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Cross-border CBDC Implications on Cournot Banks

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Abstract

This paper studies the effect of cross-border Central Bank Digital Currencies (CBDC) on the Cournot domestic banking landscape and its effect on financial stability. A simple open economy version of the classical model of bank runs, augmented with a credible and remunerated foreign CBDC, is employed. The first part of the paper investigates the effect of domestic banks' market power without foreign CBDC. We find that though some bank market powers cause the economy to have lower welfare than the social planner, it has higher welfare than perfect competition. Market-power-enhanced banks can internalize pecuniary externalities from asset price changes and generate more welfare than perfect competition. The second part is the introduction of cross-border foreign CBDC as an international safe asset. We find that the foreign CBDC causes capital outflow and increases the risk of financial disintermediation.

Keywords: Central Bank Digital Currency, bank run, Cournot, capital flight.

1. Introduction

The Central Bank Digital Currency (CBDC) can be regarded as the digital revolution of the financial system (Brunnermeier et al., 2019). It could promote monetary policy effectiveness, increase financial inclusion, and decrease financial friction, but it is too early to draw a specific conclusion on the exact impact of CBDC (Griffoli et al., 2018). This revolutionary introduction of new cash forms could carry many concerns, e.g., digital dollarization, capital outflow to other countries with a CBDC issued by a foreign central bank (Popescu, 2022), and the central bank as a competitor for the deposit (Auer et al., 2022).

This paper aims to characterize optimal contracts offered by Cournot banks and introduce foreign CBDC with safe features to find their implication on the market power and run condition of domestic Cournot banks. We build a simple open economy Diamond and Dybvig (1983) model of bank runs, as in Popescu (2022), augmented with the price effect from selling and buying illiquid assets in the fashion of Eisenbach and Phelan (2022). We depart from Popescu (2022) by introducing bank market power and allowing a bank to internalize the change in asset price effects and their liquidity holdings. If banks have market power, they realize that their decision to choose liquidity will affect the price of the assets in the interim period. They will internalize the effect when they choose the optimal liquidity.

Related Literature: A large part of the recent boom in CBDC literature focuses on two aspects: monetary policy effectiveness and financial stability. The adoption of digital currencies poses a challenge to the central bank's ability to carry out monetary policy. Dollarization might occur when people in an economy use other currencies as a medium of exchange instead of their domestic currency, e.g., the US dollar and other stablecoins. The issuing of CBDC prevents such a situation by incorporating design elements that enable it to rival other currencies (Mkhatrishvili & Boonstra, 2022).

The transmission mechanism of monetary policy can be enhanced with the use of a CBDC. If CBDC were remunerated and made available to the public on a retail basis, the central bank would be able to relay changes in the policy rate to the market more quickly, as consumers would have the ability to convert their deposits into CBDC without any restrictions. Hence, commercial banks will be compelled to adjust their interest rates in accordance with the policy rate of the CBDC (Bordo, 2021).

By replacing physical cash with a CBDC, a central bank can effectively eliminate the zero lower bound and attain price stability. Bordo and Levin (2017) argued that implementing a negative interest rate can effectively stimulate consumption and lending during an economic crisis. Nonetheless, Beniak (2019) argued that non-remunerated CBDC will have an impact on monetary policy as long as the policy rate remains above zero. If the central bank were to decrease the policy rate to a value below zero and commercial banks attempted to transfer this decrease to consumers, the existence of non-remunerated CBDC would cause customers to shift from depositing money in banks to holding CBDC instead. Therefore, implementing a non-renumerated CBDC would result in a more restrictive lower bound, reducing the scope for an interest rate mechanism.

Another potential monetary policy benefit is so-called helicopter drops, meaning the government can directly inject money into targeted individuals if necessary. This would require the central bank to be able to identify the user of

CBDC, and CBDC must be retail so that one can spend their CBDC in the market. Nevertheless, BIS (2020a) points out that "if the fiscal transfer were made with CBDC, there is a risk of blurring the division between monetary and fiscal policy and a potential reduction in monetary policy independence."

Benefits and concerns regarding financial stability have also been discussed extensively. Recently, the banking landscape has become more and more concentrated, which could lead to a "single point of failure" problem. This is a real possibility since, nowadays, big firms can have highly cost-efficient structures and can leverage their bigger dataset to their advantage (BIS, 2020b). What the central bank can do is to ensure that competition is there in the payment market through CBDC. To avoid a closed-loop payment system, central banks can provide a public infrastructure that is operable across platforms. Furthermore, the infrastructure could incentivize non-bank Payment Service Providers (PSPs) to further compete with other big banks. Nevertheless, if CBDC were the main payment method, such infrastructure would be too important to fail. Even if this risk is not specific to CBDC, it will likely suffer from systematic risk, just like any other system.

Although the impact of CBDC on the stability of the payment system is a significant concern, there are also other issues that need to be considered. If CBDC were designed to function like traditional bank deposits, it might potentially divert deposits away from commercial banks. This could lead to a reduction in bank lending and a structural disintermediation of commercial banks. Fernandez-Villaverde et al. (2021) asserted that the introduction of CBDC enables the central bank to engage in competition for deposits. Should people internalize the fact that the central bank is not subjected to run, the central bank might attract all the deposits in the system. Consequently, the central bank may attract all the deposits inside the system. According to Kim and Kwon (2019), the implementation of CBDC can raise the likelihood of bank panic.

In an international context, if people have access to foreign CBDC, the economy will be subjected to capital flight from the issuance of CBDC (Popescu, 2022). Currency substitution, especially in countries with high inflation, is another concern. It might also affect economies with stable currencies if the currencies lose some of their function and traction. Consequently, it would harm monetary policy effectiveness (Minesso et al., 2022).

