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Could the Issuance of CBDC Reduce the Likelihood of Banking Panic?¹

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Abstract: This paper delves into the relationship between the issuance of Central Bank Digital Currencies (CBDC) and the likelihood of banking panic. The issuance of CBDC acts as a disturbing shock that incentivizes depositors to withdraw all/part of their deposits from the commercial banks, to swap it for CBDC which are offered by the central bank. We determine a variety of tools that central banks can use in order for the issuance of CBDC to act as a stabilizing factor of the banking system (by reducing the likelihood of banking panic).

Keywords: Central bank digital currency, liquidity, financial stability.

JEL classifications: E31, E42, G11.

1. Introduction

The determinants and impacts of Central Bank Digital Currency (CBDC)'s issuance is the subject of an increasingly number of research papers and experimental projects by central banks. Unlike crypto-currencies which are not backed by any sovereign authority, CBDC is considered as a new form of central banks currencies. This new form of sovereign currency is expected to contribute to faster, easier, cheaper and more secure financial transactions. The effects of issuing this new currency are not yet well understood. While some researchers and financiers (e.g. Davoodalhosseini, 2018; Panetta, 2018; Cooper, Esser and Allen, 2019;

¹ The authors declare that the current research has not benefited from any source of funding and that there are no conflicts of interest with third parties.

Kaczmarek, 2022) emphasize its benefits, others are more sceptic. The main argument against the issuance of CBDC is related to the financial stability issue that might be exacerbated by bank run. For example, Genberg (2020) argues that the issuance of CBDC could threaten the intermediation function of commercial banks. Besides, it is not clear if CBDC will replace cash or if it will be considered a financial asset?

This paper tries to contribute to this nascent literature by investigating the impacts of CBDC's issuance on financial stability. Our paper is in line with Kim and Kwon (2019) and Brunnermeier and Niepelt (2019) which analyse the conditions under which CBDC issuance does not affect financial stability. It studies the effects of CBDC issuance on financial stability through a simplified model based on Kim and Kwon's paper with three main modifications: space, time, and investment choice. In our model, CBDC does not exist initially, and is issued at the end of the first period. This shock incentivizes the depositors to withdraw their deposits from the commercial banks and swap it (totally or partially) for CBDC. We then study the effect of this event on financial stability and the possible options to preserve it. We show that avoiding the bank run is possible if the central bank transfers the CBDC into loans for the commercial banks, in an attempt to preserve the stability of the reserve-deposit ratio. In addition, we show that this is not the only possible option. Indeed, the central bank could also intervene by restricting the access to CBDC accounts, either by limiting its available amount or by imposing a substitution fee. The next option is to suspend the convertibility of bank deposits into CBDC (à la Diamond and Dybvig, 1983). For this option, we show that the proportion of lenders converting their deposits into CBDC shall be kept below an endogenously determined bank panic cut-off.

The remaining of this paper is organized as follows. We begin with a literature review on the economics of CBDC. The second section presents the theoretical model which is used to analyse the effects of CBDC issuance on financial stability. The third section is devoted to the analysis of the equilibrium without CBDC issuance. In the fourth section, we study the impacts of CBDC issuance on financial stability. Finally, we determine various other options that could limit the impacts of CBDC issuance on financial stability.

2. The literature review

There are emerging studies analysing the determinants and impacts of central bank digital currency (CBDC) issuance. Auer and Böhme (2020) focus on the economic and institutional drivers of CBDC projects. It suggests a CBDC pro-

ject index taking higher values in countries where mobile phone use is widespread and innovation capacity is developed. Cooper et al. (2019) and Vučinić and Luburić (2022) show that CBDC can accelerate the financial inclusion by facilitating the interoperability of the payment systems, improving their efficiency, and reducing the financial costs and risks. These studies show that the impacts of CBDC 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. For Panetta (2018), if the CBDC are used as a means of payment, they will have a positive effect on financial inclusion. The main idea is that a proportion of consumers who do not have bank accounts could use it without incurring the cost of holding bank accounts. From the perspective of the central banks, the use of CBDC are expected to reduce the cost of using cash. If CBDC 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 the fees due to the management of their deposit accounts). CBDC 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 impacts on the financial stability, since it could generate bank runs and impact the intermediation role of commercial banks. In this context, Vučinić (2020) shows that FinTech could have an adverse systemic impact on financial stability through microfinancial and macrofinancial risks. CBDCs can have this same impact on financial stability since they are part of fintech.

