THE EFFECT OF CBDCs ON BANKS PANICS IN AN OVERLAPPING GENERATION MODEL

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This paper assesses the effects of Central Bank Digital Currencies (CBDCs) on both financial stability within an overlapping generation general equilibrium model. To that end we extend Kim and Kwon (2019), where CBDCs compete with bank deposits according to the following specific rules: i) an interest rate is paid on CBDCs deposits, ii) distinction between reserves and non-convertible CBDCs, iii) non-convertibility of bank deposits into CBDCs deposits, and iv) issuance of CBDCs against eligible securities. We show that, under the above rules, the issuance of CBDCs by the Central Bank reduces the likelihood of banks panics.

Key words: Central bank digital currency, liquidity, financial stability.
JEL Classification: E31, E42, G11.

Introduction:

Central Bank Digital Currency (CBDC), has started in the last couple of years to be the focus of some research and communication by Central Banks in different countries. They represent a government response to non-sovereign crypto-currencies and are the result of using new technologies to offer a digital currency indexed to the domestic currency. Unlike crypto-currencies that are not backed by any sovereign authority, CBDCs are backed by the credibility of Central Banks and are subject to regulations.

This new currency might represent a good prospect for dematerializing payments, which will be faster, easier and more secure, and especially having the advantage of being less expensive than the usual deposit accounts. Work on CBDCs projects has accelerated with the new global circumstances and the emergence of the Covid-19 pandemic. New avenues of research are opening up on expanding the role of CBDCs to support international payments, as presented in the report of the Committee on Payments and Market Infrastructures (July 2021) of the Bank for International Settlements.

Research about this topic is very diverse and the effects of issuing this new currency are not yet well defined. While some researchers and financiers such as Davoodalhosseini (2018), Panetta (2018), Cooper, Esser and Allen (2019), emphasize the benefits of this new currency, others are doubtful about its effects. The main argument is the impact that the issuance of this currency could have on financial stability with the appearance of the risk of deposit flight. Indeed, Genberg (2020) argues that the issuance of CBDCs could threaten the intermediation function of commercial banks. In addition, the approach to be adopted to issue this currency, the technology to be used and the type of this new currency must be considered: will it replace cash or will it be considered as a financial asset?

This paper tries to contribute to the nascent literature investigating the impact of CBDC issuance on financial stability. Indeed, we align ourselves with Kim and Kwon (2019) and Burrenmeier and Niepelt (2019) which analyze the conditions under which a CBDC issuance does not affect financial stability. This concerns in particular conditions related to open-market operations and refinancing of commercial banks. The contribution of the present paper relatively to the above studies is about the conditions that maintain financial stability after the issuance of a new CBDC. Indeed, while considering an overlapping generation model, we show that a slight modification of the economic environment considered by Kim and Kwon (2019) induces new conditions for the issuance of CBDC not to affect financial stability.

Unlike Kim and Kwon (2019), we consider the model and events to be located in a single location. Thus, we replace the lender relocation event with the exchange of deposits in bank accounts for CBDC accounts following the issuance of this new currency by the Central Bank. By choosing this environment, we also extend the model of Champ, Smith and Williamson (1996), which analyzes the impacts of location change (that requires the withdrawal of cash) on financial stability. Our proposed modification is justified by the fact that the CBDC issuance shall be modeled as a new event that might incentivize agents to withdraw cash from their banks deposit accounts and swap it for the CBDC account at the central bank.

Indeed, our second extension appears in the timing of the new digital currency. Contrary to the work of Kim and Kwon (2019) where CBDC are available to lenders from the start, we propose to study the case where deposits are first made in their entirety in commercial banks and then converted into CBDCs accounts at the Central Bank following the issuance of this currency by this central authority. The economic agent will then make the choice between keeping his deposits in commercial banks or investing in CBDCs accounts which are assimilated to non-risky assets and we use the same principles of Kumhof and Noone (2018). Finally, we assume that the economic agent has the possibility to choose the level of investment in CBDCs that could represent part or all of its available capital.