Regarding market power in the banking sector, a traditional view is that increased competition might undermine bank stability and have significant implications for stressed banking systems in developing economies (Ariss, 2010). Eisenbach and Phelan (2022) found a similar result, where the Cournot agent can correct some inefficiency from the liquidity risk due to pecuniary externalities. Andolfatto (2021) studied the effect of CBDC in a monopolistic bank context, using an overlapping generations model, and found that CBDC could induce the monopolistic bank to increase its deposit rate, leading to an increase in bank deposits and financial inclusion. Our framework combines the Cournot bank run by Eisenbach and Phelan (2022) and the classic bank run in an open economy purposed by Popescu (2022) to explore the domestic financial stability of the Cournot banks with the existence of foreign CBDCs. This is the first attempt to understand how cross-border CBDC affects financial stability in an oligopolistic banking landscape.

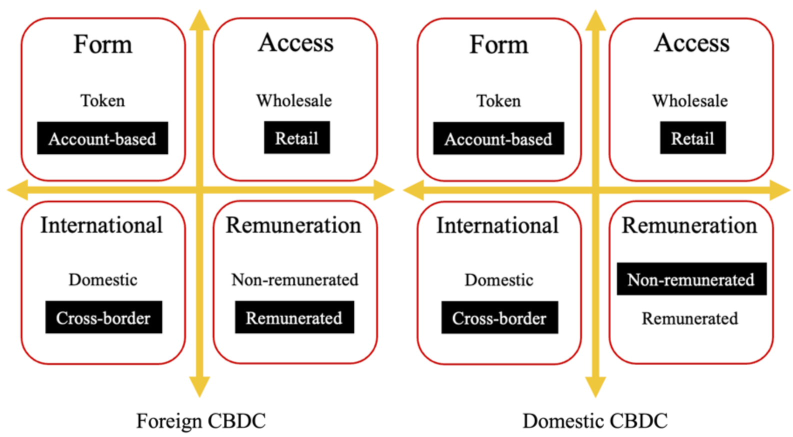
CBDC design: Figure 1 provides an overview of the main characteristics of both domestic and foreign CBDCs. One important factor to address is whether the CBDC should be based on accounts or tokens. The token-based system shares similarities with cash but offers different levels of anonymity instead of complete anonymity, and it exists in a digital format. The account-based system is similar to our deposit account with commercial banks, but it differs in that the account is held with the central bank, either directly or indirectly. An account-based CBDC offers the central bank the advantage of being able to detect anomalies in the financial system, which is a fundamental objective of every central bank. This makes it a more plausible assumption.

The second defining feature pertains to whether the CBDC would be intended for retail or wholesale use. Retail CBDC refers to its accessibility to the general public, whereas wholesale CBDC access may be restricted to select major financial institutions or corporations. CBDC must be made accessible to the public in order to realize several advantages, including financial inclusion. The retail CBDC is the most relevant option.

Next is remuneration. CBDC can have either interest-bearing or non-interest-bearing characteristics. CBDC could be designed to be remunerated due to its significant potential as a tool for implementing monetary policy in the literature. Nevertheless, due to worries about financial disintermediation, the central bank may choose to make the CBDC non-interest-bearing in order to prevent significant negative consequences. The final component of CBDC is its capacity to be accessed and used across international borders. One of the most hopeful outcomes of CBDC is the reduction of financial friction, which enables the smoother movement of capital. Ensuring interoperability across multiple CBDCs necessitates a substantial level of collaboration among central banks.

In this paper, we introduce two types of CBDCs: domestic and foreign. We focus on the following elements: form, access, remuneration, and cross-border availability. This paper will define both CBDCs as retail[1], account-based central bank liability[2], publicly accessible, and internationally available to non-residents[3]. The only difference between the two is remuneration. We define domestic CBDC to be non-remunerated (can be thought of as cash), while foreign CBDC will be remunerated to reflect the possibility of differences in CBDC design between economies[4]. For instance, Thailand is now piloting its non-remunerated CBDC project within limited areas, while the central bank of Sweden (Riksbank) is considering ways to implement interest rate on the e-krona.

Figure 1. CBDC design



The rest of the paper is structured as follows: The model will be presented in Section 2. In Section 3, we discuss the implications in the context of the

[1] We choose retail CBDC because of the potential benefit of a more effective monetary policy. Even though we treat this feature of CBDC as exogenous in our paper and do not directly study its effect on financial stability, much CBDC literature investigates the impact of retail CBDC, and many central banks around the world have been researching it.
[2] Account-based CBDC.
[3] Many central banks have conducted a pilot project on CBDC with cross-border applications. For example, the mBridge project, pioneered by the Bank of International Settlement and other central banks around the world, has been developing a cross-border platform as well as the related and underlying technology to make it cheap and safe to transfer CBDC across countries.
[4] Even if there are many designs and features of CBDC, we believe that the characteristics of CBDC we choose to study are most likely to be implemented since much literature exists on it, and several consultation papers by central banks around the world mention the pros and cons of other designs.

domestic economy. We will then extend to the open economy with foreign CBDC to explore run conditions in Section 4, and Section 5 provides our conclusions.

2. The Model

The model considers two economies, domestic and foreign, using the canonical form of Diamond and Dybvig (1983). There are three discrete time periods[5] $T = 0, 1,$ and 2. The domestic economy is populated with N banks and a [0,1] continuum of ex-ante consumers who are endowed with a unit of non-remunerated domestic CBDC, which can be saved domestically or abroad. For simplicity, in the foreign economy, there is only a foreign central bank issuing CBDC. There are two investment opportunities: liquid and illiquid assets. The liquid asset delivers 1 in $T = 1$ or $T = 2$; the illiquid asset delivers $R > 1$ in $T = 2$ for each unit invested in $T = 0$ and nothing in $T = 1$. In $T = 1$, the illiquid asset can be traded in the market at endogenous price l[6]. Consumers behave as price takers. Next, we assume that the liquidation price l is determined by cash-in-the-market pricing, which will be explained in 2.2.