Bindseil (2020) analyses the effect of CBDC creation in two forms: by replacing banknotes and by replacing bank deposits. It concludes that the first form has a neutral effect on financial stability while the second form does not. Some other studies tried to analyse the impacts of CBDC on financial stability by using general equilibrium models or attempting to analyse the neutrality conditions of the introduction of this new currency. Brunnermeier and Niepelt (2019) develop a general model of money, liquidity, and financial frictions and attempts to define the equivalence conditions between different monetary systems. The exchange equivalence between a private and a public currency is studied. The authors analyse if CBDC's issuance affects the allocations and equilibrium prices. They show that the issuance shall be accompanied by measures that guarantee wealth and liquidity neutrality. Besides, they show that a substitution operation accompanied by open-market operations and transfers has no effects on wealth and liquidity. Kim and Kwon (2019) propose an OLG model with agents that move between locations, in which CBDC competes with bank deposits and is accessible to all agents in all locations. It shows that an increase in CBDC deposits leads to a reduction in commercial bank deposits, and to an increase of the probability of banking panic. The authors argue that the financial system could keep its stability if the central bank uses CBDC deposits to extend credit to commercial

banks. Mersch (2017) confirms this idea regarding the destabilizing effect of the introduction of CBDC, mainly through the increase in the risk of deposit flight. Bitter (2020) tries to study how the introduction of CBDC affects the likelihood of aggregate bank runs. It shows that CBDC does not affect the aggregate output and prices in a steady state. However, it changes the composition of household savings, bank funding and capital investment. Besides, central banks can accommodate CBDC in their balance sheet via some options as loans to banks and corporate asset purchases. The author concludes that these two CBDC policies have a stabilizing effect on the economy during crises.

Brunnermeier and Niepelt (2019) and Kim and Kwon (2019) suggest different approaches of measures to reduce the negative impacts of CBDC on financial stability. The former considers the neutrality of the equilibrium allocations while the latter focuses on a cut-off threshold that triggers banking panic. Nevertheless, the two studies converge to quite similar conclusions. Indeed, they show that for the CBDC's issuance not to affect financial stability, the central bank should activate specific instruments. Brunnermeier and Niepelt suggest open market operations and clearing transfers, whereas Kim and Kwon (2019) propose the refinancing of commercial banks by the central bank. In the same vein, Kumhof and Noone (2018) outline the following four principles that must be followed in order to control the impacts of CBDC issuance on financial stability: i) Payment of an adjustable interest rate for CBDC, ii) Distinction between reserves and (non-convertible) CBDC, iii) No convertibility of bank deposits into CBDC held in commercial banks, iv) Issuance of CBDC against eligible securities. The payment interest rate on CBDC 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 CBDC.

3. The model

We consider a two-periods and three-dates $t = 0, 1, 2$ economy. There is a $[0, 1]$ continuum of agents with a unit mass. Agents live for two periods. In the first period, they are young and starting from $t = 1$ they become old. Half of the agents are lenders while the other half are borrowers. The preferences of agents are described by the following utility function:

$$u(c_1, c_2) = \ln c_1 + \beta \ln c_2 \quad (1)$$

Where $c_j \in \mathfrak{R}_+$ is consumption in period j . β is a 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 $t = 0$, there is a continuum of old agents with a unit mass. They have an initial donation of money $M > 0$ and from this time there is no injection or withdrawal of money. At the beginning of the first 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. Finally, we consider that cash exists in the economy and is used by agents to make transactions.

We assume that the central bank chooses to issue the CBDC during at $t = 1$ as a liquid and non-risky asset which is accessible directly to agents. The central bank keeps the CBDC accounts and pays a remuneration (r^c) that compete with bank deposits. The central bank purchases government securities at a rate R_c . The model has a finite number of commercial banks that live forever. They hold reserves, collect deposits and grant loans. Each bank announces its repayment schedule at $t = 0$ and the interest rate that will be charged on deposits for each unit deposited according to the type of lender.

After the issuance of the CBDC during the first period $t = 1$, a random fraction π of young lenders called "swappers" 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. We denote $F(\pi)$ the distribution function of the random variable π and $f(\pi)$ its continuously differentiable density function.

