted and circulated.

In this paper, we depart from the existing angles and understand CBDC from a user-sided viewpoint. As users of money, households value anonymity in transaction ensured by cash payment. Such a motive is stronger in developing countries where significant informal income discourages people from using digital payments for tax evasion.[3] As one type of digital money, CBDC is likely to be traceable[4] and subject to government monitoring. We argue that accounting for the traceable feature of CBDC payment and the presence of informal economy has important implications for the adoption and effects of CBDC.

We build a two-sector monetary model with formal and informal productions to understand the relationship between CBDC and informal economy. In our framework, we highlight three differences between cash and CBDC. The latter is a more efficient means of payment in the terms of low transaction costs (Hasan et al. 2013, Kosse et al. 2017, Griffoli et al. 2018)[5], interest-bearing but subject to central bank monitoring. The last feature provides a spillover effect on enforcing tax payment, yet scarifying anonymous payments and informal incomes. In equilibrium, the features of CBDC lead to a trade-off between cost efficiency and anonymity for households who determine the optimal allocation between cash and CBDC. This decision, in turn, affects labour allocation through the income gap between formal and informal sectors. In summary, there is a two-way relationship between CBDC and informal economy which are jointly determined.

To quantitatively evaluate implications of our model, we calibrate parameters to multiple cases which allow us to conduct cross-country comparisons. Our results suggest an L-shaped relationship between the

[1] By definition, CBDC is "an electronic form of central bank money that could be used by households and businesses to make payments and store value." (Bank of England)

[2] Bindseil (2020) suggests that CBDC could be helpful to overcome illicit payments and strengthen monetary policies.

[3] There are many reasons why people value anonymity, which is unnecessary to be a monetary reason such as people's desires for privacy (Low et al. 1994), and their own belief and morality (Goldberg & Lewis 2000). In our framework, the preference for anonymity stems from informal incomes. We choose such a monetary reason due to modeling simplicity. Cash allows people to preserve their privacy. One may consider other forms of anonymity which could strengthen our argument.

[4] A purely token-based CBDC could allow anonymous payments. However, many central banks are considering limited anonymity of CBDC. For example, Riksbank (2017) suggests that Swedish CBDC, e-krona, will require registration and hence is traceable; ECB (2019) considers anonymity in small amounts of payment only.

[5] Existing literature mainly focuses transaction costs in cash management. In addition, the low transaction costs could be achieved by promoting financial inclusion, since CBDC provides a gateway to access to formal financial services (Griffoli et al. 2018).

informal economy and CBDC, implying that countries with large informal economies, typically developing countries, are less likely to adopt and use CBDC widely. Moreover, we show a formalization effect of CBDC on the informal sector due to the spillover effect of CBDC on detecting informal incomes. However, the magnitude of the formalization effect diminishes with scales of the informal economy. This finding delivers distinctive implications between developed and developing countries. For developed (developing) countries, there is sensitive (insensitive) CBDC-informal economy relationship which leads to significant (marginal) benefits of CBDC on formalization.

In order to promote CBDC adoption and usage and increase the effectiveness of CBDC, we consider two policy tools–tax reduction and CBDC interest rate. A tax reduction weakens households' incentive to evade taxes, leading to lower opportunity costs of detection when using CBDC. A positive CBDC interest rate directly increases incentives for households to hold CBDC. Both policies can encourage the adoption of CBDC. The increased CBDC share in money, in turn, results in improved monitoring of informal earnings and thus stimulates the formalization effects.

In light of model mechanisms, we apply the CBDC-informal economy relationship in a business cycle framework to study the implications of adjusting the CBDC interest rate for macroeconomic fluctuations. Following the impulse response analysis, we find that adjusting the CBDC interest rate triggers a reallocation effect between formal and informal sectors, through which increases effectiveness of both conventional monetary policy and fiscal policy. Given counter-cyclical implementation of government policies, the CBDC rate adjustment contributes to stabilizing the measured business cycles. Such a finding, combined with the effects of tax rate adjustment, suggests important roles of coordination between fiscal authorities and central banks in macroeconomic management. Furthermore, we find the effects of CBDC rate adjustment is adversely affected by scales of the informal economy, implying asymmetrical benefits between developing countries and developed countries. Moreover, we also show an efficiency gain of CBDC. When more CBDC is used in transactions, the aggregate transaction costs would be lower which in turn stimulates consumption. Such an effect also implies a welfare gain due to introduction of CBDC.

This study contributes to the existing literature by providing a crossroad to two areas of research, namely CBDC and informal economy. In terms of CBDC, the current discussions largely focus on implications for banking intermediation, financial stability and monetary policies (Barrdear & Kumhof 2016, Andolfatto 2018, Brunnermeier & Niepelt 2019, Keister & Sanches 2019, Fernández-Villaverde et al. 2020). For example, Brunnermeier & Niepelt (2019) establish conditions under which CBDC would not undermine financial stability based on a model of money, liquidity and financial frictions. Departing from financial stability analysis, we study CBDC from the user side with more focus on transaction anonymity, another important issue of CBDC. We challenge the conventional wisdom that CBDC is more useful in developing countries, and deliverer important policy implications. Although CBDC can reduce transaction costs by promoting financial inclusion which is particularly important for developing countries, such a benefit could be overweighted by

households being in favor of informal incomes. As a result, it could be more difficult for developing countries than in developed countries to adopt CBDC.

This study also relates to the literature on informal economy. Existing literature suggests roles of the informal economy as an alternative source of growth and a cushion in business cycles (Loayza & Rigolini 2011, Fernández & Meza 2015). However, the coexistence of formal and informal economies is only a second-best situation. The low productivity (Prado 2011), lack of social protection (Orsi et al. 2014) and financial exclusion (Capasso & Jappelli 2013) renders informality not a desirable component of an economy. Moreover, the presence of informality causes measurement errors (Restrepo-Echavarria 2014) and weakens propagation of government policies. This paper contributes to the literature by showing how the introduction of CBDC is conducive to the formalization process not only in the long-run but also in a short-run business cycle framework, albeit the benefits are asymmetric across countries.

The rest of the paper is organized as follows. Section 2 presents some facts and motivational evidence. Section 3 presents the model with CBDC and informal economy. Section 4 presents our parameter calibrations. In section 5, we make use of the calibrated model parameters for steady-state analyses. Section 6 studies implications of the relationship between informal economy and CBDC for business cycles. Section 8 concludes with comments.

2 Facts and Motivational Evidence

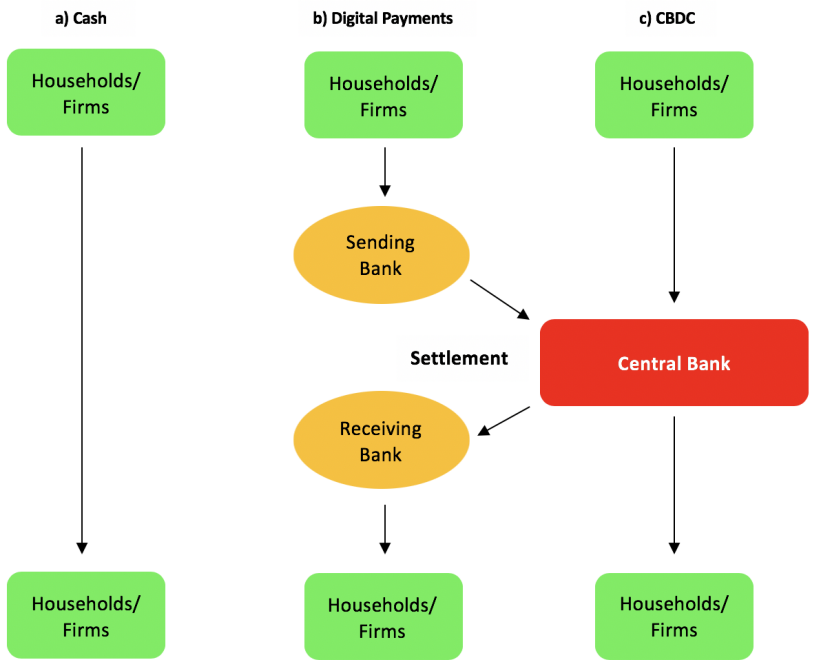
2.1 CBDC, Cash and Digital Payment

There are different types of CBDC, which can lead to various implications for payments, monetary and financial stability (Meaning et al. 2018). Similar to other forms of money, the types of CBDC can vary based on its attributes and features—access, anonymity, interest, and transfer mechanism (Coeuré & Loh 2018). With regard to access, it would have to be considered who can access to CBDC. One form of CBDC can be universally accessible or available only to limited parties such as commercial banks. It can design to provide full anonymity or to be traceable. In addition, it is feasible to pay interest on CBDC, or alternatively, it can be non-interest bearing. The interest rate can be positive or negative based on market conditions. An interest-bearing feature could offer a store of value as CBDC serves as risk-free assets. Furthermore, it would have to be considered whether CBDC is exchanged in a centralized manner or in a decentralized manner. The transfer of CBDC can be either via the central bank or on a peer-to-peer basis.