Thus our model allows us to conclude that the issuance of CBDCs by the Central Bank in the middle of the period and after all the deposits have been collected by the commercial banks, could result in a bank run and thus threaten financial stability. To avoid this negative effect, the Central Bank can, as we saw earlier, respond by transferring CBDCs in the form of loans to commercial banks to preserve the stability of reserve-deposit ratios. But this is not the only possible strategy. The central bank could also intervene by restricting access to CBDC accounts, either by limiting the volume of CBDC deposits available or by imposing a substitution fee. We also determine the maximum volume of CBDC deposits that the Central Bank could offer to agents in order to avoid the bank run from commercial banks.

The second strategy is to suspend the convertibility of deposits into cash by commercial banks (Diamond and Dybvig, 1983). The proportion of lenders converting their deposits into CBDC will be kept below the bank panic cut-off, which we have successfully determined.

The remaining of the paper is organized as follows: we begin with a general review of the existing literature on CBDCs in order to present the various models and conclusions that address this topic. The second section presents an overlapping generation model through which we will study the effect of CBDC issuance on financial stability. The third section will be devoted to the presentation of the equilibrium in the OLG model without CBDC issuance. The fourth section will study the effect of the introduction of CBDCs on financial stability through the calculation of the bank panic cut-off. Possible instruments to limit the effects of the introduction of CBDCs on financial stability will be presented in the fifth section.

I. Review of the literature

The study of CBDCs' effects on the financial and economic system has been done in different ways. Auer et al (2020) focuses on the economic and institutional drivers of the CBDCs projects. They tried to find out how the banks can respond to the different problems that may arise and which technical solutions should be used for the creation of the CBDCs. They announce that up to mid-July 2020, 36 Central Banks have already published work on CBDCs. By developing a CBDC project index (CBDCPI), they show that this index is higher in countries where mobile phone use is widespread and innovation capacity is also high. The reasons for conducting CBDC's projects differ widely across countries.

Cooper et al. (2019) shows that CBDC can accelerate financial inclusion. Indeed, CBDCs can facilitate the interoperability of payment instruments, improve their efficiency, and reduce costs and risks. Central Banks are trying, through CBDCs, to take advantage of the potential of crypto-currencies while reducing their risks. Cooper et al (2019) states that CBDCs can facilitate the financial inclusion of merchants and farmers and reduce illicit financial flows. This study shows that the effects of CBDCs are diverse and not all positive. Indeed, this digital currency can have a destabilizing impact on banking intermediation and a negative effect on financial and digital equality.

There are questions about the function of this new currency: would it be considered as a mean of payment or as a store of value? If the CBDCs are used as a mean of payment, they will have a positive effect on financial inclusion (Panetta, 2018) as a proportion of consumers who do not have bank accounts could use this new means of payment without incurring the cost of holding bank accounts. On the side of the Central Bank, the use of CBDCs will reduce the cost of using cash (printing currencies by the Central Bank, transport, etc).

If CBDCs are used as a store of value, they will be considered as assets without cost for the economic agents who will no longer have to bear additional costs due to the management of their deposit accounts. The neutrality of the agents' liquid wealth is thus preserved. CBDCs would be more suitable than bank deposits if they are issued as liquidity-free assets with a rate of return. But this option is not free of effect on financial stability since it will generate a phenomenon of bank run and will have an effect on the intermediation role of commercial banks since bank funds will be reduced.

Bindseil (2020) analyzes the effect of CBDC's creation in its two forms: replacing banknotes and replacing bank deposits. He concludes that the first form has a neutral effect on financial stability while the second form does not. Some other authors have tried to study the effect of CBDCs on financial stability by using general equilibrium models and by attempting to analyze the neutrality conditions of the introduction of this new currency.

Burrenmeier and Niepelt (2019) develop a general model of money, liquidity, and financial frictions and attempt to define the equivalence conditions between different monetary systems. The exchange equivalence between a private and a public currency is studied in terms of neutrality. This means that it should not affect allocations and equilibrium prices. The substitution must be accompanied by additional measures that guarantee wealth and liquidity neutrality. The authors show that a substitution operation accompanied by open-market operations and transfers has no effect on wealth and liquidity. The substitution of public money for private money does not change the liquidity remuneration of portfolios and does not affect the liquidity constraints of agents. In other words, agents keep the same set of choices before and after substitution.

Kim and Kwon (2019) use an OLG model with agents that move between locations and in which CBDCs compete with bank deposits and are accessible to all agents in all locations. They show that an increase in CBDC deposits will lead to a reduction in commercial bank deposits and increase the probability of bank panics due to deposit flight. According to the authors, the financial system can keep its stability if the Central Bank uses CBDC deposits to extend credit to commercial banks. Mersch (2018) has also previously confirmed this idea regarding the destabilizing effect of the introduction of CBDCs especially via the increase in the risk of deposit flight.