4. The financial equilibrium without CBDC

4.1. Agents' problem

At the beginning of the first period, lenders receive their initial donations, consume and decide on the amount to deposit. Commercial banks decide on the interest rate that will remunerate each type of lender: $r^s(\pi)$ if it is a swapper and $r(\pi)$ if it is not. Once the repayment schedule is announced, banks accept deposits and set the interest rate R applied to loans. Each lender chooses the deposit level d^b that maximizes its expected utility given the payment scheme announced at time $t = 1$. At the beginning of the first period ($t = 0$), the lender invests all his capital in a commercial bank. His expected utility is:

$$U = \ln(x - d^b) + \beta \ln(rd^b) \quad (2)$$

The volume of deposits that maximizes this utility is given by:

$$d^b = \frac{\beta x}{1+\beta} \quad (3)$$

On the other hand, a borrower observes the competitive interest rate R given at time $t = 0$ and determines the amount of the credit he will apply for in order to maximise his expected utility, whose expression is:

$$V = \ln(l) + \beta \ln(y - R l) \quad (4)$$

The borrower chooses the optimal amount of credit whose expression is:

$$l = y / (1 + \beta)R \quad (5)$$

4.2. Commercial banks' problem

Commercial banks hold reserves, collect deposits and grant credit. They hold reserves z for any positive amount of deposits in commercial banks d^b . They grant credit for the remaining amount:

$$l = d^b - z \quad (6)$$

Let $\gamma = z/d^b$ 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 $t=1, 2$. To simplify, we consider that we are in the case of a stationary equilibrium where $p_{t+1} = p_t$.

4.3. Equilibrium without CBDC

The gross interest rate is given by $R > 1$. At the equilibrium, the total amount of deposits made by the young lenders reduced by the number of bank reserves, should allow the commercial banks to cover the demand for credits. Consequently, using equation (5), we obtain the market equilibrium condition:

$$(1 - \gamma) \frac{\beta x}{1+\beta} = \frac{y}{(1+\beta)R} \quad (7)$$

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

$$R = \frac{y}{(1-\gamma)\beta x} \tag{8}$$

5. Effects of CBDC issuance on financial stability

We now consider that the central bank decides to issue the CBDC and charges an interest rate r^c . In the following sections, we study the effects of this new introduction on the behaviour of agents and the initial equilibrium values.

5.1. Agents and commercial banks problem

When the central bank announces the issuance of CBDC during a specified period $t = 1$, the young lender is proposed three strategies:

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

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 given by:

$$\ln(x - d) + \beta \int_0^1 \pi \ln[r^s(\pi)(1 - \theta) d] f(\pi) d\pi + \beta \int_0^1 (1 - \pi) \ln[r(\pi) d] f(\pi) d\pi + \beta \int_0^1 \pi \ln(r^c \theta d) f(\pi) d\pi \tag{9}$$

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

$$d^b + d^c = d = \beta x / (1 + \beta) \tag{10}$$

For borrowers, nothing is altered and the amount of credit they apply for is always the same. Once y is chosen, and credits are granted, lenders who choose to invest (swappers) in CBDC and whose proportion is equal to (π) they will make withdrawals in an amount that equals:

$$d^c \pi r^s = \theta \pi d r^s \tag{11}$$

This withdrawal amount is paid by the commercial bank in the form of banknotes since the latter do not convert deposits into CBDC. It is assumed that there is a fraction $\alpha(\pi)$ of bank reserves intended for swappers, where $\alpha \in [0,1]$.

5.2. Equilibrium in case of CBDC investment

Considering that commercial banks do not make profit at the equilibrium, the values of $r^s(\pi)$, $r(\pi)$, r^c , $\alpha(\pi)$ and γ should be chosen in order to maximize the utility which is expressed as follows:

$$\ln\left[x/(1+\beta)\right] + \beta \int_0^1 \pi \ln\left[r^s(\pi)(1-\theta)\frac{\beta x}{1+\beta}\right] f(\pi) d\pi + \beta \int_0^1 (1-\pi) \ln[r(\pi) \beta x/(1+\beta)] f(\pi) d\pi + \beta \int_0^1 (r^c \theta \beta x/(1+\beta)) f(\pi) d\pi \quad (12)$$