CBDC is a new form of money that can be distinguished from cash and other digital payments (Carstens 2018, Berentsen & Schar 2018). Physical cash is accessible to everyone on a peer-to-peer basis, offers full anonymity, and has no counterparty or cyber risk. However, it has high transaction costs[6] while it does not offer interest and has a fixed nominal value. Bank deposits are in electronic form issued by commercial

[6]The transaction costs link to the distance between a customer and an ATM and cash withdrawal fees.

banks, and has high transaction costs to merchants of accepting card payments.[7] In contrast, CBDC could be designed with no service or intermediary fees at the point of transaction and offers relatively cheap payment services (Jiang 2020). Bank deposits are used to make digital payments in most countries (Bech et al. 2018), and require some of verification[8], which delays the payments. Figure 1 shows how payments work when paying by cash, electronic money, and CBDC. There are several parties involved in this process - customers, commercial banks and the central bank. Unlike cash or CBDC, digital payments are not immediate and need to verify by settlement agents, typically central banks. For instance, the Bank of England operates the Real-Time Gross Settlement (RTGS) infrastructure as the main communication network in the UK (Dent & Dison 2012). Given specific design features of CBDC, it can improve the efficiency of payment systems as it facilitates faster settlement, traceability, and has a cost advantage compared with other digital payments (Ward & Rochemont 2019).



Source: Author's compilation

Figure 1 Payment Process - Cash, Digital Payment and CBDC

2.2 Informal Economy and Digital Payment

In order to successfully increase the adoption and usage of CBDC, it is crucial to learn lessons from the historical patterns of other payments. In this subsection, considering the similar features between CBDC

[7] When the issuing bank and the acquiring bank are different, the acquiring bank needs to pay interchange fees to the issuing bank. They are the sum paid by merchants for using debit or credit card payment services to card-issuing payment service providers. (Schmalensee 2002).

[8] Central banks act as the the primary role in the settlement for payment transaction as they provide safe and reliable liquidity assets and have low credit risk (Listfield & Montes-Negret 1994).

and other digital payments presented in Section 2.1, we study the relationship between digital payment and one of its hindrances, informal economy that provides us important implications for CBDC implementation.

In recent years, there have been a greater use of digital payments across countries. It has become one of the main payment methods for various economic agents from households and firms to financial intuitions and public authorities. For numerous reasons such as tackling tax evasion and increasing financial inclusion[9], policymakers encourage the use of digital payments and try to change the payment behavior of individuals[10]. However, compared with developed countries, digital payments still have not been widely adopted in developing countries (Patil et al. 2017), which now can turn CBDC adoption stories to do the same since CBDC and other electronic payments have much in common. The adoption of digital payments hence put calls for CBDC into sharper focus, and we can take some learning for CBDC adoption from other digital payments in their adoption journey. Among the inhibitors of the adoption of digital payments[11], the size of the informal economy plays a major role.

Informal economy defines from the viewpoint of tax and regulations (Schneider et al. 2010). One of its activities is undeclared work which includes all paid and unpaid of work that are not declared to the tax authorities (Pfau-Effinger 2009). All sectors have an element of undeclared work; however, relatively high incidence of undeclared work seems to appear more in certain sectors such as agriculture, and household service. In the informal economy, cash is the crucial medium for undeclared monetized exchange as it is not traceable by public authorities. In such way, firms can evade tax and social security contributions, and employees can avoid paying income tax. However, cash payments aggravate the tax enforcement problem (Gordon & Li 2009). Cash transactions and tax evasion are one of the key aspects of the informal economy.

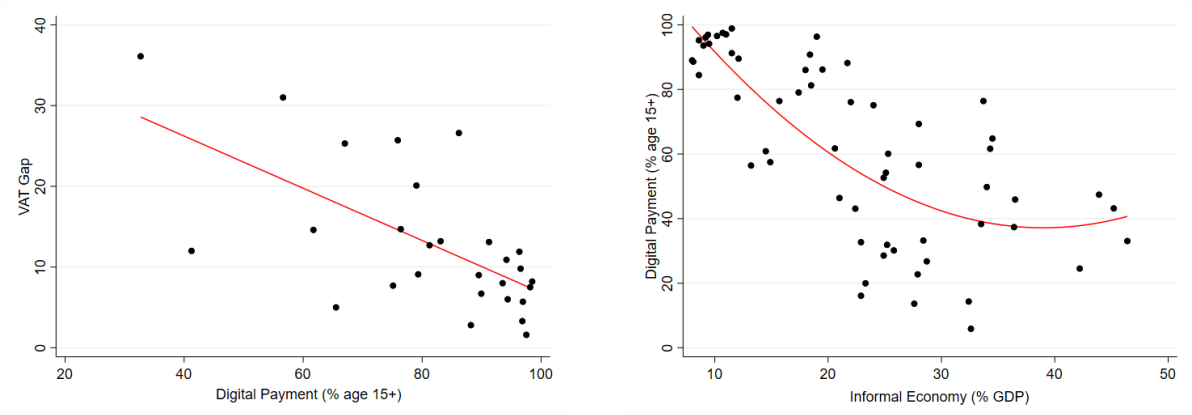
The size of informal activities in developing economies is bigger than ones in developed economies (Capasso & Jappelli 2013). This also links to the fact that cash still rules in developing economies in spite of the rapid development of financial innovation across the countries (Bech et al. 2018). The reason is that cash provides the anonymity of users which allows people to hide their transaction history. In contrast, most forms of electronic money or digital payments can be easily traced by the public authority. For instance, bank account records and the uses of credit or debit cards have a high probability of detection as they can be cross-checked via third-party reporting. VAT invoice data and third-party reporting data enable tax authorities to identify and cluster taxpayers, which enhances tax evasion detection.

The traceability of the digital payments would allow countries to curb tax evasion activities. The relationship between tax evasion and digital payment is confirmed by Figure 2a. It shows that, in Europe, a higher frequency of digital payments is associated with lower tax evasion. The figure plots the average

[9]Cash is difficult to monitor by authorities and causes tax enforcement problems (Gordon & Li 2009). Okello Candiya Bongomin et al. (2018) show that there is a positive relationship between mobile money and financial inclusion.

[10]Numerous countries have applied tax incentives to encourage to use electronic payments (Sung et al. 2017). For instance, Japan introduced the consumption tax reward point program for electronic payments in October 2019. In this system, cashless payment will receive certain percentage points (2% or 5%) or cash back.

[11]The digital payment adoption rate can vary depending on the availability of ATM and POS terminals, the level of banking industry concentration, and illegal activities (Humphrey et al. 1996).



(a) Digital Payment and Tax Evasion

(b) Informal Economy and Digital Payment

Note: 2(a) contains 30 European economies in 2(a), and 2(b) includes 60 economies. VAP gap is from Poniatowski et al. (2018) and digital payment is from Wold Bank Global Findex. Informal economy is from Prof. DR. F. Schneider; A.T. Kearney analysis.

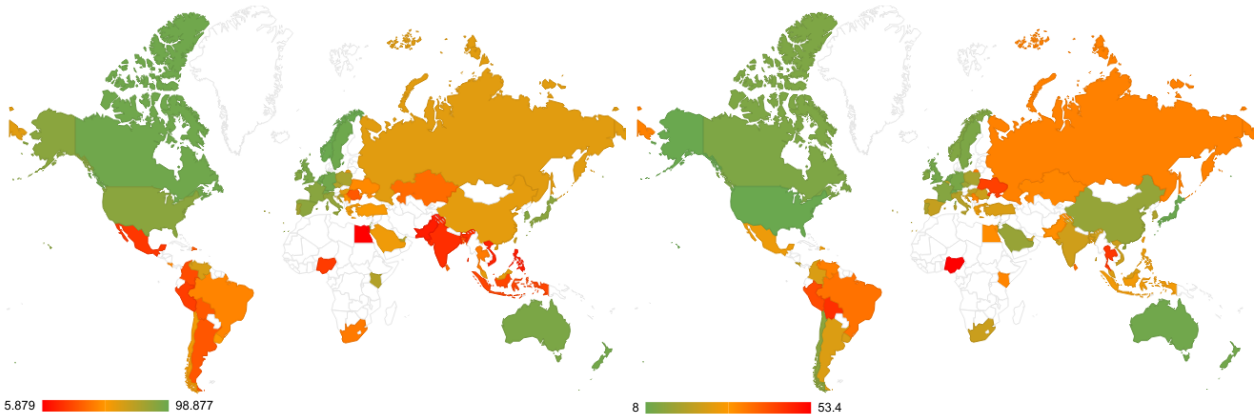
Figure 2 Digital Payment, Tax Evasion, and Informal Economy in 2016

VAT gap (the difference between the theoretical VAT liability and the actual VAT revenue), against digital transactions for the year 2016. The negative relationship confirms that countries with more digital payments are characterized by lower VAT evasion. This evidence suggests that policies aimed at encouraging the use of digital payments might actually help curb tax evasion.