Studying the two models of Burrenmeier and Niepelt (2019) and Kim and Kwon (2019), we found that the measure of financial stability differs between the two approaches: it is measured by the neutrality of equilibrium allocations for one and by the cut-off value of banking panic for the other. This difference is quite normal given that there is no clear definition of financial stability. Nevertheless, the two papers converge in their conclusions. Indeed, they show that for the introduction of CBDCs not to affect financial stability, the Central Bank must intervene by using certain instruments: open-market operations and clearing transfers for the first model, and refinancing of commercial banks for the second model. However, the findings seem not to converge for an OLG-type model. Indeed, applying a simplified OLG-type model to the general model of Burrenmeier and Niepelt (2019), we find that the private-public money substitution does not affect the wealth of individuals, nor the liquidity of securities in view of the fact that this model does not have liquidity constraints. In this particular case, no Central Bank intervention is required

Contrary to this result, the OLG model proposed in Kim and Kwon (2019) with the agent’s relocation requires the intervention of the Central Bank to neutralize the effect of a partial substitution of deposits by CBDC accounts. Kumhoff and Noone (2018) outlined four principles that must be followed in order to control the effects of CBDC issuance on the stability of the already existing financial system. These four principles are as follows:

- The payment of an adjustable interest rate for CBDCs,
- Distinction between reserves and CBDCs which should not be convertible,
- No convertibility of bank deposits into CBDCs in commercial banks,
- The issuance of CBDCs by the Central Bank is made against eligible securities.

The interest rate payment for CBDCs should be adjustable so that it can be used as a monetary policy tool to maintain financial stability, price stability, and parity between bank deposits and CBDCs. The adjustable interest rate will also allow the volume of CBDCs to be adjusted. The distinction between reserves and CBDCs preserves the different objectives of each. By making this distinction, CBDCs cannot be used as a financial asset for interbank trading. As for the third principle, its objective is to safeguard financial stability. Indeed, if only one bank offers the possibility of converting deposits into CBDCs, a deposit run appears because several agents will transfer their deposits to this bank in order to convert them into CBDCs, which may generate a bank run. Finally, and still following the principles stated by Kumhoff and Noone (2018), CBDCs are exchanged for eligible securities such as government bonds. They cannot be exchanged for reserves.

II. General settings of the model

We suggest studying the effect of the CBDC’s introduction on financial stability by developing an Overlapping Generation Model as in Champ, Smith and Williamson (1996) and Kim and Kwon (2019) with three main modifications: space, time and investment choice. The model does not include CBDCs and agents invest their donations in deposit accounts only. The issuance of CBDCs will take place over the period and will have an effect on agent’s’ behaviour. A fraction of the latter will prefer to invest in CBDCs and will withdraw a proportion or all of their deposits in commercial banks in accordance with the principle of non-convertibility of bank deposits into CBDCs. We then study the effect of this event on financial stability and the possible strategies to preserve it.

We consider an Overlapping Generation Model where time is discrete and indexed by $t = 1,2, \ldots..$ In each period there is a continuum of agents who live for two periods with a unit mass. Half of the agents are lenders while the other half are borrowers. Agents have preferences described by the following utility function:

$$u(c_t, c_{t+1}) = \ln c_t + \beta \ln c_{t+1}$$

Where $c_j \in \Re_+$ is consumption in period j. $0 < \beta < 1$ is the stochastic discount factor. Lenders have an initial endowment $x > 0$ of consumable good when they are young and no donations when they are old. Borrowers have no donation when they are young and have a donation $y > 0$ when they are old. We assume that $\beta x > y$.

At time $t = 1$, there is a continuum of old agents with a unit mass. They have an initial donation of money $M > 0$ and at this time there is no injection or withdrawal of money.At the beginning of each period, agents receive their donations. The young lenders will use their allocation to purchase goods and services and invest the rest as deposits in commercial banks that will be remunerated at the end of the first period. Young borrowers contact commercial banks to get loans in the first period which they will repay increased by interest at the beginning of the second period.