Such as:

$$\theta \pi r^s(\pi) \leq \alpha(\pi) \gamma \quad (13)$$

$$(1-\theta \pi) R(\pi) \leq [1-\alpha(\pi)] \gamma + (1-\gamma) R \quad (14)$$

$$r^c \leq R_c \quad (15)$$

The optimal solution must satisfy equations (13) and (14) as equalities. In this case, and assuming $r^s(\pi) = r(\pi)^2$, we can determine the maximal level of bank reserves that can be withdrawn by swappers:

$$\alpha(\pi) = \theta \pi \frac{R}{\gamma} \quad (16)$$

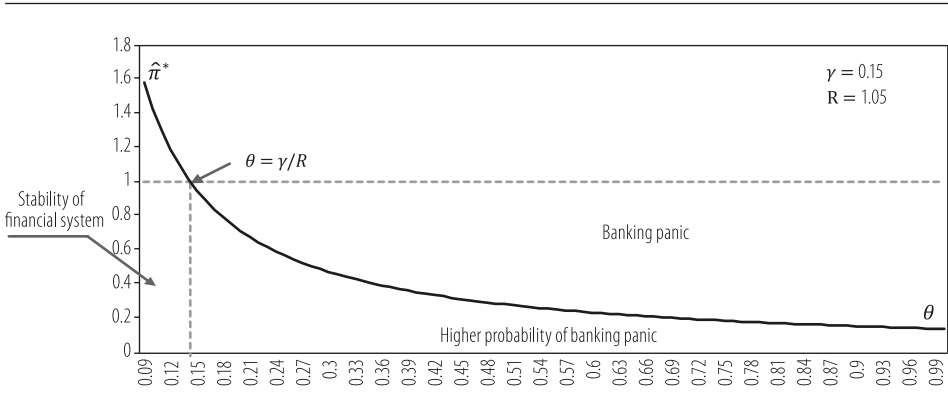
where $\gamma \in [0,1]$ and $\alpha(\pi) \in [0,1]$. This fraction of reserves cannot exceed the maximum value of 1. Therefore, we can define π^* as the bank panic cut-off point for which $\alpha(\pi^*) = 1$, i.e. all bank reserves will be liquidated by agents switching to CBDC, and above which commercial banks can no longer satisfy liquidity withdrawal demand. Considering equation (16), we have:

$$\pi^* = \frac{\gamma}{\theta R} \equiv g(\gamma, R) \quad (17)$$

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^* will be high, signifying low exposure to bank panic. In particular, there is no banking panic for $\theta < \frac{\gamma}{R}$ since $\pi^* > 1$. It is already clear that this restriction emanates as one of the tools that the central bank can use to mitigate the negative effects of the CBDC issuance on financial stability. As shown in Graph 1, below the θ threshold, the bank panic threshold is too high and the stability of the financial system can be preserved.

² 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).

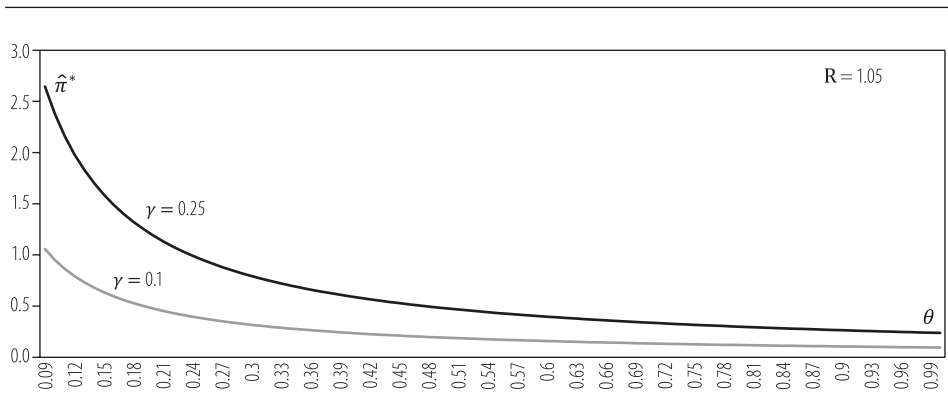
Graph 1: Cut-off variation as a function of CBDC conversion ratio