2.1 Consumers

In period 1, a portion $\lambda \in (0,1)$ of consumers faces idiosyncratic liquidity shock, causing them to become early consumers. That is, they will value consumption in period 1 (referred to as c_L). On the other hand, those who did not

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[5] We abstract our model away from a dynamic version because we want to focus on the welfare analysis of the Cournot agent's internalization of a change in asset price and financial stability. While there could be some influences on asset price from the dynamic behavior of agents, that impact will also be internalized by Cournot banks. For a precise result, we leave that for future research.

[6] We can think of an illiquid asset as a deposit into commercial banks with some exogenous return R.

face liquidity shock will become late consumers, preferring consumption in period 2 (referred to as c_H). Each consumer knows their type in period 1, which is private information. Hence, banks cannot discriminate among consumers. In period 1, each consumer can choose whether to withdraw in a sequentially random order. Let $\alpha \in (0,1)$ denote the fraction of consumers choosing to withdraw in period 1. Consumer preference is described as:

$$U(c_H, c_L) = \begin{cases} u(c_H), & \text{with probability } \lambda \\ u(c_L), & \text{with probability } 1-\lambda \end{cases}$$

where the properties of utility follow Diamond and Dybvig (1983). That is, their discount rate and utility function follow $1 \geq \beta > \frac{1}{R}$ and $u : \mathbb{R}+ \rightarrow \mathbb{R}$ and is twice differentiable, increasing, strictly concave, and satisfies Inada condition, respectively. Also, the relative risk aversion coefficient $\frac{cu''(c)}{u'(c)}$ is greater than 1 everywhere.

Since consumers cannot anticipate the shock, they are subjected to costly liquidation of the illiquid asset in period 1. This justifies the introduction of demand deposit contracts of banks to achieve superior allocation through resource pooling. Consumers can save through domestic commercial banks or foreign central banks offering CBDC deposits, in which consumers can save up to capital account constraint k. This means consumer foreign investment will be capped by the exogenous variable k. The constraint can be justified as a result of domestic capital control policies, which can be commonly seen, or it can also be seen as financial frictions or biases that restrict foreign investment.

For a consumer problem, they must decide whether to deposit with domestic commercial banks, consuming c_L in period 1 or c_H in period 2, or with foreign central banks, consuming c_L^* in period 1 or c_H^* in period 2. We define $d_i \in \{0,1\}$ as the decision of the consumer $i \in [0,1]$, where $d_i = 0$ means depositing into domestic commercial banks and $d_i = 1$ means depositing with the foreign central bank. Consumers will choose the contract that delivers the highest ex-ante expected utility. For simplicity, we assume that consumers can invest internationally but not borrow.

Consumers must strategically decide when to withdraw their deposit. We define a withdrawal strategy for the consumer i as the variable $w_i \in \{1,2\}$. Consumers will withdraw in periods 1 and 2 if $w_i = 1$ and 2, respectively. If the consumer was hit by the liquidity shock, one must have $w_i = 1$. That is, one must withdraw in period 1. Those who were not hit by the liquidity shock will have the option to withdraw early or late. Their strategic decision will depend on their belief regarding the actions of others, denoted as w_{-i}.

2.2. Domestic Commercial Banks

In the domestic economy, there are banks offering demand deposit contracts $(c_L, c_H) \in \mathbb{R}_+^2$. This means the bank will pay either c_L in period 1 or c_H in period 2 in return for one's endowment. These banks are assumed to be owned by consumers in the economy. This assumption allows us to interpret the total welfare of the consumers as the banks' profits, justifying the bank optimization problem. Note that if a bank cannot fulfill c_H in period 2, the rest of the bank's assets will be equally distributed to the rest of the consumers.

After obtaining consumers' endowment, each bank j then decides to invest a portion $y_j \in (0,1)$ in the liquid asset, giving a return of 1, and the rest of $1 - y_j$ in the illiquid asset. The optimal portion y_j comes from maximizing the expected utility of consumers in the economy. In a symmetric equilibrium, all N banks behave similarly. Therefore, total liquidity holding y will be equal to $\sum_{j=1}^{N} y_j = yN$. The optimization problem can be written as follows

$$\max_{\mathrm{y_j}, c_L, c_H} V = \lambda u(c_L) + (1-\lambda)u(c_H) \tag{1}$$

subject to:

$$0 \leq y_j \leq 1 \tag{2}$$

$$\lambda c_L \leq y_j + (1-y_j)l \tag{3}$$

$$(1-\lambda)c_H \leq R(1-l)(1-y_j) + y_j + (1-y_j)l - \lambda c_j \tag{4}$$

$$c_L \leq c_H \tag{5}$$

$$\lambda(1-y)l = (1-\lambda)y \tag{6}$$

Equation (3) is the feasibility constraint in period 1. The total of consumption goods required to fulfill the obligation in period 1 must not exceed the return of the liquid asset and the total liquidation of the illiquid asset. Equation (4) is the feasibility constraint in period 2. The total asset required to fulfill the obligation in period 2 must not exceed the total return from the non-liquidated illiquid asset and the leftover from period 1 (if any).

Equation (5) is the incentive-compatibility constraint for those who did not face a liquidity shock. In other words, no late consumers will pretend to be early consumers. To achieve this, c_H must be greater than c_L, making the consumption in period 1 inferior to the consumption in period 2. Following Eisenbach and Phelan (2022), Equation (6) is the cash-in-the-market constraint and determines the liquidation price, l, in the interim period. The left-hand side is the total value of illiquid assets supplied by sellers. The right-hand side is the total value of liquid assets buyers used to buy illiquid assets. We define $c_L = y_j + (1 - y_j)l$, consisting of the initial investment in the liquid asset (or can be thought of as cash holding) and the total CBDC that one can raise from fire-selling in period 1. We also define $c_H = y_j \frac{R}{l} + (1 - y_j)R$ as the total return from the initial investment in an illiquid asset and the total net return from an illiquid asset bought in period 1 at price l. Note that $l \leq R$ in equilibrium, since no one would want to pay more than R to receive the illiquid asset.