We assume that the Central Bank chooses to issue its digital money during a certain period t as a liquid and non-risky asset that is accessible directly to agents in the form of an account at the Central Bank. The latter pays a remuneration for CBDC investments that compete with bank deposits. The Central Bank purchases securities at a rate R_c.

The model has a finite number of commercial banks that live forever. They hold reserves, collect deposits and make loans. Each bank announces its repayment schedule at the beginning of period t and the interest rate that will be charged on deposits for each unit deposited according to the type of lender. The Central Bank sets the interest rate r_t^c to be charged to CBDCs.

After the issuance of the new digital currency in a period t, a random fraction π_t of young lenders called "swappers" will decide to invest a part or all of their commercial bank deposits in CBDC. Thus a lender may have a diversified portfolio of commercial bank deposits and CBDC deposits. Swappers contact their banks to withdraw their deposits and remunerations in the form of banknotes as bank deposits cannot be converted into CBDC in commercial banks.

III. The financial equilibrium without CBDC

III.1. Agent's problem

At the beginning of the first period, lenders receive their initial donations, consume the goods and decide on the amount of the deposits. Commercial banks decide on the interest rate that will be charged to each type of lender: $r_t^s(\pi)$ if it is a swapper and $r_t(\pi)$ if it is not. Once repayment schedules are announced, banks accept deposits and set the interest rate R_t applied to loans. Each lender chooses the deposit level d_t that maximizes its expected utility given the payment scheme announced at time t. At the beginning of period t, the lender invests all his capital in a commercial bank. His expected utility is:

$$u_t = \ln(x - d_t) + \beta \ln(r_t d_t) \quad (1)$$

The deposit volume that maximizes this utility is given by the expression:

$$d_t = \frac{\beta x}{1+\beta} \quad (2)$$

On the other hand, borrower observes the competitive interest rate R_t given at time t and determines the amount of the credit he will apply for in order to maximise his expected utility, whose expression is:

$$l_t + \beta \ln(y_t - R_t\, l_t) \quad (3)$$

The borrower will choose the optimal amount of credit whose expression is:

$$l_t = y_t / (1+\beta) R_t \quad (4)$$

III.2. Commercial banks problem

Commercial banks hold reserves, collect deposits and grant credit. They hold reserves z_t for any positive amount of deposits in commercial banks d_t . They grant credit for the remaining amount:

$$l_t = d_t - z_t \quad (5)$$

Let $\gamma_t = {}^{z_t}\!/_{d_t}$ be the reserve-deposit ratio decided by the Central Bank.

The reserves are remunerated at the rate $\frac{p_{t+1}}{p_t}$ where p_t is the inverse of the price level at time t.

To simplify, we consider that we are in the case of a stationary equilibrium where $p_{t+1} = p_t$.

R_t is an exogenous value.

III.3. Equilibrium without CBDC

If we use the same assumptions of Kim and Kwon (2019), we assume that the quantity of credit provided must always be positive, so that equilibrium exists. The nominal interest rate R_t must be positive and we have $R_t > 1$.

In equilibrium, the total amount of deposits made by the new generation of young lenders reduced by the number of bank reserves, should allow commercial banks to cover the demand for credits. Consequently, using equation (4), we obtain the market equilibrium condition:

$$(1-\gamma_t)\frac{\beta x_t}{1+\beta} = \frac{y}{(1+\beta)R_t} \quad (6)$$

We can then derive the expression of the nominal interest rate in equilibrium in a regime where only fiat money exists:

$$R_t = \frac{y_t}{(1-\gamma_t)\beta\, x} \quad (7)$$

IV. Effects of CBDC issuance on financial stability

We now consider that the Central Bank decides to issue its new digital currency and charges an interest rate r_t^c. In the following section, we will study the effect of this new introduction on the behaviour of agents and the initial equilibrium values.

1. Agents and commercial banks problem :

When the Central Bank announces the issuance of CBDC during a specified period t, the young lender is given three strategies:

- Keep the full deposit in the commercial bank : $d_t^b = d_t$
- Withdraw all its deposits from the commercial bank and transfer them to a CBDC account at the Central Bank: $d_t^c = d_t$
- Withdrawing a proportion θ of its commercial bank deposits to convert them into CBDC, where $\theta \in [0,1]$: $d_t = d_t^b + d_t^c = (1-\theta)d_t + \theta d_t$

In case the lender decides to invest in a CBDC account at the Central Bank, he will be qualified as a swapper.