Source: Authors' simulations

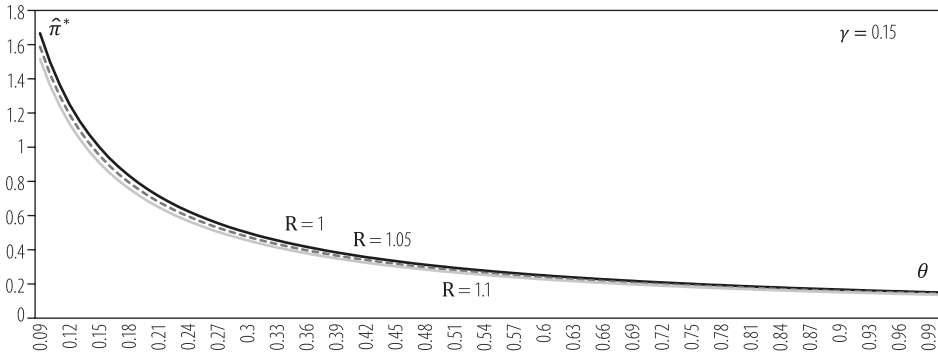
The bank panic threshold depends not only on θ but also on the reserve-deposit ratio γ . In Graph 2, we vary this ratio for a given interest rate R . We observe that as γ increases, the bank panic threshold increases for a given CBDC conversion ratio. This means that the more reserves the commercial banks hold to satisfy the liquidity needs of their customers (who want to convert their deposits into CBDC), the longer it takes for the banking panic to trigger. This same threshold of banking panic is weakly sensitive to a variation in the interest rate R applicable to bank loans, if we keep the reserve-deposit ratio of commercial banks at the same level (Graph 3).

Graph 2: Impact of the variation in the reserve-deposit ratio



Source: Authors' simulations

Graph 3: Impact of interest rate changes



Source: Authors' simulations

However, what is more interesting is the analysis of determinants of the highest level θ^* (see section V) for a given swap proportion π . From another viewpoint, condition (17) means that if depositors wish to convert all their deposits into CBDC ($d^c = d$ et $d^b = 0$) corresponding to $\theta = 1$), the cut-off probability of switching to CBDC π^* will be equal to the level γ/R , 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 to swappers and the banking panic phenomenon takes longer to appear. On the other hand, if deposits are not converted into CBDC or if this proportion is close to zero, the cut-off value of banking panic will incline towards infinity. Thus, bank panic is less likely to occur.

If the probability of lenders leaving to CBDC remains below the bank panic cut-off ($\pi \leq \pi^*$), then we will have $\alpha(\pi) \leq 1$ and commercial banks have enough reserves to honour all liquidity demands. In the presence of banking competition and in a market characterized by stability, i.e. the absence of a banking panic, the interest rate applied to deposits for swappers and non-swappers is the same and is given by the expression:

$$r(\pi) = r^S(\pi) = \gamma + (1 - \gamma)R \tag{18}$$

However, if $\pi \geq \pi^*$ then $\alpha(\pi) = 1$, 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:

$$r^s(\pi) = \frac{\gamma}{\theta\pi} \tag{19}$$

$$r(\pi) = \frac{1-\gamma}{1-\theta\pi} R \tag{20}$$

These two expressions allow us to conclude that $r^s \leq r$. Hence, in case of bank run, swappers will be disadvantaged compared to non-swappers, since they will have a lower remuneration. The optimal strategy for commercial banks is then:

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

By analysing equation (17) the cut-off of banking panic π^* 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 favour 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 CBDC following its $t = 1$, 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 the banking panic. Following Kim and Kwon (2019), we define the optimal reserve-deposit ratio. Let us define the function $H : [0,1] \rightarrow [0,1]$ as:

$$H(x) = \int_x^1 F(\pi) d\pi \tag{21}$$

The optimal reserve-deposit ratio can be expressed as:

$$\gamma = 1 - \int_{\pi^*}^1 F(\pi) d\pi \tag{22}$$

Considering equation (17), we can then rewrite equation (22) as:

$$1 - \gamma = H[g(\gamma, R)] \tag{23}$$

The function $H[g(\gamma, R)]$ is decreasing and concave in γ , $H[g(0, R)] = H(0) < 1$ and $H[g(1, R)] = H(1) = 0$ for all $R > 1$. If $R = 1$, then (23) is satisfied only by $\gamma = 1$. If $R > 1$, then (23) has two solutions and the interior solution solves the optimization problem. Results of the optimal choice of γ can be summarized as follows: the optimal reserve-deposit ratio is given by $\gamma = \gamma(R)$; with $\gamma(1) = 0$ and $\gamma' < 0$.