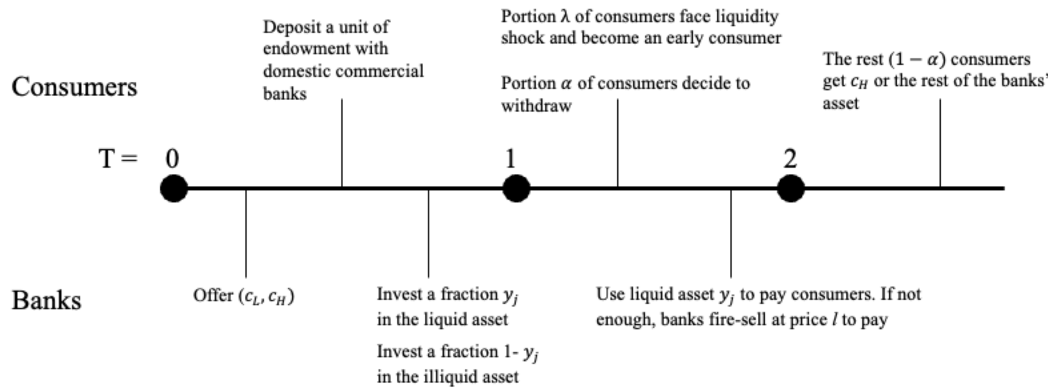
2.3 Foreign CBDC-issuing Central Banks

We now introduce the foreign CBDC-issuing central bank based on the aforementioned CBDC design. Assume that consumers can directly invest in foreign CBDC contracts. We intend to study how foreign-remunerated CBDC will affect the decisions of the Cournot agents in terms of how they exercise their market power. As in Popescu (2022), we assume the foreign central bank to be perfectly credible, open to foreigners, and independent in terms of conducting monetary policies.

3. Domestic Economy Without Foreign CBDC

We consider the first scenario with a closed economy without foreign CBDC. The purpose of this section is to provide the implication of the market power of the domestic banks to the economy. Without foreign CBDC, consumers are assumed to deposit their endowment with domestic commercial banks in the initial period. The timeline of this scenario is illustrated in Figure 2.

Figure 2. Timeline of the domestic economy without foreign CBDC



In period 0, domestic banks offer (c_L, c_H) and consumers deposit a unit of endowment with the domestic banks. Then, the domestic banks choose a portion y_j to invest in the liquid asset based on the perceived probability of a liquidity shock, λ. Next, in period 1, a portion $\alpha \in (0,1)$ of consumers will choose to withdraw from the banks. These consumers become early consumers regardless of whether they face liquidity shock or not. To pay these consumers, the banks must use their liquid assets. If the liquid assets were not enough, banks must fire-sell some of the illiquid assets to fulfill their obligations. In period 2, the late consumers will get c_H or the rest of the banks' assets.

There are three scenarios of the banking landscape considered. The first one is the Walrasian case, where the number of banks approaches infinity, illustrating a perfect competitive banking market structure. Thus, every bank does not account for the effect of selling or buying an illiquid asset and behaves as a price-taker. Secondly, the social planner averages the price effect over all agents as both buyers and sellers, achieving the first best allocation of liquidity holding. Lastly, the Cournot equilibrium considers an economy in which banks only take a "partial" price effect as buyers or sellers. That is, the Cournot agent only considers the effect of holding more liquidity when buying (state *H*) or the effect of holding less illiquid assets when selling (state *L*) based on the perceived probability of liquidity shock λ.

3.1 Walrasian Equilibrium

Consider a perfectly competitive market in the banking industry. Definition 1 displays the Walrasian case with all the banks as price-taker. Hence, they will take *l* as exogenous.

Definition 1 (Walrasian equilibrium without foreign CBDC): An equilibrium consists of a demand deposit contract (c_L, c_H) from the domestic commercial bank, a strategy profile $w_i \in \{1,2\}$ for the withdrawal game in period 1, a fraction $\alpha \in [0,1]$ of depositors who withdraw in period 1, and the liquidation price of the illiquid asset, such that:

1. The strategy profile $w_i \in \{1,2\}$ represents a Nash equilibrium of the withdrawal game in period 1.

2. Each commercial bank offers (c_L, c_H) such that it maximizes profit in period 2.

3. Withdrawal game in period 1 satisfies $\alpha = 1 - \int_{\{i \in [0,1], w_i = 2\}} d_i$

4. The liquidation price l satisfies cash-in-the-market assumption, i.e., $\mathrm{\lambda(2N)l(1 - y_j) = (1 - \lambda)2Ny_j}$

Banks will find the optimal liquidity holding by taking the first-order necessary condition with respect to y_j. We get

$$(1 - l)\left[\lambda u'(c_L) + (1 - \lambda)\frac{1}{l}\beta R\, u'(c_H)\right] = 0$$

From cash-in-the-market assumption, the illiquid asset price thus satisfies $\lambda(2N)l(1-y_j) = (1-\lambda)2Ny_j$ or

$$l = \frac{(1-\lambda)}{\lambda}\frac{y_j}{1-y_j}$$

The first-order necessary condition implies that $l = 1$ in equilibrium as $[\lambda u'(c_L) + \frac{(1-\lambda)1}{l}\beta R u'(c_H)]$ is positive. If $l < 1$, the illiquid assets are traded below cost. Sellers would not want to sell them. On the other hand, $l > 1$ is not possible due to the no-arbitrage condition. Therefore, we get $y = \lambda$. By substituting the asset price into the Walrasian first-order necessary condition, $c_L = 1$ and $c_H = R$. This is consistent with the standard Diamond and Dybvig (1983) model without a bank. They find that $u'(1)$ is greater than $\beta R u'(R)$, which means the banks hold too little liquidity in the initial period, causing inefficiency. That is, banks can choose to hold more liquidity and offer higher c_L to achieve optimal risk sharing.