The expression of the utility is then as follows:

$$\ln(x - d_t) + \beta \int_0^1 \pi \ln[r_t^s(\pi)(1-\theta)\, d_t]\, f_t\,(\pi) d\pi + \beta \int_0^1 (1-\pi) \ln[r_t(\pi)\, d_t]\, f_t(\pi)\, d\pi + \beta \int_0^1 \pi ln(r_t^c\, \theta d_t)\, f(\pi) d\pi \quad (8)$$

The lender will always choose the optimal deposit level that maximizes his utility:

$$d_t^b + d_t^c = d_t = {}^{\beta x}/_{(1+\beta)} \quad (9)$$

For borrowers, nothing is altered and the amount of credit they apply for is always the same.

Once γ_t is chosen, and credits are granted, lenders who choose to invest (swappers) in CBDC and whose proportion is equal to (π_t) they will make withdrawals in an amount that equals:

$$d_t^c\, \pi_t r_t^s = \theta\, \pi_t d_t r_t^s \quad (10)$$

This withdrawal amount is paid by the commercial bank in the form of banknotes since the latter do not convert deposits into CBDCs.

It is assumed that there is a fraction $\alpha(\pi_t)$ of bank reserves intended for swappers, where $\alpha_t \in [0,1]$.

2. Equilibrium in a CBDC investment situation

Considering that in equilibrium commercial banks do not make a profit, the values of $r_t^s(\pi_t)$, $r_t(\pi_t)$, r_t^c, $\alpha_t(\pi_t)$ and $\gamma_t$should be chosen in order to maximise the utility which is expressed as follows:

$$\ln[x/(1+\beta)] + \beta \int_0^1 \pi \ln[r_t^s(\pi)(1-\theta)\, \beta x/(1+\beta)]\, f_t\,(\pi) d\pi + \ \beta\ \int_0^1 (1-\pi) \ln[r_t(\pi)\, \beta x/(1+\beta)]\, f_t(\pi)\, d\pi + \beta \int_0^1 (r_t^c\, \theta \beta x/(1+\beta))\, f(\pi) d\pi \quad (11)$$

Such as:

$$\theta\pi\, r_t^s(\pi) \leq\ \alpha_t(\pi)\gamma_t \qquad (12)$$

$$(1-\theta\pi) r_t(\pi) \leq\ [1-\alpha_t(\pi)]\,\gamma_t\ + (1-\gamma_t)R_t \qquad (13)$$

$$r_t^c \leq R_c \qquad (14)$$

The optimal solution must satisfy equations (12) and (13) as equalities.

Considering equations (12) and (13) as equalities, and assuming $r_t^s(\pi) =\ r_t(\pi)$ (under the pressure of bank competition and under the condition of no bank panic, which will be made explicit later, following Kim and Kwon (2019)), we can determine the maximal level of bank reserves that can be withdrawn as liquid by swappers:

$$\alpha_t(\pi_t) =\ \theta\pi_t \frac{R_t}{\gamma_t} \qquad (15)$$

where $\gamma_t\ \in\ [0,1]$ and $\alpha_t(\pi_t) \in\ [0,1]\ \forall\, \pi$.

This fraction of reserves cannot exceed the maximum value of 1. We can define π^* as the bank panic cut-off point for which $\alpha_t(\pi^*) = 1$, i.e. all bank reserves will be liquidated by agents switching to CBDC, and above which commercial banks can no longer satisfy liquidity withdrawal demand.

Considering equation (15), we have:

$$\pi_t^* = \frac{\gamma_t}{\theta R_t} \qquad (16)$$

This value is interpreted as the cut-off value for the probability of migration to CBDC that can generate a deposit run. If the amount of CBDC deposit per individual is low (θ is small), the cut off value of π_t^* will be high signifying low exposure to bank panic. In particular, there is no banking panic for $\theta < \frac{\gamma_t}{R_t}$ since $\pi_t^* \leq 1$.

It is already clear that this restriction emanates as one of the tools that the Central Bank can use to restrict the negative effects of the introduction of CBDC on financial stability. However, what is more interesting is the analysis of the determinants of the highest level θ^* (see section V) for a given swap proportion π_t.