Figure 2b shows the L-shaped relationship between the share of digital payments and the size of the shadow economies of 60 economies for the year 2016. Simple bivariate evidence points to digital payments having a negative, and non-liner relationship with informal economy. In other words, the countries with low levels of informal economic activities have a high number of digital payment transactions. However, such effects become less important at higher levels of informal economy. Countries that constitute more than 35% of informal economic activities show a narrow range of the use of digital payments.

Figure 3a and Figure 3b illustrate the share of digital payments and the size of informal economy, respectively, globally for one year, 2016. We use the red-orange-green and green-orange-red scales. In Figure 3a, greener denotes a larger share of digital payments, and in Figure 3b, redder denotes a a greater size of informal economy. It also confirms the inverse relationship between digital payment and informal economy. Countries with a low number of digital payment uses, such as Nigeria (23.72%) and Bolivia (33.05%), also have the highest and second-highest informal economies, at 53.4 and 46.4 %, respectively. Switzerland and Sweden, where the share of digital payments exceeds 95%, show low levels of informal economic activities, at 8.6% and 10.7% respectively.

To better understand the effect of informal economy on digital payments, we construct a multivariate cross-country regression analysis for a sample of 60 economies for the year 2013 and 2016. The regression results are shown in Table 1. A negative relationship between informal economy and digital payments indicates that



(a) Digital Payment

(b) Informal Economy

Note: The countries include 60 economies. Digital payment is from Wold Bank Global Findex. Informal economy is from Prof. DR. F. Schneider; A.T. Kearney analysis.

Figure 3 Digital Payment and Informal Economy Globally in 2016

Table 1 Informal Economy and Digital Payment

Variables	(1) 2013		(2) 2016	
Informal economy	**-2.128*** **	**-0.513***	**-1.779*** **	-0.219
	(-8.32)	(-1.69)	(-9.21)	(-0.93)
Control variables				
Financial depth		**31.614*** **		**19.811** **
		(3.95)		(2.43)
Financial access		6.734		12.614
		(0.72)		(1.21)
Log of GDP per capita		**11.879*** **		**13.468*** **
		(3.13)		(3.72)
Trade openness		-0.005		-0.006
		(-0.29)		(-0.24)
Inflation		0.026		-0.382
		(0.08)		(-1.47)
R Squared	0.525	0.805	0.494	0.775
Observations	60	58	60	57

Note: This table reports cross-section estimation results for the years 2013, and 2016. The dependent variable is digital payment. Numbers in parenthesis are ordinary least squares standard errors. ***, **, and * represent 1%, 5%, and 10%. All variables are defined in Appendix A.1.

countries with large informal sectors will have a small number of digital payment transactions. It implies larger informal economies prefer or rely on cash or other payment methods to make payments. In order to fight tax evasion, promote business transparency, and formalize the economy, several countries[12] have employed specific tax measures to promote cashless transactions and banking channels (Awasthi & Engelschalk 2018). However,

[12]For example, a 2 percent VAT refund is applied to any purchases made by credit card in Colombia, and some European countries such as Greece, Hungary, and Italy have introduced cash payment limits since 2012.

despite these efforts, digital payment adoption in developing economies relatively low among business and households. Ligon et al. (2019) confirm that the concerns about increased tax liabilities will hinder business and consumers' adoption of digital payment.

Our approach then rests on shifting focus from the digital payments to the adoption of CBDC. Taken together, these empirical findings imply that the adoption and the effect of CBDC on the economy will differ depending on the size of the informal economy. Similar to digital payments, the traceability of CBDC can benefit the government, which can efficiently trace tax evasion and other illegal activities, and help increase the fluidity of the overall economy. However firms and consumers are unlikely to adopt a CBDC if it is less convenient and beneficial to use than cash payments. It provides a certain motivation and guidance for our theoretical exploration.

3 The Model

We expand some typical informal economy models such as Fernández & Meza (2015) and Orsi et al. (2014), incorporating money in both utility and household budget constraint, and distinguishing two types of money, namely cash and CBDC. Compared with cash, CBDC has negligible transaction costs but incurs government monitoring on household informal income. Hence, the use of CBDC creates a trade-off between cost efficiency and anonymity for household. In the extended version of the model, we also consider the interest-bearing feature of CBDC, which could be remunerated like bank deposits. In other words, CBDC not only acts as a mean of transaction but also a store of value. With this extended framework, we can further study the implications of the CBDC interest rate on the propagation of a set of conventional shocks and a CBDC policy shock.

3.1 Household

The representative household derives utility from consumption, money holding and leisure. Households supply formal (H_t^f) and informal labour (H_t^I) measured in hours, used for the production of formal and informal goods. Following Orsi et al. (2014), we include an informal labour specific disutility which captures the lack of social protection in the informal sectors.

The household faces the following utility:

$$\max E_t \sum_{l=0}^{\infty} \beta^l [log(C_{t+l}) + \xi log(\frac{M_{t+l}}{P_{t+l}}) - \frac{\psi_1 (H_{t+l}^f + H_{t+l}^i)^{1+\eta} + \psi_2 (H_{t+l}^i)^{1+\eta}}{1+\eta}] \tag{1}$$

subject to the budget constraint without CBDC

$$C_t(1+\phi) + I_t + \frac{D_t}{P_t} + \frac{M_t}{P_t} = R_{t-1}\frac{D_{t-1}}{P_t} + \frac{M_{t-1}}{P_t} + (1-\tau)(w_t^f H_t^f + r_t^{kf} K_t^f) + (1-\tau Pr)(w_t^i H_t^i + r_t^{ki} K_t^i) \tag{2}$$

where C_t denotes consumption, I_t investment, D_t saving, M_t money R_t interest rate, P_t price, w_t^f formal wage, H_t^f formal labour, w_t^i informal wage, H_t^i informal labour, r_t^{kf} formal capital rent, K_t^f formal capital, r_t^{ki} informal capital rent, and K_t^i informal capital. ϕ measures the transaction cost, η measures the elasticity of labour supply with respect to wage, τ is the tax rate and Pr is the detection rate of informal income. Our framework assumes that households only pay tax to formal and detected informal incomes.

The total capital stock K_t is held by household and evolves according to the following law of motion

$$K_{t+1} = (1-\delta)K_t + I_t \tag{3}$$

where δ is the capital depreciation rate and

$$K_t = K_t^f + K_t^i \tag{4}$$

The household utility maximization subject to (2)-(4) yields the following first order conditions:

$$\frac{1}{C_t(1+\phi)} = \lambda_t \tag{5}$$

$$\lambda_t = E_t\lambda_{t+1}\beta R_t \frac{P_t}{P_{t+1}} \tag{6}$$

$$\psi_1(H_t^f + H_t^i)^\eta = \lambda_t(1-\tau)w_t^f \tag{7}$$

$$\psi_1(H_t^f + H_t^i)^\eta + \psi_2(H_{t+l}^i)^\eta = \lambda_t(1-\tau Pr)w_t^i \tag{8}$$

$$\lambda_t = \beta E_t\lambda_{t+1}[(1-\tau)r_{t+1}^{kf} + (1-\delta)] \tag{9}$$

$$\lambda_t = \beta E_t\lambda_{t+1}[(1-\tau Pr)r_{t+1}^{ki} + (1-\delta)] \tag{10}$$

$$\frac{\xi}{M_t/P_t} = \frac{\lambda_t}{P_t} - E_t\frac{\lambda_{t+1}}{P_{t+1}}\beta = \lambda_t(1-\frac{1}{R_t}) \tag{11}$$