The inefficiency arises from the fact that in a perfect competition setting, agents who take prices as given do not consider how their decision to hold liquidity may impact prices following shocks, resulting in a pecuniary externality. Inadequate liquidity will cause a decline in the value of the illiquid asset during period 1, resulting in a reduction in the overall welfare of the economy.

3.2 Social Planner

Definition 2 shows the social planner problem. The difference between Walrasian and social planner problems is that the social planner takes into account the change in price, that is, $l = \frac{(1-\lambda)}{\lambda}\frac{y_j}{1-y_j}$, following Eisenbach and Phelan (2022).

Definition 2 (Social Planner equilibrium without foreign CBDC): The planner's problem is to maximize the ex-ante utility of consumers, Equation (1), and account for the effect of holding liquid assets on the liquidation price by choosing liquidity holding y_j. Thus, an equilibrium consists of a demand deposit contract (c_L, c_H) from the domestic commercial bank, a strategy profile $w_i \in \{1,2\}$ or the withdrawal game in period 1, a fraction $\alpha \in (0,1)$ of depositors who withdraw in period 1, and the liquidation price of the illiquid asset l, such that:

1. The strategy profile $w_i \in \{1,2\}$ represents a Nash equilibrium of the withdrawal game in period 1.

2. Each commercial bank offers (c_L, c_H), such that it maximizes profit in period 2.

3. Withdrawal game in period 1 satisfies $\alpha = 1 - \int_{\{i\in[0,1],w_i=2\}} d_i$

4. The liquidation price l satisfies cash-in-the-market assumption, i.e., $\lambda(2\mathrm{N})\mathrm{l}(1-\mathrm{y_j}) = (1-\lambda)2\mathrm{Ny_j}$

When solving for an optimal allocation, social planner considers the effect of liquidity holding on the price of an illiquid asset:

$$\frac{\partial L}{\partial y_j} + \frac{\partial L}{\partial l}\frac{\partial l}{\partial y_j} = 0$$

We obtain:

$$(1-l)\left[\lambda u'(c_L) + (1-\lambda)\frac{1}{l}\beta R\, u'(c_H)\right] + \underbrace{\lambda(1-y)\left[u'(c_L) + \frac{1}{l}\beta R\, u'(c_H)\right]\frac{\partial l}{\partial y}}_{\text{Social Planner's Choice}} = 0$$

The social planner takes into account that *l* is increasing in *y*:

$$\frac{\partial l}{\partial y_j} = \frac{1-\lambda}{\left(1-y_j\right)^2\lambda}$$

The social planner will choose higher liquidity holding than the Walrasian equilibrium if the Walrasian one yields $u'(c_L) > \beta R u'(c_H)$, leaving room for more y and c_L. This is true from the standard condition of the Diamond and Dybvig (1983) model as a result of $\beta \leq 1$ and a relative risk aversion greater than 1. Substituting $\frac{\partial l}{\partial y_j}$ in the first-order necessary condition yields the optimal risk-sharing condition as follows:

$$u'(c_L) = \beta R u'(c_H)$$

3.3 Cournot Banks

Cournot banks have a certain degree of market power and can manipulate liquidity and price. Their decisions in buying or selling assets will result in a price effect internalization. Definition 3 gives an overview of Cournot choices and constraints.

Definition 3 (Cournot equilibrium without foreign CBDC): Cournot banks choose optimal liquidity holding $\mathrm{y_j}$ by maximizing Equation (1) and internalizing the price effect of assets as buyers and sellers. Thus, an equilibrium consists of a demand deposit contract (c_L, c_H) from the domestic Cournot bank, a strategy profile $w_i \in \{1,2\}$ or the withdrawal game in period 1, a fraction $\alpha \in (0,1)$ of depositors who withdraw in period 1, and the liquidation price of the illiquid asset l, such that:

1. The strategy profile $w_i \in \{1,2\}$ represents a Nash equilibrium of the withdrawal game in period 1.

2. Each commercial bank offers (c_L, c_H), such that it maximizes profit in period 2.

3. Withdrawal game in period 1 satisfies $\alpha = 1 - \int_{\{i \in [0,1], w_i = 2\}} d_i$

4. The liquidation price l satisfies cash-in-the-market assumption, i.e., $\lambda(2N)l(1-y_j) = (1-\lambda)2Ny_j$

The Cournot agent accounts for the effect of their liquidity choice, adding one more term to the first-order necessary condition:

$$\frac{\partial L}{\partial y_j} + \frac{\partial L}{\partial l_L}\frac{\partial l_L}{\partial y_j} + \frac{\partial L}{\partial l_H}\frac{\partial l_H}{\partial y_j} = 0$$

We obtain the following first-order necessary condition:

$$(1-l)\left[\lambda u'(c_L) + (1-\lambda)\frac{1}{l}\beta R\, u'(c_H)\right] + \underbrace{\lambda(1-y_j)\left[\frac{\partial l_L}{\partial y_j}u'(c_L) + \frac{\partial l_H}{\partial y_j}\frac{1}{l}\beta R\, u'(c_H)\right]}_{\text{Cournots' Effect}} = 0$$