5.3. The general equilibrium in case of CBDC issuance

Proposition 1

In equilibrium, the CBDC issuance increases the nominal interest rate which is given by:

$$R = \frac{y}{(1-\theta)(1-\gamma)\beta x} \quad (24)$$

Proof. At the equilibrium, the total amount of bank deposits must cover the bank's reserves and the granted loans. In other words:

$$d^b = (1 - \theta)d = z + l \quad (25)$$

We then have the following equilibrium condition:

$$(1 - \theta)(1 - \gamma) \frac{\beta x}{1 + \beta} = \frac{y}{(1 + \beta)R} \quad (26)$$

It is clear from equation (26) that if the proportion θ of bank deposits converted into CBDC increases, then the nominal interest rate also increases. Consequently, there will be less lending by commercial banks, for a given deposit-to-reserve ratio. Therefore, if $\theta = 0$ (absence of CBDC), the nominal interest rate is at its minimum threshold compared to interest rate, in the presence of CBDC. In other words, the issuance of CBDC will be more expensive for the borrowers. The increase in the interest rate could have an impact on the volume of granted loans. However, the decrease is not only due to the increase in the nominal interest rate, but also to the declining volume of private deposits since there will be a run-off of lenders' deposits to CBDC accounts at the central bank.

6. Limiting the negative effects of CBDC on financial stability

In this section, the various strategies for dealing with the potential effects of CBDC issuance on financial stability are analysed. We have seen previously, that following this issuance, which occurs at $t = 1$, lenders could withdraw their deposits from commercial banks and convert it into CBDC accounts at the central bank. Commercial banks must hold enough reserves to meet this need for liquidity. Beyond a certain limit π^* withdrawals could generate a bank panic and reduce the amount of granted loans. To overcome this panic, Kim and Kwon (2019) propose that the central bank use CBDC deposits to extend credits to commercial banks, which could then use the new reserves to pay lenders. Bitter (2020) shows

that under two different scenarios: loans to banks and corporate asset purchases, CBDC issuance does not destabilize the economy. On the contrary, it could improve financial stability by postponing the emergence of bank run equilibrium. The authors opt for the principle of managing the issuance of CBDC through the interest rate. In the same context, Gross and Schiller (2021) show that the central bank can decrease the remuneration of CBDC in order to reduce the volume held. However, the authors show that if CBDC are not interest-bearing, the central bank cannot govern the demand for its digital currency.

6.1. Intervention on the volume of CBDC

Here, we study the possibility of central bank intervention through the volume of issued CBDC. This intervention instrument can be applied to cases where CBDC are issued with or without interest.

Proposition 2

To prevent a bank run and provide the required liquidity to lenders, conversion to CBDC should not exceed the highest level given by:

$$\theta^*(\pi) = \frac{\gamma_t \alpha_t (\pi_{t-1})}{\pi_{t-1} [\gamma_t + (1-\gamma_t)R_t]} \text{ for all } \pi_{t-1} < \pi_{t-1}^* \quad (27)$$

Proof. We saw in the previous section that when the central bank issues its new form of money at $t = 1$, a proportion of young lenders (swappers) equal to π will choose to invest a volume θ of their deposits in CBDC. We showed that there is a threshold π^* at which there is a banking panic phenomenon for any $\pi \geq \pi^*$, leading to financial instability. Let us consider an overlapping generation model, extending the time horizon to infinity. In this context, it is possible for the central bank to prevent this banking panic with new generations being born starting from $(t = 2)$, by constraining the volume of CBDC to be converted to a ceiling, based on previous periods $(t = 1)$ observations. 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 $(t = 1)$, it has to implement a new strategy to avoid a banking panic arising from the conversion of deposits into CBDC. This implies that:

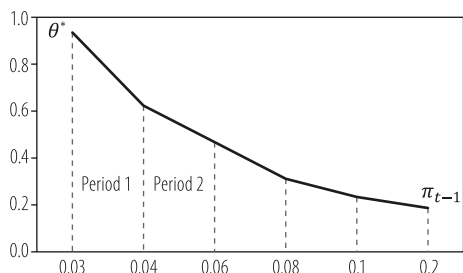
$$d_t^c \pi_t r_t^s (\pi_{t-1}) = \alpha_t (\pi_{t-1}) z_t \quad (28)$$

Replacing d_t^c by θd_t and r_t^s by its expression in (17), we can easily deduce the expression of θ^* .