3.1.1 With CBDC

The introduction of CBDC will change household budget constraint.

$$\begin{aligned} C_t(1+\phi\frac{M_t^c}{M_t}) + I_t + \frac{D_t}{P_t} + \frac{M_t}{P_t} =& R_{t-1}\frac{D_{t-1}}{P_t} + \frac{M_{t-1}^c + R_{t-1}^m M_{t-1}^{cbdc}}{P_t} \\ &+(1-\tau)(w_t^f H_t^f + r_t^{kf}K_t^f) + ((1-\tau pr_t(\frac{M_t^{cbdc}}{M_t}))(w_t^i H_t^i + r_t^{ki}K_t^i) \end{aligned} \tag{12}$$

where M_t^{cbdc} denotes CBDC money, M_t^c cash and R_t^m is the CBDC interest rate. This budget constraint shows that only consumption paid by cash incurs transaction costs, which is consistent with the convenience feature of CBDC. Moreover, the inclusion of CBDC could make monitoring of informal incomes more efficient. That is because a central bank can trace patterns of CBDC-based transactions and money flows. We model such a CBDC-monitoring link by endogenizing the detection probability.

$$pr_t = Pr + \frac{(M_t^{cbdc}/M_t)^{1+\theta}}{1+\theta}, \quad \theta > 0 \tag{13}$$

where θ is the elasticity of detection probability with respect to CBDC share in money. Equation (13) implies that the more CBDC used by households, the more likely their informal income will be detected. The second component in equation (13) reflects the enhanced monitoring due to CBDC.

Household money holding satisfies

$$M_t = M_t^{cbdc} + M_t^c \tag{14}$$

With CBDC, the representative household maximizes (1) subject to (3), (4), (12), (13) and (14). The first order conditions for CBDC and cash are:

$$\frac{\xi}{M_t/P_t} = \lambda_t[(1 - C_t\phi\frac{M_t^c}{M_t^2}) + (\frac{M_t^{cbdc}}{M_t})^\theta \frac{M_t^c}{M_t^2}\tau(w_t^i H_t^i + r_t^{ki}K_t^i) - \frac{R_t^m}{R_t}] \tag{15}$$

$$\frac{\xi}{M_t/P_t} = \lambda_t[(1 + C_t\phi\frac{M_t^{cbdc}}{M_t^2}) - (\frac{M_t^{cbdc}}{M_t})^\theta \frac{M_t^{cbdc}}{M_t^2}\tau(w_t^i H_t^i + r_t^{ki}K_t^i) - \frac{1}{R_t}] \tag{16}$$

Combining (15) and (16) and rearranging, we obtain

$$\underbrace{(\frac{M_t^{cbdc}}{M_t})^\theta \tau(w_t^i H_t^i + r_t^{ki}K_t^i)}_{\text{cost due to the detection}} = \underbrace{\frac{R_t^m - 1}{R_t} M_t}_{\text{benefit due to interest payment}} + \underbrace{C_t\phi}_{\text{benefit due to transaction cost deduction}} \tag{17}$$

Equation (17) suggests that in equilibrium marginal cost of CBDC, namely the detection cost, should be equal to marginal benefits that from interest payment and transaction cost deduction. Define the CBDC share in money as $s_t^{cbdc} = M_t^{cbdc}/M_t$. We can solve equation (17) to obtain

$$s_t^{cbdc} = [\frac{\frac{R_t^m - 1}{R_t} M_t + C_t\phi}{\tau(w_t^i H_t^i + r_t^{ki}K_t^i)}]^{\frac{1}{\theta}} \tag{18}$$

Equation (18) implies a negative relationship between CBDC money shares and the size of informal economy given others remain constant; sizeable informal economy could prevent people from using CBDC as the detection cost is large.

3.2 Firm

The production sector consists of two sub-sectors, namely formal and informal firms. In each sub-sector, the representative firm j use labor and capital to produce output based on the following Cobb-Douglas production function

$$Y_{jt}^{o} = A_{t}^{o}(K_{jt}^{o})^{\alpha}(H_{jt}^{o})^{1-\alpha}, \quad o = f, i \tag{19}$$

where index f and i denote formal and informal variables respectively. Productivity A_t^o has two components common to both types of firms, including a deterministic trend $(1+g^y)^t$ and a common productivity shock ε_t^a following an AR(1) process. For formal firms, there is a formal-specific productivity shock ε_t^f following an AR(1) process.

$$A_{t}^{f} = (1+g^{y})^{t}\varepsilon_{t}^{a}\varepsilon_{t}^{f} \tag{20}$$

$$A_{t}^{i} = (1+g^{y})^{t}\varepsilon_{t}^{a} \tag{21}$$

Profit maximization for each type of firm yields the following first order conditions.

$$w_{t}^{o} = (1-\alpha)\frac{Y_{jt}^{o}}{H_{jt}^{o}}, \quad o = f, i \tag{22}$$

$$r_{t}^{ko} = \alpha\frac{Y_{jt}^{o}}{K_{jt}^{o}}, \quad o = f, i \tag{23}$$

3.3 Equilibrium

With symmetric equilibrium, we obtain the aggregate output, formal output and informal output as follows.

$$Y_{t} = Y_{t}^{f} + Y_{t}^{i} \tag{24}$$

$$Y_{t}^{o} = A_{t}^{o}(K_{t}^{o})^{\alpha}(H_{t}^{o})^{1-\alpha}, \quad o = f, i \tag{25}$$

Combining (7) and (8), we solve for the equilibrium informal labor

$$H_{t}^{i} = \begin{cases} \lambda_{t}[(1-\tau Pr)w_{t}^{i} - (1-\tau)w_{t}^{f}]/\psi_{2} & \text{if } (1-\tau Pr)w_{t}^{i} > (1-\tau)w_{t}^{f} \\ 0 & \text{otherwise} \end{cases} \tag{26}$$

which suggests a negative relationship between the detection rate and the incentive to engage in informal work. With CBDC, PR in (26) would be replaced with pr_t

Combining (9) and (10), we obtain the relationship between r_t^{kf} and r_t^{ki} as follow.

$$(1-\tau Pr)r_{t}^{ki} = (1-\tau)r_{t}^{kf} \tag{27}$$

The labor and capital markets must be clear $H_t = H_t^f + H_t^i$, $K_t = K_t^f + K_t^i$. The resource constraint is

$$Y_t = C_t + I_t + G_t \tag{28}$$

G_t is an exogenous spending shock following an AR(1) process. Interest rate is given by a Taylor rule:

$$R_t = (R_{t-1})^{\psi_r}[R^m(\frac{\pi_t}{\overline{\pi}})^{\psi_\pi}(\frac{Y_t^f}{Y_{t-1}^f})^{\psi_y}]^{1-\psi_r}\varepsilon_t^m \tag{29}$$

where ε_t^m is a conventional monetary policy shock. In order to close the model, we need to specify a CBDC interest rate rule. We assume a Taylor rule for R_t^m which is likely to be used (Barrdear & Kumhof 2016) after CBDC is issued.

$$R_t^m = (R_{t-1}^m)^{\rho_r}[R^m(\frac{\pi_t}{\overline{\pi}})^{\rho_\pi}(\frac{Y_t^f}{Y_{t-1}^f})^{\rho_y}]^{1-\rho_r}\varepsilon_t^r \tag{30}$$

where ε_t^r is a CBDC monetary policy shock.

4 Calibration

Our calibration strategy is similar to Restrepo-Echavarria (2014). For parameters well-identified in the literature and less variant across countries, we give them fixed values. For other parameters which show significant cross-country differences or affect the CBDC-informal economy relationship, we consider a benchmark and some alternative values. In terms of the benchmark values, we mainly focus on Mexico as it is considered as a representative emerging economy and it has extensively studied (see Aguiar & Gopinath (2007) among others).

Table 2 Calibrated parameters

Parameters	Description	Value
α	capital share	0.35
β	discount factor	0.992
δ	capital depreciation	0.05
η	labor elasticity	2
ξ	money preference	0.02
ϕ	transaction cost	0.01
τ	tax rate	0.22
θ	elasticity of detection rate	1
Steady-State (ss)		
$1+g^y$	ss per capita GDP growth	1.006
G/Y	ss exogenous demand share	0.15
H	ss labor hour	0.33
H^I/H	ss informal labor share	0.32
Pr	no CBDC detection rate	0.02

Table 2 shows calibrated parameters. We set capital share α and capital depreciation rate δ as 0.35 and 0.05 respectively, in line with Fernández & Meza (2015). The discount factor β is calibrated as 0.99 to match the interest rate, 1.0145. The inverse labor elasticity is calibrated as 2 which is a standard value used in the literature. The money preference parameters ξ is calibrated as 0.02 based on money to output ratio (105%) for low and middle income countries. The ϕ is calibrated as 0.01 which implies that transaction costs account for 0.6% of output. Such a level is found from some Latin American countries such as Uruguay (Griffoli et al. 2018), European countries (Hasan et al. 2013) and Canada (Kosse et al. 2017). Following Restrepo-Echavarria (2014), we set the benchmark tax rate τ as 0.22. The elasticity of detection with respect to CBDC share is calibrated as unity. This implies 1% increase in CBDC share rises 1% detection probability.