Unlike the social planner, the Cournot agent takes only a "partial" price effect based on the perceived chance of liquidity hit, λ. Higher λ means more chance of liquidating in period 1. The Cournot agent must give more weight to the case when they were a seller (state L), maximizing the total assets the bank can raise from liquidation. Vice versa, the buyer case maximizes the total amount of illiquid assets one can buy. Buyers have the incentive to buy the illiquid asset in the interim period at a price less than R because the buyers can benefit from the return in period 2. Hence, buyers will consider the effect of holding more liquidity when buying ($\frac{\partial l_H}{\partial y_j}$) and sellers will consider the effect of holding less illiquid assets when selling ($\frac{\partial l_L}{\partial y_j}$). With 2N banks, we have:

$$\frac{\partial l_L}{\partial y_j} = \frac{1}{N}\frac{(1-\lambda)y_j}{\lambda^2(1-y_j)^2} \text{ and } \frac{\partial l_H}{\partial y_j} = \frac{1}{N}\frac{1}{\lambda^2(1-y_j)}$$

Substituting $\frac{\partial l_L}{\partial y_j}$ and $\frac{\partial l_H}{\partial y_j}$ into the first-necessary condition gives:

$$\lambda u'(c_L) - (1-\lambda)\beta R\, u'(c_H) = \left(\lambda - \frac{1}{N}\right) l\, u'(c_L) - \left(1 - \lambda - \frac{1}{2N}\right)\frac{1}{l}\beta R u'(c_H)$$

4. Result

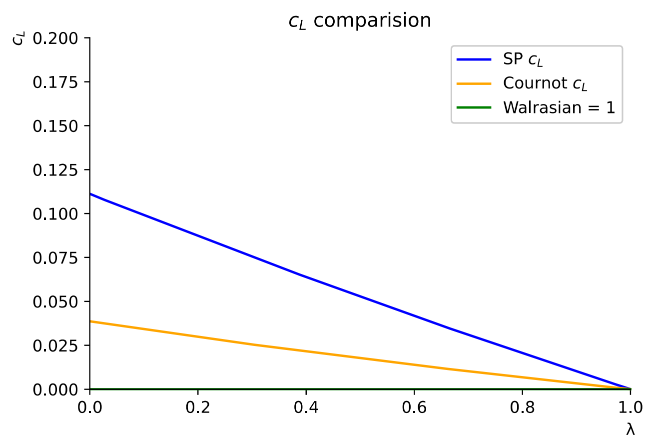
4.1 Welfare Comparison Without Foreign CBDC

From the first-order necessary conditions of the social planner and Cournot banks, we assume parameters and functional forms that satisfy the assumptions of the model. We can obtain the optimal y_j for each bank. Then, we substitute the optimal liquidity holding y_j to the functional form of c_L and c_H. The contract offered by each scenario is presented in Figures 3 and 4.

Figure 3 represents c_L chosen by the social planner and the Cournot bank. The Cournot agent would offer less c_L than the social planner for all levels of probability of liquidity shock, $\lambda \in (0,1)$, but both provide higher c_L than the Walrasian equilibrium. We can interpret this as when the Cournot banks have market power, they will give less than optimal interest rates to consumers as well as correct some inefficiencies in the market. The Walrasian equilibrium is not optimal because of the pecuniary externality, as price takers do not internalize the price effect in their actions. The Cournot banks, on the other hand, make the economy more efficient by partially internalizing their liquidity choices.

As Cournot agents offer less c_L, there will be more assets left for late consumers in the terminal period than the social planner, causing Cournot's c_H to be higher than the social planner (Figure 4). In terms of total welfare, the social planner is, however, the first and best choice since they can achieve the equivalence of intertemporal marginal utility. The total welfare of the economy under the social planner and Cournot agents is presented in Figure 5.

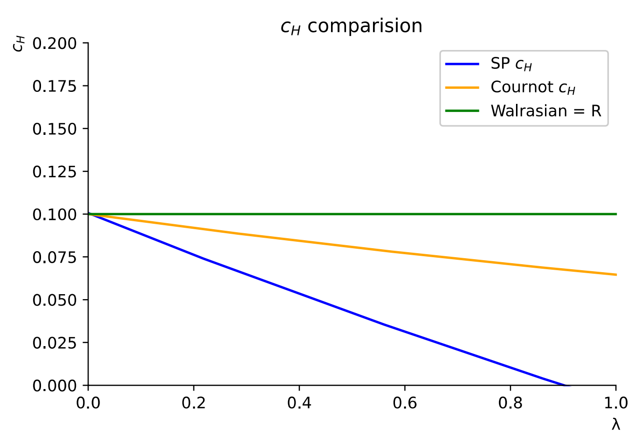
Figure 3. Comparison of consumption in state *L*



Source: Authors' computation.

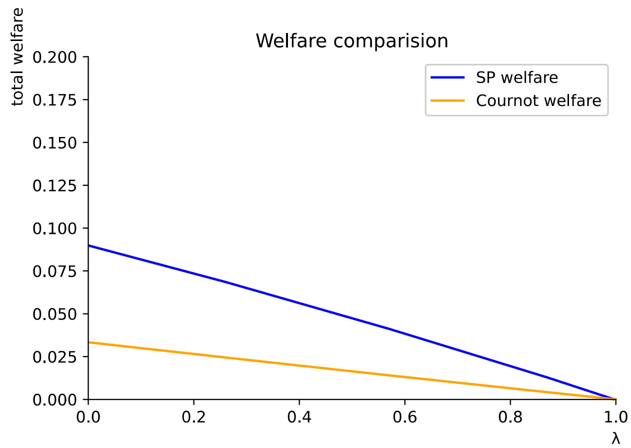
Note: Given $u(c) = 1 - \frac{1}{c}$, $\beta = 0.9, N = 2,$ and $R = 1.1$

Figure 4. Comparison of consumption in state *H*



Source: Authors' computation.

Figure 5. Total welfare in Social Planner and Cournot's cases



Source: Authors' computation.