From another viewpoint, condition (16) means that if depositors wish to convert all their deposits into CBDCs ($d_t^c = d_t\ et\ d_t^b = 0$ corresponding to $= 1$, the cut-off probability of switching to CBDCs π_t^* will be equal to the level ${}^{\gamma_t}/_{R_t}$, which itself depends on the interest rate charged on the loans and on the reserve-deposit ratio. The higher this ratio is, the more reserves commercial banks have to pay swappers and the banking panic phenomenon takes longer to appear.

On the other hand, if deposits are not converted into CBDCs or if this proportion is close to zero, the cut-off value of banking panic will tend towards infinity. Thus, bank panic is less likely to occur.

If the probability of lenders leaving to CBDCs remains below the bank panic cut-off ($\pi_t \leq \pi_t^*$) then we will have $\alpha_t\,(\pi_t) \leq 1$ and commercial banks have enough reserves to honor all liquidity demands.

In the presence of banking competition and in a market characterized by stability, i.e. the absence of banking panic, the interest rate applied to deposits for swappers and non-swappers is the same and is given by the expression:

$$r_t(\pi) = r_t^s(\pi) = \gamma_t + (1-\gamma_t)R_t \qquad (17)$$

However, if $\pi_t \geq \pi_t^*$ then $\alpha_t\,(\pi_t) = 1$, the commercial banks use all their bank reserves to pay the liquidity requests and we are then faced with a situation of bank run. In this case, the interest rates charged to swappers and non-swappers are no longer equivalent and we have:

$$r_t^s(\pi) = \frac{\gamma_t}{\theta\pi_t} \qquad (18)$$

$$r_t(\pi) = \frac{1-\gamma_t}{1-\theta\pi}\, R_t \qquad (19)$$

These two expressions allow us to conclude that $r_t^s \leq r_t$. This can be interpreted by the fact that in case of bank run, swappers will be disadvantaged compared to non-swappers, they will have a lower remuneration than if they had kept their deposits in commercial banks

The optimal strategy for commercial banks is then:

$$\alpha_t(\pi_t) = min\left[\frac{\pi_t}{\pi_t^*}, 1\right]$$

By analyzing the equation (16) the cut-off of banking panic π_t^* is an increasing function of the reserve-deposit ratio. The higher this ratio, the higher the threshold and thus the lower the probability of a banking panic.

On the other hand, if lenders choose to decrease their bank deposits in favor of CBDC deposits at the Central Bank, they will make massive liquidity withdrawals, bank reserves will decrease and the bank panic cut-off will also decrease.

It can be concluded that if lenders choose to convert their deposits into CBDCs at the Central Bank following the introduction of this new currency in the period t, they will need to make liquidity withdrawals. Commercial banks can meet this withdrawal demand as long as it does not exceed the threshold of its reserves. Otherwise, reserves will fall to zero and the proportion of lenders leaving banks will approach the limit for a banking panic. Financial stability could then be affected.

3. General equilibrium in a CBDC issue situation

At equilibrium, the total amount of bank deposits made by the younger generation must cover the bank's reserves and the loans granted.

In other words:

$$d_t^b = (1-\theta)d_t = z_t + l_t \qquad (20)$$

Using equations (15) and (16), we have the following equilibrium condition:

$$(1-\theta)(1-\gamma_t)\frac{\beta x}{1+\beta} = \frac{y}{(1+\beta)R_t} \qquad (21)$$

This gives us,

$$R_t = \frac{y}{(1-\theta)(1-\gamma_t)\beta x} \qquad (22)$$

If the proportion θ of bank deposits that are converted into CBDC increases, then the nominal interest rate also increases, resulting in less lending by commercial banks, for a given deposit-to-reserve ratio.

Consequently, if the central bank chooses to issue its new electronic money, the nominal interest rate will be higher than the interest rate in the simple monetary regime ($\theta = 0$).

The increase in the interest rate could have an impact on the volume of private credit granted. However, the decrease is not only due to the increase in the nominal interest rate, but also to the decrease in the volume of private deposits since there will be a run-off of a fraction of young lenders deposits to CBDC accounts at the Central Bank.

V. Limiting the effects of CBDCs on financial stability

In this section, the different strategies for dealing with the potential effect of a CBDC issue on financial stability are analyzed. We have seen previously that following this event, which occurs during period t, lenders could withdraw their deposits from commercial banks and convert them into CBDC accounts at the Central Bank. Commercial banks must hold enough bank reserves to meet this need for liquidity, and exceeding a certain limit π^* could generate a bank panic and reduce the amount of credit granted.