The lower part of Table 2 shows the calibrated values of steady-state parameters. We set the quarterly output growth rate as 1.006, consistent with Fernández & Meza (2015). The steady state labor hour is calibrated as 0.33 as commonly used in the literature. The exogenous demand share is calibrated as 0.15, to be consistent with data. In terms of informal labor share, we use 0.32 as in Fernández & Meza (2015) for the benchmark. This is a moderate level among others. For the detection rate Pr without CBDC, we choose 0.02 as the value based on Italy (Orsi et al. 2014) in the absence of other references. Finally, we defer calibration of monetary policy parameters and shock processes to Section 6 as they do not affect the steady-state.

5 Steady-State Analysis

We simulate the model to study the relationship between informal economy and CBDC, starting from steady-state analysis. In next section, we consider the relationship in a business cycle framework using impulse response functions.

5.1 The effects of informal economy on CBDC

Table 3 shows model predicted CBDC share based on the benchmark calibration and alternative informal economy shares as well. We begin our analysis with a non-interest bearing CBDC for ease of comparison. Starting from a moderate informal economy share, such as the Mexican case (0.32), the CBDC share in money would be around 8%. This share indicates a low capacity for the economy to accommodate CBDC and the likelihood to replace large amount of cash by CBDC would be low. As the informal economy share increases, such as the Brazilian (0.43) and Thailand (0.55) cases, the cost of holding CBDC (or detection costs) would become higher relative to the benefits such as convenience and efficiency and hence leading to even lower CBDC shares. On the contrary, with smaller informal economy shares, such as the US (0.1) and Spain (0.22) cases, the detection costs relative to the benefits would be lower and hence CBDC could be more acceptable in the economy. To summarize, Table 3 shows a negative relationship between informal economy and CBDC share, consistent with the theory proposed in Section 3.

Table 3 Comparison of Steady-State CBDC Shares

Informal share	US (0.1)	Spain (0.22)	Benchmark (Mexico, 0.32)	Brazil (0.43)	Thailand (0.55)
CBDC share	0.250	0.112	0.077	0.059	0.046

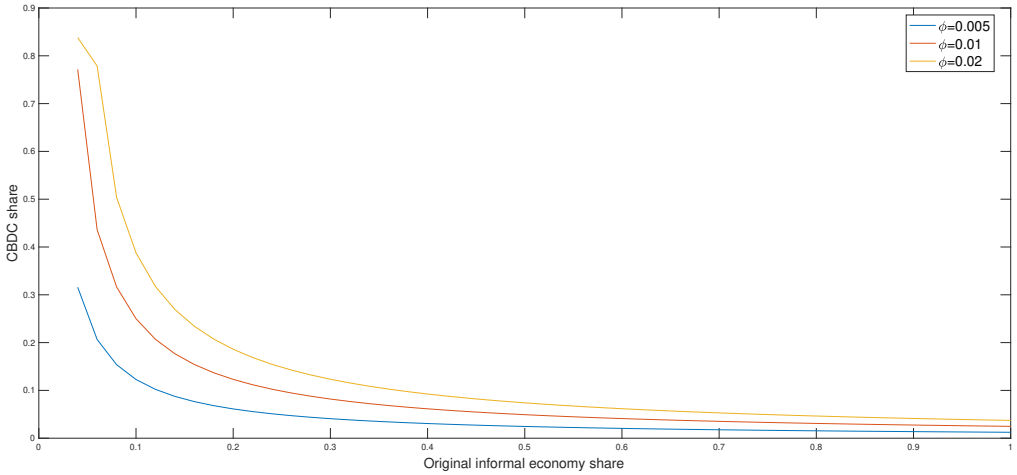


Figure 4 The relationship between CBDC share and original informal economy share

While we consider some specific cases in Table 3, Figure 4 plots the relationship between informal economy and CBDC share in a more general way. In addition to the negative relationship as shown in Table 3, Figure 4 shows a L-shaped relationship, consistent with Figure 2b. The main mechanism driving the L-shaped pattern relies on disproportional effects of the detection costs and the benefits with regards to the convenience. In order to understand the mechanism, we rewrite Equation (18) in steady state and set R^m as unity to satisfy a non-interest bearing CBDC condition.

$$(s^{cbdc})^{\theta} = \frac{C\phi}{\tau(w^i H^i + r^{ki} K^i)} = \frac{C\phi}{\tau Y^i} = \frac{\phi}{\tau y^i} \tag{31}$$

$$\frac{\partial s^{cbdc}}{\partial y^i} = -\frac{\phi}{\theta}\frac{1}{\theta}(\frac{1}{\tau y^i})^{\frac{1}{\theta}+1} < 0$$

$$\frac{\partial \text{detection cost effect}}{\partial y^i} = \left|\frac{\partial s^{cbdc}}{\partial y^i}\right| / \partial y^i = -\frac{\phi}{\theta}\frac{1}{\theta}(\frac{1}{\theta}+1)(\frac{1}{\tau y^i})^{\frac{1}{\theta}+2} < 0$$

where $y^i = Y^i/C$ is a measure of informal economy share. The convenience benefit which appears as nominator in Equation (31) has fixed marginal impact on the CBDC share while the detection cost, appeared as the denominator, has negative and diminished marginal effects on the CBDC share. Such a L-shaped pattern is robust to different levels of transaction cost ϕ. Furthermore, Figure 4 suggests that the curves become flat when the informal economy share becomes approximately higher than 30%. Considering that

informal economy shares in developed countries are basically below 30% while that in many developing countries are greater than 30%[13], Figure 4 delivers two important implications. Shrinking informal economy would be useful to promote acceptance of CBDC in developed countries. However, implementing the same policy might not be effective for developing countries; the presence of sizeable informal economy leads to the marginal effect of detection costs being insensitive to change in the informal economy share.

5.2 The implications of CBDC

Table 4 shows impacts of CBDC on the economy. We focus on three key variables, namely detection probability, formal output share and formalized output share. The formalized output is defined as the sum of formal output and detected informal output $y_t^f + pr_t y_t^i$.

Table 4 Impacts of CBDC

Original informal share	0.1	0.22	0.32	0.43	0.55
Increase in detection prob (θ)	3.120%	0.630%	0.290%	0.170%	0.100%
Increase in formal output share (y_t^f)	0.230%	0.094%	0.062%	0.045%	0.031%
Increase in formalized output share ($y_t^f + pr_t y_t^i$)	0.510%	0.220%	0.150%	0.110%	0.088%

Note: The informal economy shares for the US, Spain, Mexico (Benchmark), Brazil, and Thailand are 0.1, 0.22, 0.32, 0.432, and 0.55 respectively.

Similar to Table 3, we consider five original informal economy shares. Table 4 shows negative relationships between original informal economy shares and its impacts on the three variables. With the original informal economy share increases, the increase in detection probability become smaller and thereby leading to less increase in formal and formalized outputs. As suggested by our previous analysis in Section 5.1, high shares of original informal economy decrease households' acceptance of CBDC and through the spillover of CBDC on detection, the increases in formal and formalized outputs become smaller.

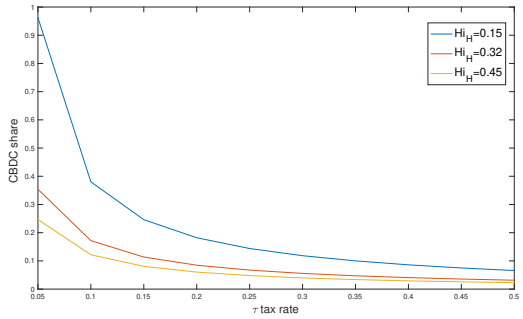
Among the five original informal economy shares considered in Table 4, we find the most significant impacts when the original informal economy share is 10%. In this case, the issuance of CBDC stimulates a detection rate from 2% to 5%, increase formal and formalized output shares by 0.2% and 0.5% respectively. The increase in formalized output is larger than that of formal output because not only some informal employees shift to formal production but also the detection of informal output is more effective.