4.2 Domestic Bank Run

The contract (c_L, c_H) is derived from the perceived λ as common knowledge. However, these banks are subjected to a self-fulfilling run, following Diamond and Dybvig (1983). The payoff in the contract is achieved if and only if every consumer behaves according to their type. Since the type of each consumer is private information, there is a possibility that a consumer will decide to withdraw even if he or she does not face liquidity shock. We define α as the actual portion of consumers deciding to withdraw. If $\alpha > \lambda$, consumers who were late consumers become early consumers.

When $\alpha > \lambda$, the commercial banks must liquidate some of the illiquid assets to finance their obligations in period 1. The sequence of the events is as follows: In period 1, consumers come to the banks to withdraw in random order. The commercial banks must satisfy sequential service constraint, meaning that the withdrawal will be a first-come-first-served service. If the banks were forced to liquidate too many illiquid assets, the liquidation price would be driven down. Fewer assets will be available for banks to fulfill their obligations. If banks cannot fully satisfy every consumer, that is, $\alpha c_L > y_j + (1 - y_j)l$, the expected payoff of consumers will be rationed by the number of consumers in the queue demanding to withdraw, or $\frac{y_j+(1-y_j)l}{\alpha c_L}$. If every consumer attempted to withdraw, banks would run out of resources and fail before period 2, implying that the payoff in period 2 is 0.

If the banks can still fulfill their obligations, no run happens. Those who withdraw will get paid c_L. Nonetheless, as banks liquidate some of the illiquid assets, net assets in the terminal period decrease. All the leftovers will be shared among late consumers. The late consumers will be paid $\frac{R(1-y_j)-(\alpha-\lambda)\frac{c_L}{l}}{1-\alpha}$. The payoff matrix can be written as follows:

Table 1. Payoffs of consumers in domestic economy

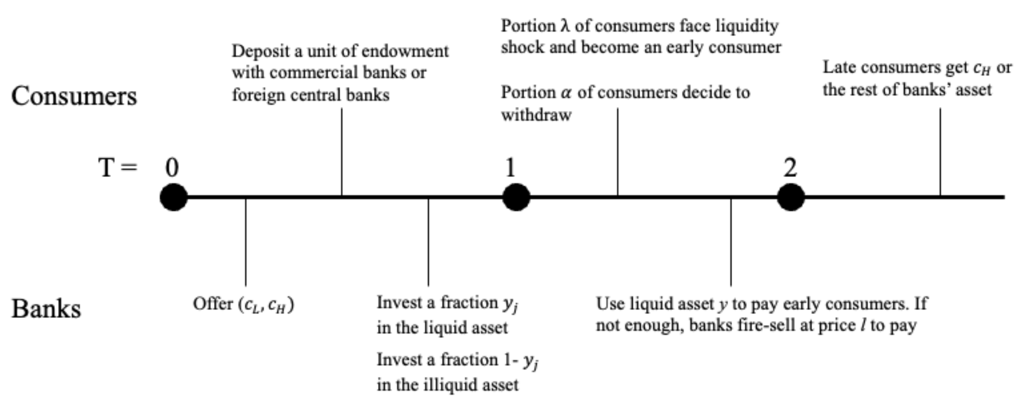
Event	Withdraw	Roll-over
No run	$u(c_L)$	$u\left(\frac{R(1-y_j)-(\alpha-\lambda)\frac{c_L}{l}}{1-\alpha}\right)$
Run: $\alpha \in (\lambda, 1)$	$\frac{y_j+(1-y_j)l}{\alpha c_L}u(c_L)$	0

From the payout structure, conditioning on the run, the payoff from withdrawing dominates the payoff from rolling over, and withdrawing is optimal. If there were no run, the payoff from rolling-over would be greater than withdrawing, and rolling-over is optimal since $c_L < c_H$.

4.3 Open Economy With Foreign CBDC

The second case is the open economy with a foreign CBDC. The purpose of this section is to provide the implication of remunerated cross-border CBDC to the market power of Cournot banks. With two demand deposit contracts to consider, consumers must choose the contract that delivers the highest ex-ante utility. We define $d_i \in \{0,1\}$ to represent the decision of the consumer $i \in [0,1]$, where $d_i = 0$ means depositing with the commercial banks and $d_i = 1$ means depositing with the foreign CBDC. If both contracts offer the same utility, then some fraction $f \in (0,1)$ will pick the foreign central bank, and the remaining fraction will pick the domestic commercial banks. The timeline with the presence of foreign CBDC is presented in Figure 6. We also assume the foreign CBDC to be a riskless contract (c_L^*, c_H^*). This is empirically reasonable from the fact that central banks can continue their operations even if in a state of negative equity without being forced into bankruptcy.

Figure 6. Timeline of the domestic economy with foreign CBDC



4.3.1 Cournot Banks With Foreign CBDC

We first investigate the effect of foreign CBDC on riskless contracts. Definition 4 provides the mechanism of the contract.

Definition 4 (Cournot equilibrium foreign CBDC): Cournot banks choose the optimal liquidity holding y_j by maximizing Equation (1) and internalizing the price effect as buyers and sellers. With a foreign central bank issuing CBDC, there are three more elements in the equilibrium: the foreign central bank deposit contract (c_L^*, c_H^*), consumers' deposit decision $d_i \in \{0,1\}$ in period 0, and a fraction $f \in [0,1]$ of consumers depositing in the foreign CBDC, a demand deposit contract (c_L, c_H) from the domestic commercial bank, a strategy profile $w_i \in \{1,2\}$ for the withdrawal game in period 1, a fraction $\alpha \in [0,1]$ of depositors who withdraw in period 1, and the liquidation price of the illiquid asset, such that:

1. In the initial period, given two deposit contracts: (c_L, c_H) and (c_L^*, c_H^*), each consumer i optimally decides where to deposit one's endowment so that the ex-ante utility is maximized. The total deposit in the foreign CBDC cannot exceed the capital account constraint k. That is, $f \leq k$.