The highest level of conversion to CBDC is established by replacing r^s in (28) by its expression in equation (18). 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 CBDC so that it does not exceed the limit defined in equation (28). The highest volume of CBDC to be issued is a decreasing function of the swapper ratio observed, given a defined reserve-to-deposit ratio, as shown in Graph 4. 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 (28) turns into:

$$\bar{\theta} = \frac{\theta_{t-1}R_t}{r_t^s} \tag{29}$$

Graph 4: Relation between CBDC issuance and bank run



Source: Authors' simulations

Then the maximum volume of CBDC issued by the central bank during a period following a banking panic $\bar{\theta}$, will depend on the volume of CBDC issued in the previous period. We agree with the findings of Panetta (2018) that the strategy of limiting the volume of CBDC can reduce the risk of a bank run, while developing an approximate expression of this maximum volume. If the central bank chooses to adopt a strategy of limiting the volume of CBDC, 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 shall be made through the interest rate applied to CBDC.

6.2. Intervention through commercial banks' suspension of convertibility

We saw previously that the central bank can intervene through the limitation of CBDC issuance. 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 analysed in Diamond and Dybvig (1983). In this model, a deposit contract between the commercial bank and the lender fixes the deposit remuneration. Besides, the withdrawal of liquidity by the agents is done sequentially until the bank reserves are exhausted. We have already defined d^c as the amount of deposits that will be withdrawn from the bank in the form of cash to

be converted into CBDC. We also assume that the central bank sets a maximum threshold for conversion to individual CBDC that is the same for all lenders.

We assume that liquidity demanders can make liquidity withdrawals of deposits 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 behaviour of 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:

$$V_1(\mu_j, r^s) = \begin{cases} r^s & \text{si } \mu_j \leq \hat{\mu} \\ 0 & \text{si } \mu_j > \hat{\mu} \end{cases} \quad (30)$$

Proposition 3

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.

$$\hat{\mu} = \frac{\alpha_t(\pi_t)z_t}{\theta_t \pi r_t^s} \frac{1 + \beta}{\beta x} \quad (31)$$

Proof. In order to determine the expression of $\hat{\mu}$, we propose the following reasoning. We know that each lender will invariably have a total deposit amount equal to $d_t = d_t^b + d_t^c = (1 - \theta_t)d_t + \theta_t d_t$. Once γ_t and $\alpha_t(\pi_t)$ are decided and the volume θ_t of CBDC allowed for conversion, is chosen by the central bank, commercial banks must set the number of withdrawals made by lenders such that:

$$\begin{aligned} \sum_{j=1}^{\mu} d_t^{c,j} V(\mu_j, r^s) &= \alpha_t(\pi_t)z_t \\ \sum_{j=1}^{\mu} \theta_t d_t^j r_t^s &= \alpha_t(\pi_t)z_t \end{aligned} \quad (32)$$

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 maximize their utility described in equation (8). Yet, we know that at the equilibrium, each lender (j) will choose the level of deposit that maximises its utility, i.e.:

$$d_t^j = \frac{\beta x}{1 + \beta} \quad (33)$$

By substituting this individual deposit expression into equation (32), we can then derive the expression for $\hat{\mu}$.

If the number of withdrawals by lenders for conversion into CBDC, reaches the level of $\hat{\mu}$, the banks no longer pay any remuneration and the agents have an incentive to keep their bank deposits 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 the CBDC conversion volume generates a lower threshold of convertibility suspension.** In a situation where lenders choose to convert their deposits into CBDC, banks may choose to serve them sequentially according to their position in the line-up until their reserves are exhausted. At that point, the commercial banks pay no further remuneration and agents have an incentive to keep their deposits at their banks until receiving their final remuneration.

7. Conclusion

The issuance of CBDC by central banks is generating a lot of interest. New research is emerging to study their various economics impacts. Several authors have shown that the introduction of CBDC could remain without effect on financial stability if it is accompanied by some measures by central banks such as open market operations or granting of credits to commercial banks to guarantee the stability of their reserves.

In this paper, we tried to analyse the impacts of CBDC's issuance on financial stability through a simplified model inspired from Kim and Kwon (2019). CBDC are assimilated to non-risky liquid financial assets competing with bank deposits. The issuance of this new money takes place over a period of time after lenders have already invested in bank deposits. We enable lenders to convert a part or their total bank deposits into CBDC, and we analyse the impacts of such behaviour on the likelihood of banking panic. We show that under certain conditions, two strategies are possible to avoid the negative effects of CBDC issuance on financial stability. The central bank could limit the volume of issued CBDC to a predetermined threshold in order 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. Although our results are consistent with existing work on the impacts of CBDC issuance on financial stability, we of-

fer original recommendations in relation to the options available for the central bank to mitigate these negative impacts.

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