5.3 Roles of tax rate and CBDC interest rate

In this section, we consider alternative values of tax rate τ and CBDC interest rate R^m to study the implication of them to further understand the relationship between informal economy and CBDC. As suggested by Equation (18), tax rate and CBDC interest rate are important determinators of the CBDC share.

[13]In 2016, US, Japan, and United Kingdom show low levels of informal economic activities at 8%, 8.1% and 9.5% respectively. In contrast, Nigeria, Ukraine, and Sri Lanka show have high informal economies, at 53.4%, 43.9%, and 36.4% respectively.

(a) CBDC share and tax rate



(b) CBDC share and CBDC interest rate

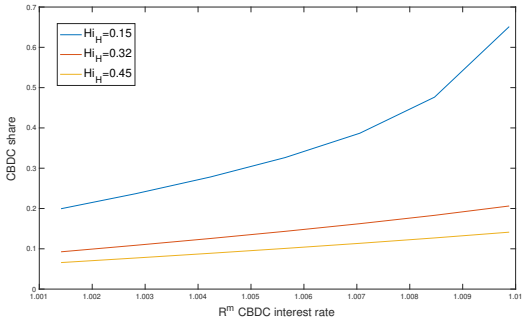


Figure 5 The relationship between CBDC share and tax rate or CBDC interest rate

Figure 5a suggests a negative relationship between tax rate and CBDC share. As the tax rate increases, incentives to engage in the informal activities would be larger and the potential detection loss could be more significant. With such a concern, household would avoid detection due to using CBDC, which results in a lower CBDC share. This mechanism has important implication for issuance of CBDC as tax cut has potential to encourage people to use CBDC. Comparing with the benchmark result as in Table 3 (7.7% of CBDC share), cutting tax rate from 22% to 10% alongside with CBDC issuance leads to much larger CBDC share (17%). However, it should be noted that tax rate in developing countries are not high on average, implying limited policy space of tax reduction to promote the acceptance of CBDC.

Shifting our attention to another policy tool, namely CBDC interest rate, Figure 5b suggests a positive relationship between CBDC interest rate and CBDC share. Higher CBDC interest rate adds one more benefit to hold CBDC in addition to the convenience gain, making CBDC more attractive for households. This mechanism implies that a positive CBDC interest rate enhances acceptance of CBDC, which complement the effect of tax reduction. For instance, setting CBDC interest rate as 70% of deposit rate could double the CBDC share compared with the benchmark result.

Table 5 Impacts of CBDC on formalized output share

(a) with lower tax rate

Original informal share	0.15	0.32	0.45
τ=0.05	9.120%	2.990%	2.060%
τ=0.10	1.650%	0.720%	0.510%
τ=0.15	0.710%	0.320%	0.230%

(b) with CBDC interest rate

Original informal share	0.15	0.32	0.45
r^m=0.3r	0.930%	0.400%	0.280%
r^m=0.5r	1.780%	0.670%	0.450%
r^m=0.7r	4.780%	1.080%	0.700%

Note: τ is tax rate. r^m is CBDC interest rate, shown as percentage of conventional interest rate.

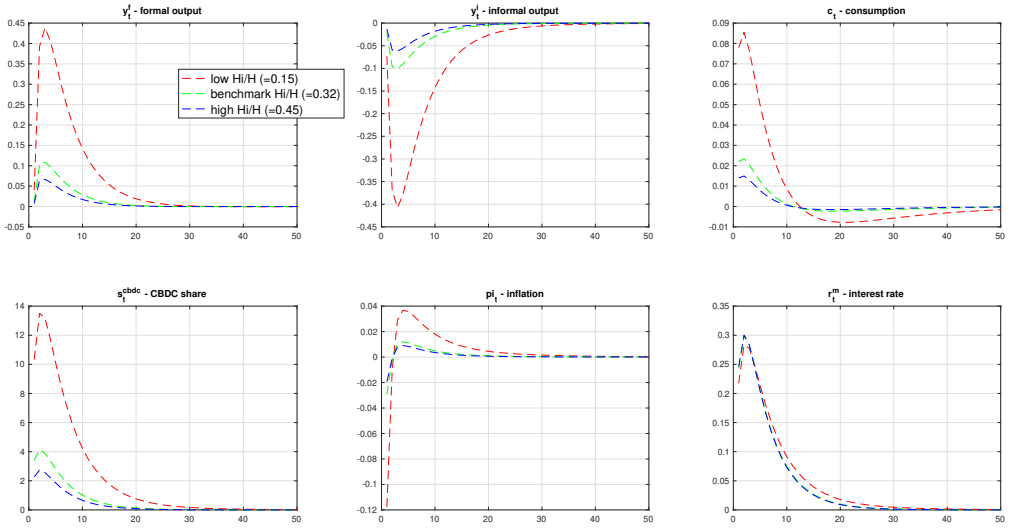
Next we investigate how the tax reduction and positive CBDC interest rate affect the role of CBDC in formalizing output. We consider three alternative tax rates in Table 5a, all of which are lower than the benchmark value (0.22). Unlike Table 4 where issuance of CBDC only has minor impacts on formalized output share, Table 5a suggests more significant effects when tax rate is lower. For example, when tax rate

is 10% and original informal economy share is 32%, the issuance of CBDC could stimulate about 0.7% of formalized output share rather than 0.15% as in Table 4. If we further cut off the tax rate to 5%, the effect can rise to 3%. Moreover, a more formalized economy provides a larger tax base which partially offsets the fiscal burden results from the tax reduction.

Turning to the CBDC interest rate, Table 5b suggests that a positive CBDC interest rate can also boost formalized output share. For instance, when the CBDC interest rate reach 70% of the deposit rate and original informal economy share is 32%, the issuance of CBDC could stimulate about 1.08% of formalized output share. This effect is much larger than the case (0.15%) with a zero CBDC rate (see the last entry of fourth column in Table 4). The presence of CBDC interest rate increases CBDC share and strengthens its spillover effect on detection, through which promotes both formal output and detected informal output.

6 Business Cycle Implications

In this section, we exploit the negative relationship between informal economy and CBDC share as established in Section 5 to investigate implications of the relationship in business cycles.



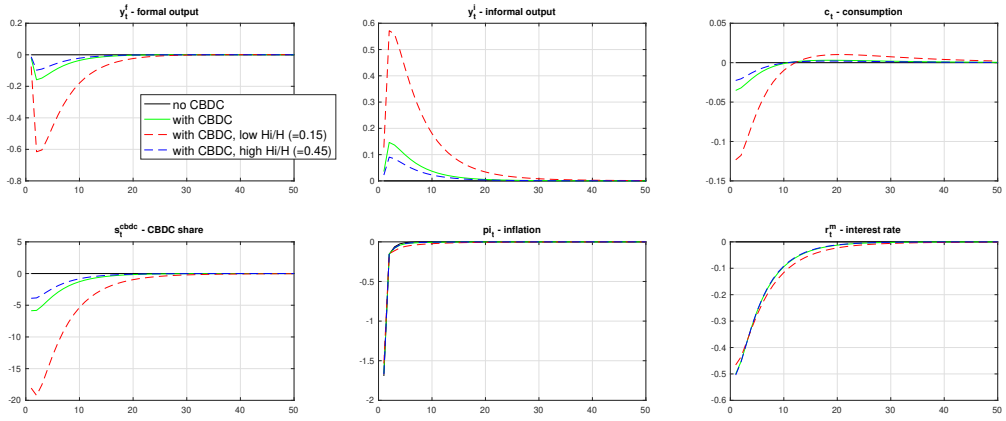
Note: We compare the cases with low (red lines), benchmark (green lines), and high (blue lines) informal economy shares.

Figure 6 IRFs to the CBDC shock

We calibrate the Taylor parameters of conventional money policy ψ_r, ψ_y and ψ_π as 0.8, 1.5 and 0.1 which are commonly used in the literature (e.g. Galí (2015)). These values are also used for counterpart parameters in the CBDC rate policy ρ_r, ρ_y and ρ_π. In terms of shock processes, we estimate persistence and volatility of TFP and government spending shocks using OLS based on the Mexican TFP and government spending data during the period 1990Q1-2018Q4. The estimated AR(1) parameters of TFP shock (ρ_a) and that of

government spending shock (ρ_g) are 0.95 and 0.89 respectively. The shock volatility σ_a and σ_g are estimated as 0.91 and 1.02. The two monetary policy shock persistence parameters are set as 0.4 which is line with the existing literature (e.g. Galí (2015)).