2. The strategy profile $w_i \in \{1,2\}$ represents a Nash equilibrium of the withdrawal game in period 1.

3. Each commercial bank offers (c_L, c_H) such that it maximizes profit in period 2.

4. Withdrawal game in period 1 satisfies $\alpha = 1 - \int_{\{i \in [0,1], w_i = 2\}} d_i$

5. The liquidation price l satisfies cash-in-the-market assumption, i.e., $\lambda(2N)l(1 - y_j) = (1 - \lambda)2Ny_j$

6. The foreign CBDC deposits satisfy $\mathrm{f} = \int \mathrm{d_i di}$

From the "safe" feature[7] of the foreign CBDC, if the contracts offered by the foreign central bank were the same as one from the domestic commercial banks, then the foreign central bank would attract the deposit up to the capital account constraint k. The intuition is that consumers are subjected to the risk of a

[7] Both domestic and foreign CBDCs are safe. Nonetheless, in the equilibrium, domestic CBDC can be perceived as not safe due to it is inherently prone to cause bank runs.

run if they deposit with domestic commercial banks. Hence, the foreign central bank contract is less risky than one from domestic banks, formalized in Proposition 1:

Proposition 1: When consumers internalize the "safe" feature of the foreign CBDC, the foreign central bank can offer a contract with even lower payoffs than the domestic banks and still attract all the deposits up to capital account constraint k.

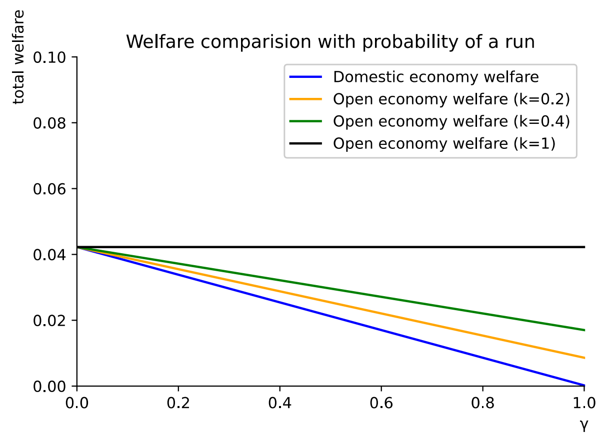
Proof: Define $u(c_L, c_H)$ *and* $u(c_L^*, c_H^*)$ as an ex-ante utility from domestic banks and the foreign central bank with the same payoffs. Since domestic banks are subject to a run, there exists some possibility $\gamma \in (0,1)$ that a consumer will not be paid. Thus, the expected total utility of a consumer is: $(1-\gamma)u(c_L, c_H) + \gamma \cdot 0 < u(c_L^*, c_H^*)$ by concavity of utility function. Since the utility function is strictly increasing, there exists some contract $(\tilde{c}_L, \tilde{c}_H) < (c_L^*, c_H^*)$, which makes $(1-\gamma)u(c_L, c_H) + \gamma \cdot 0 = u(\tilde{c}_L, \tilde{c}_H)$.

We argue that there is a possibility of capital flight due to the "safe" feature of the CBDC. Next, we will discuss the difference in welfare with and without the foreign CBDC in the presence of the probability of a bank run (γ). We found that consumers are better off in the presence of foreign CBDC because of its perfectly safe feature.

4.3.2 Welfare Improvement

We compute welfare of consumers in the economy under scenarios with and without cross-border investment. In Figure 7, we construct the ex-post welfare of the consumers in the Cournot case[8] with the presence of the foreign CBDC, using run probability γ, payoff from Table 1, and the capital constraint k. By plotting the total welfare against γ, we find that a higher probability of a run leads to lower total utility because consumers get a lower payoff in the case of a run. Note that the foreign central bank contract offering is assumed to be equal to the domestic bank contract offering.

Figure 7. Total Welfare with run probability (γ)



Source: Authors' computation.

If cross-border investment is not allowed, total welfare approaches zero when the domestic banks are prone to a run or γ is increasing. If, instead, the economy is open for capital flows, welfare is increasing in capital constraint k without a need for price effect internalization from Cournot banks. When more people can invest abroad, more consumers can secure run-proof and renumerated contracts with the foreign central bank. When the economy is fully open, or the capital constraint k is equal to 1, all consumers will deposit with the foreign central banks, and the total welfare will be constant since a contract from the foreign

[8] For Walrasian and social planner, the result will be the same if the foreign central bank can offer a contract with a similar payoff as the domestic banks.

CBDC is not subjected to a run. A complete financial disintermediation in the domestic economy is a consequence. This result accentuates the importance of capital control policy once any kind of CBDC is introduced. Furthermore, it also highlights the effect of CBDC implementation even though it was the foreign economy that issued the CBDC.

5. Conclusion

Cournot banks address the pecuniary externality by partially including the price impact of their liquidity decision. Consequently, the Cournot model can provide a demand deposit contract that is preferable to the one under perfect competition. But Cournot banks do not completely account for the price effect. As a result, the deposit contract is still considered to be inferior to the one designed by a social planner. This is consistent with the traditional view that some market power in the bank market is beneficial to the economy.

In the international context, we have found that the presence of safe and remunerated foreign CBDC leads to competition between the foreign central bank and domestic commercial banks. The foreign CBDC can lead to capital outflow and raise consumer welfare when capital constraint k is further liberalized with the risk of financial disintermediation. Worldwide cooperation in designing CBDCs is crucial to prevent the widespread implementation of capital control against countries that have secure and renumerated CBDCs.

There is room to explore in the open economy set-up version of financial stability. Incorporating an endogenous exchange rate and interest rate into the model is another aspect worth investigating since the capital outflow might cause the domestic currency to depreciate, allowing us to further study the interactions between domestic and international financial stability.

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