To overcome this panic, Kim and Kwon (2019) propose that the Central Bank use CBDC deposits to extend credit to commercial banks, which could then use the new reserves to pay lenders. On our part, we study the possibility of Central Bank intervention through the volume of CBDCs that are issued. Reducing the probability of deposit flight is not limited to the Central Bank, but can be done by commercial banks using the convertibility suspension tool, as presented by Diamond and Dybvig (1983).

V.1. Intervention on the volume of CBDCs

It is assumed in this section that there is a CBDC appearance phenomenon during a certain period t'. C This new money will then be present in the periods to follow for the new generations of lenders that will appear.

We saw in the previous section that when the Central Bank issues its new money at t', a proportion of young lenders (swappers) equal toπ will choose to invest a volume θ of their deposits in CBDCs. We found that there is a threshold π^* at which there is a bank run from commercial banks to the Central Bank which generates a banking panic phenomenon for any $\pi \geq \pi^*$, financial stability is then affected.

To prevent this banking panic with new generations being born starting from$(t' + 1)$, the Central Bank can limit the volume of CBDC to be converted to a ceiling volume that should not be exceeded, based on observations in the previous period t'. Accordingly, and in order to avoid a banking panic, the demand for withdrawals of deposits that would be converted into CBDC has to be at most equal to the proportion of reserves left for swappers.

Since the central bank has already observed the proportion of swappers at time $(t - 1)$, it has to implement a new strategy to avoid a banking panic arising from the conversion of deposits into CBDCs. This implies that:

$$d_{t-1}^{c}\, \pi_t\, r_t^{s}\, (\pi_{t-1}) = \alpha_t(\pi_{t-1}) z_t \quad (23)$$

Using expression (17), we can then derive the highest level of conversion to CBDC that prevents the bank run and provides the required liquidity to lenders:

$$\theta^*(\pi) = \frac{\gamma_t\, \alpha_t(\pi_{t-1})}{\pi_{t-1}\,[\gamma_t + (1-\gamma_t) R_t]} \quad \text{for all } \pi_{t-1} < \pi_{t-1}^* \quad (24)$$

Therefore, if the proportion of swappers in the preceding period is observed, and knowing the cut-off point for the bank panic, the Central Bank can limit the issuance of the new digital money so that it does not exceed the limit defined in equation (24). The highest volume of CBDCs to be issued is a decreasing function of the swapper ratio observed, given a defined reserve-to-deposit ratio. In case the bank reserves of a period $(t - 1)$ are fully liquidated, the proportion of swappers π_{t-1} at time $(t - 1)$ is equal to the bank panic threshold π_{t-1}^*,, then $\alpha_t(\pi_{t-1}^*) = 1$. The expression (24) turns into :

$$\bar{\theta} = \frac{\theta_{t-1} R_t}{r_t^s} \quad (25)$$

Then the maximum volume of CBDCs issued by the Central Bank during a period following a banking panic $\bar{\theta}$, will depend on the volume of CBDCs issued in the previous period. We agree with the findings of Panetta (2018) that the strategy of limiting the volume of CBDCs can reduce the risk of bank runs, while developing an approximate expression of this maximum volume.

If the central bank chooses to adopt a strategy of limiting the volume of CBDCs, it will not be able to issue an additional quantity of this new money if the demand for it increases. In this case, the adjustment is made through the interest rate applied to CBDCs.

V.2. Intervention through commercial banks' suspension of convertibility

The idea of convertibility suspension was discussed in the bank run model proposed by Diamond and Dybvig (1983). In this model, a deposit contract between the commercial bank and the lenders fixes the deposits remuneration. Besides, the withdrawal of liquidity by the agents is done sequentially until the reserves of the Central Bank are exhausted.

We have already defined d_t^c as the amount of deposits that will be withdrawn from the commercial bank in the form of cash to be converted into CBDC at the Central Bank. We also assume that the Central Bank sets a maximum threshold for conversion to individual CBDCs that is the same for all lenders.

We assume that liquidity demanders can make deposits of liquidity withdrawals in a sequential manner and in a well-defined order. Furthermore, we assume that banks accept each agent's withdrawal request given only his position in the queue and without any additional information about the behavior of the agents who are ranked after him. Finally, we assume that lenders are served in order.