Figure 6 plots impulse responses of some key variables to a rise of 25 basis points of CBDC interest rate. Increase in CBDC interest rate makes CBDC more attractive over cash, hence results in higher CBDC share in the economy. Through the spillover effect on detection, higher CBDC rate discourages tax evasion and triggers labor reallocation from informal to formal sector, thereby leading to increased formal output and decreased informal output. In addition to this reallocation effect, higher CBDC share reduces the transaction cost and hence stimulates consumption. Owing to both the reallocation and the cost-reduction effects, an increase in CBDC rate has an expansionary effect on the measured economy and is helpful to formalize the economy. Furthermore, we find that the effect of CBDC policy shock can be amplified when original informal economy share becomes smaller. In line with the steady state analysis in Section 5, small share of informal economy results in more CBDC circulated in the economy, which makes the CBDC policy more powerful.

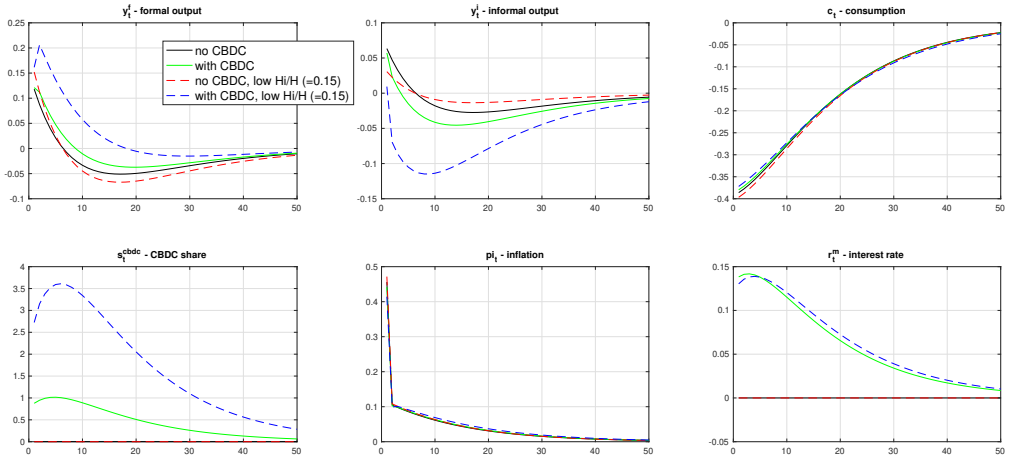


Note: We conduct two comparisons. The first one is comparing the cases with (green lines) and without CBDC (black lines); the second one is comparing the cases with low (red lines) and high (blue lines) informal economy shares.

Figure 7 IRFs to the interest rate shock

Figure 7 plots impulse responses to a tightened conventional monetary policy shock with interest rate risen by 25 basis points. As a standard finding in the Real Business Cycle (RBC) framework, money has no real effect in the absence of nominal frictions. However, we find that money become not neutral when CBDC is circulated in such a flexible economy. An increase in conventional policy rate curbs inflation. Responding to this, the central bank reduces CBDC interest rate, leading to a decrease in CBDC share. Due to the spillover effect on detection, there would be a reallocation effect from formal to informal production. Although the modelled economy is flexible, we can think the black lines (no CBDC) in Figure 7 as normalized effects of the conventional monetary policy. With this regard, we can interpret difference between the black line and others in Figure 7 as additional effect of the monetary policy due to CBDC rate adjustment. In

this sense, the presence of CBDC can improve effectiveness of conventional monetary policy. Moreover, our results provide another angle to address the coordination between CBDC and conventional money policy (see Barrdear & Kumhof (2016), Brunnermeier & Niepelt (2019) among others). Unlike the aforementioned literature which focuses on banking sectors, we address the coordination through the labor reallocation. Furthermore, Figure 7 suggests that the additional effects provided by adjusting CBDC rate diminishes with original informal economy share, implying that developed countries would benefit more than developing countries from the issuance of CBDC in a business cycle perspective.



Note: We conduct two comparisons. The first one is comparing the cases with (green lines) and without CBDC (black lines); we also make the similar comparison (red lines v.s.blue lines) when the informal economy share is low.

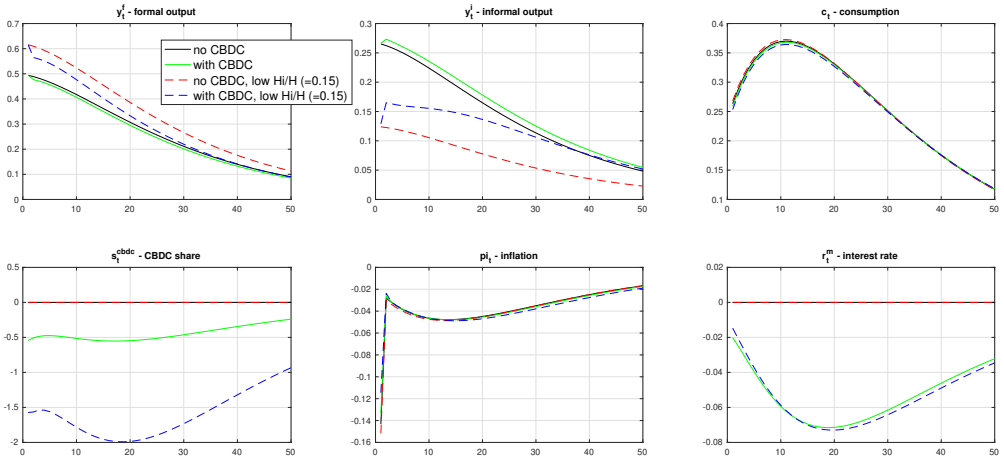
Figure 8 IRFs to the government spending shock

In terms of the government spending shock, Figure 8 shows that the presence of CBDC amplifies the propagation of government spending shock on formal output. Expansionary government spending heats the economy and results in increased CBDC interest rate. Consequently, there is an increase in CBDC share which triggers a reallocation effect on labour toward formal sector and thereby increase in formal output would be amplified. Comparing the difference between blue and red lines and that between green and black lines, we find that the amplification effect provided by adjusting CBDC rate diminishes with original informal economy share. Such a finding is similar to that of conventional monetary policy shock. Furthermore, our results suggest that government spending is helpful to formalize an economy, which is consistent with existing literature (Mauricio 2011, Restrepo-Echavarria 2014)[14]. Unlike existing literature where government spending is linked to detection, we model a spillover effect of CBDC on detection and suggest a coordination between monetary and fiscal policy in promoting formality.

Contrary to the amplification effect on policy shocks, Figure 9 shows that the presence of CBDC dampens

[14]In the literature, government spending could be in the form of purchasing formal goods and enhanced monitoring. They either provides direct support to the formal sector or discourage informal production, both of which contribute to a formalized economy.

the propagation of TFP shock on formal output. A positive TFP shock push down price level, lowering inflation. The monetary authority decreases CBDC policy rate which leads to the decline of CBDC share. This triggers a reallocation effect on labor toward informal sector which leads to a decline in formal output.



Note: the same as above

Figure 9 IRFs to the TFP shock

Overall, we find that the presence of CBDC can improve effectiveness of three policy shocks and dampen real-side shock such as TFP shock, both of which implies a benefit of adjusting CBDC rate in stabilizing measured business cycles.

7 Conclusion

In this paper, we examine whether central banks should issue CBDC and what benefits of CBDC are by exploiting cross-country differences in informal economy and its relationship with CBDC. To this end, we develop a two-sector monetary model featured three important elements of CBDC including convenient way of payment, deposit-like money and spillover effect on detecting informal economy. These three factors formulate a trade-off for household and thus an endogenous relationship between CBDC and informal economic activities.

The model shows a L-shaped relationship between CBDC and informal economy, suggesting that large scale of informal economy would dwindle use of CBDC. On the other hand, the presence of CBDC is conducive to formalizing an economy by improving detection rate when using CBDC. Based on these relationships, we further investigate implications of CBDC for business cycle stabilization. By adjusting CBDC interest rate, the presence of CBDC can improve effectiveness of government policies and dampen the propagation of TFP shock. Such adjustment is helpful to stabilize business cycle fluctuation.