We denote by V_1 the remuneration of deposits that will be withdrawn. This remuneration depends on the lender's position in the line-up at period t. We will define μ as the total number of deposit withdrawal demands and μ_j as the number of withdrawal demands served before individual j. μ_j is a fraction of μ. Thus, we have :

$$V_1(\mu_{j,} r^s) = \begin{cases} r^s \; si \; \mu_j \leq \hat{\mu} \\ 0 \; si \; \mu_j \; > \; \hat{\mu} \end{cases}$$

The bank deposit convertibility is suspended as soon as $\mu_j = \hat{\mu}$ in order to avoid the exhaustion of the fraction $\alpha_t(\pi_t)$ of reserves intended for swappers and so the emergence of bank run. For all withdrawal sequences that occur before reaching the point $\hat{\mu}$, we are in an equilibrium situation with CBDC where agents are seeking to maximise their utility described in equation (8).

The lender will invariably have a total deposit amount equal to $d_t = d_t^b + d_t^c = (1-\theta)d_t + \theta d_t$. Once γ_t and $\alpha_t(\pi_t)$ are decided and the volume of CBDC allowed for conversion, θ, is chosen by the Central Bank, commercial banks must set the number of withdrawals made by lenders such that:

$$\sum_{j=1}^{\mu} d_t^{cj} V(\mu_j, r^s) = \alpha_t(\pi_t) z_t$$

$$\textstyle\sum_{j=1}^{\mu} \theta d_t^j r_t^s = \alpha_t(\pi_t) z_t \quad (26)$$

Yet we know that in an equilibrium situation, each lender (j) will choose the level of deposit that maximises its utility, i.e. :

$$d_t^j = \frac{\beta x}{1+\beta}$$

By substituting this individual deposits expression into equation (26), we can then derive the expression for $\hat{\mu}$:

$$\hat{\mu} = \frac{\alpha_t(\pi_t) z_t}{\theta \pi r_t^s} \frac{1+\beta}{\beta x} \qquad (27)$$

If the number of withdrawals by lenders for conversion into CBDCs, reaches the level of $\hat{\mu}$, the banks no longer pay any remuneration and the agents have an incentive to keep their deposits at the commercial bank in question until the end of the first period to receive their remuneration. **This critical limit for the number of withdrawals is a decreasing function of CBDC volume. An increase in CBDC conversion volume generates a lower convertibility suspension threshold.**

In a situation where lenders choose to convert their deposits into CBDCs and need to make liquid withdrawals, commercial banks may choose to serve them sequentially according to their position in the line-up until its reserves are exhausted. At that point, the commercial bank pays no further remuneration and agents have an incentive to keep their deposits at that bank until the end of the first period to receive their remuneration.

Conclusion

The introduction of a new electronic currency by Central Banks is generating a lot of interest. Research is accelerating on these projects in order to study the different impacts of the creation of CBDCs on the different economic actors. Several authors have shown that the introduction of CBDCs could remain without effect on financial stability if it is accompanied by some measures by Central Banks such as open-market operations or the granting of credits to commercial banks to guarantee the stability of bank reserves.

In this paper, we tried to verify the effect of issuing CBDCs on financial stability through an overlapping generation model. CBDCs are assimilated to non-risky liquid financial assets in direct competition with bank deposits. The creation of this new money takes place over a period of time after lenders have already invested in deposit accounts at commercial banks. Lenders who choose to invest in CBDCs are called swappers and we compare the situations before and after swapping deposits for the new currency.

We show that under certain conditions, two strategies are possible to avoid the negative effects of CBDC creation on financial stability. The Central Bank could determine a maximum volume of CBDCs to avoid the occurrence of a bank run. Commercial banks could also limit the convertibility of deposits into cash as soon as the banking panic cut-off is reached.

Our results are consistent with existing work on the neutral effect of the introduction of CBDCs on financial stability if accompanied by appropriate measures. However, our results include new avenues of research. Indeed, the extended model considers that CBDCs compete with bank deposits and are freely available to economic agents. It would then be interesting, in the same OLG model, to study the effect of CBDCs if they are introduced as a substitute for cash and if their acquisition is made at a cost. This cost could be interpreted as the renunciation by economic agents of their anonymity.

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