Our results deliver a number of important policy implications. The presence of CBDC is helpful to for-

malize an economy and stabilize business cycles. However, such benefits are not asymmetric across countries. Developed countries which have low share of informal economy tend to be easier to adopt CBDC, hence policymakers have more flexibility than ever to advance monetary and fiscal policies. On the contrary, developing countries which have high share of informal economy would be harder to circulate CBDC and only enjoy its limited benefits. In spite of this, tax reduction and positive CBDC interest rate are useful tools to enhance successful CBDC adoption and further enable developing countries to enjoy greater benefits of CBDC.

References

Aguiar, M. & Gopinath, G. (2007), 'Emerging market business cycles: The cycle is the trend', *Journal of Political Economy* **115**(1), 69–102.

Andolfatto, D. (2018), 'Assessing the impact of central bank digital currency on private banks', *FRB St. Louis Working Paper* (2018-25).

Awasthi, R. & Engelschalk, M. (2018), *Taxation and the shadow economy: how the tax system can stimulate and enforce the formalization of business activities*, The World Bank.

Barrdear, J. & Kumhof, M. (2016), The macroeconomics of central bank issued digital currencies, Technical report, Bank of England working paper.

Bech, M. L., Faruqui, U., Ougaard, F. & Picillo, C. (2018), 'Payments are a-changin'but cash still rules', *BIS Quarterly Review, March* .

Berentsen, A. & Schar, F. (2018), 'The case for central bank electronic money and the non-case for central bank cryptocurrencies'.

Bindseil, U. (2020), 'Tiered CBDC and the financial system', *ECB Working Paper* (2351).

Brunnermeier, M. K. & Niepelt, D. (2019), 'On the equivalence of private and public money', *Journal of Monetary Economics* **106**, 27–41.

Capasso, S. & Jappelli, T. (2013), 'Financial development and the underground economy', *Journal of Development Economics* **101**, 167–178.

Carstens, A. (2018), 'Money in the digital age: what role for central banks?', *lecture at the House of Finance, Goethe University, Frankfurt* **6**.

Coeuré, B. & Loh, J. (2018), 'Central bank digital currencies', *Committee on Payments and Market Infrastructures BIS Report* .

Dent, A. & Dison, W. (2012), 'The bank of england's real-time gross settlement infrastructure', *Bank of England Quarterly Bulletin* p. Q3.

ECB (2019), 'Exploring anonymity in central bank digital currencies', *ECB in Focus* (4).

Fernández, A. & Meza, F. (2015), 'Informal employment and business cycles in emerging economies: The case of Mexico', *Review of Economic Dynamics* **18**(2), 381–405.

Fernández-Villaverde, J., Sanches, D., Schilling, L. & Uhlig, H. (2020), Central bank digital currency: Central banking for all?, Technical report, National Bureau of Economic Research.

Galí, J. (2015), *Monetary policy, inflation, and the business cycle: an introduction to the new Keynesian framework and its applications*, Princeton University Press.

Goldberg, H. & Lewis, R. T. (2000), *Money madness: The psychology of saving, spending, loving, and hating money*, Wellness Institute, Inc.

Gordon, R. & Li, W. (2009), 'Tax structures in developing countries: Many puzzles and a possible explanation', *Journal of Public Economics* **93**(7-8), 855–866.

Griffoli, M. T. M., Peria, M. M. S. M., Agur, M. I., Ari, M. A., Kiff, M. J., Popescu, M. A. & Rochon, M. C. (2018), *Casting Light on Central Bank Digital Currencies*, International Monetary Fund.

Hasan, I., De Renzis, T. & Schmiedel, H. (2013), Retail payments and the real economy, Technical report, ECB Working Paper.

Humphrey, D. B., Pulley, L. B. & Vesala, J. M. (1996), 'Cash, paper, and electronic payments: a cross-country analysis', *Journal of Money, Credit and Banking* **28**(4), 914–939.

Jiang, J. H. (2020), CBDC adoption and usage: some insights from field and laboratory experiments, Technical report, Bank of Canada.

Keister, T. & Sanches, D. (2019), 'Should central banks issue digital currency?', *Federal Reserve Bank of Philadelphia* (19-26).

Kosse, A., Chen, H., Felt, M.-H., Jiongo, V. D., Nield, K. & Welte, A. (2017), The costs of point-of-sale payments in Canada, Technical report, Bank of Canada Staff Discussion Paper.

Ligon, E., Malick, B., Sheth, K. & Trachtman, C. (2019), 'What explains low adoption of digital payment technologies? evidence from small-scale merchants in Jaipur, India', *PloS one* **14**(7).

Listfield, R. & Montes-Negret, F. (1994), *Modernizing payment systems in emerging economies*, Vol. 1336, World Bank Publications.

Loayza, N. V. & Rigolini, J. (2011), 'Informal employment: safety net or growth engine?', *World Development* **39**(9), 1503–1515.

Low, S. H., Paul, S. & Maxemchuk, N. F. (1994), Anonymous credit cards, *in* 'Proceedings of the 2nd ACM Conference on Computer and Communications Security', pp. 108–117.

Mauricio, P. (2011), 'Government policy in the formal and informal sectors', *European Economic Review* **55**, 1120–1136.

Meaning, J., Dyson, B., Barker, J. & Clayton, E. (2018), 'Broadening narrow money: monetary policy with a central bank digital currency'.

Okello Candiya Bongomin, G., Ntayi, J. M., Munene, J. C. & Malinga, C. A. (2018), 'Mobile money and financial inclusion in sub-saharan africa: the moderating role of social networks', *Journal of African Business* **19**(3), 361–384.

Orsi, R., Raggi, D. & Turino, F. (2014), 'Size, trend, and policy implications of the underground economy', *Review of Economic Dynamics* **17**(3), 417–436.

Patil, P. P., Dwivedi, Y. K. & Rana, N. P. (2017), Digital payments adoption: an analysis of literature, *in* 'Conference on e-Business, e-Services and e-Society', Springer, pp. 61–70.

Pfau-Effinger, B. (2009), 'Varieties of undeclared work in european societies', *British Journal of Industrial Relations* **47**(1), 79–99.

Poniatowski, G., Bonch-Osmolovskiy, M., Duran-Cabré, J. M., Esteller-Moré, A. & Śmietanka, A. (2018), 'Study and reports on the vat gap in the eu-28 member states: 2018 final report', *Available at SSRN 3272816* .

Prado, M. (2011), 'Government policy in the formal and informal sectors', *European Economic Review* **55**(8), 1120–1136.

Restrepo-Echavarria, P. (2014), 'Macroeconomic volatility: The role of the informal economy', *European Economic Review* **70**, 454–469.

Riksbank, S. (2017), 'The riksbank's e-krona project–Report 1', *E-krona reports* .

Schmalensee, R. (2002), 'Payment systems and interchange fees', *The Journal of Industrial Economics* **50**(2), 103–122.

Schneider, F., Buehn, A. & Montenegro, C. E. (2010), 'Shadow economies all over the world: New estimates for 162 countries from 1999 to 2007', *World Bank policy research working paper* (5356).

Sung, M. J., Awasthi, R. & Lee, H. C. (2017), 'Can tax incentives for electronic payments reduce the shadow economy', *Korea's attempt to reduce underreporting in retail businesses. World Bank policy research working paper* (7936).

Ward, O. & Rochemont, S. (2019), 'Understanding central bank digital currencies (CBDC)', *Institute and Faculty of Actuaries (March 2019)* .

Appendix

Table A.1 Definitions of Variables and Data Sources

Variables	Description
Informal economy	Size of the informal economy as % of GDP Source: Prof. DR. F. Schneider; A.T. Kearney analysis.
Digital payment	Made digital payments in the past year (% age 15+) Source: World Bank Data - Global Financial Inclusion. globalfindex.worldbank.org (accessed March 2020).
VAP gap	Difference between the theoretical VAT liability and the actual VAT revenue Source: Poniatowski et al. (2018)
Financial depth	A composite measure of bank credit to the private sector in percent of GDP, pension fund assets to GDP, mutual fund assets to GDP, and insurance premiums, and life and nonlife to GDP Source: IMF Data - Financial Development. data.imf.org (accessed March 2020).
Financial access	A composite measure of bank branches per 100,000 adults and ATMS per 100,000 adults Source: IMF Data - Financial Development. data.imf.org (accessed March 2020).
GDP per capita	Logarithm of GDP at purchaser's prices divided by total population Source: World Bank Data - data.worldbank.org (accessed March 2020).
Trade openness	Trade openness is the sum of exports and imports of goods and services measured as a share of GDP Source: World Bank Data - data.worldbank.org (accessed March 2020).
Inflation	GDP deflator (annual %) Source: World Bank Data - data.worldbank.org (accessed March 2020).