2023

The future of financial liquidity: CBDCs and Automated Market-Making

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AMM and decentralized liquidity pools are the subject of ongoing exploration by central banks. There is great interest in adapting the control mechanisms created by DeFi for CBDC liquidity management. We show that this is possible with some refinement and careful design, though important questions remain to be considered.

Table of Contents

The authors would like to thank all of the many people who contributed to this paper. In particular: Khai Pham, Austen Appleby, Yingying Zhang and Zolbayar Enkhbaatar.

Executive Summary

In a development that no one expected, the titans of financial stability—central banks—are looking to the wild west of decentralized finance (DeFi) to understand how to design control mechanisms for natively digital assets.

The issuance of central bank digital currencies (CBDC) will change the composition of the money supply. We expect that CBDC will act differently than existing forms of money that we use today—for example by having greater velocity and programmability. These differences open up an opportunity to consider additional methods of foreign exchange.

One such potential mechanism uses automated market makers (AMM). These are common in the DeFi ecosystem. AMM structures increase price transparency, work for low liquidity instruments, and bring the process of trading and settlement closer together. Such outcomes could benefit segments of today's foreign exchange market.

The question we explore here is whether this infrastructure applies beyond cryptocurrency? Specifically, CBDC is natively digital in the same way as cryptocurrency. We might expect that an infrastructure that performs efficiently for natively digital private money could at least have some lessons for natively digital public money. But it is not immediately clear how to adapt a concept born in decentralized finance for a central bank-issued currency.

We are not the first to ask this question. In 2021, Singapore and France experimented with the concept of AMM in their project on **Liquidity management in a multi-tenancy corridor network**. In 2022, **Project Dunbar** participants listed AMM as one of the four potential FX models under consideration for testing.[1] And finally, in 2022, **Project Mariana** was initiated by MAS, Banque de France, Swiss National Bank, and BIS innovation hubs in Switzerland, Singapore and the Eurosystem. This project directly investigates AMM for cross-border payments.

Both AMM and CBDC are novel concepts. Aside from the projects mentioned above however, they have been explored and developed separately. Our contribution to this nascent field is to consider how a decentralized exchange might be adapted for use in regulated financial markets.

We focus in particular on spot foreign exchange (FX) transactions, which are the purchase/sale of one currency against another with delivery typically two business days after the trade date. This focus highlights our belief that AMM can be an interesting additional tool within the diverse set of liquidity marketplaces and ways of transacting that already exist.

Adaptation of this structure for spot FX will need to answer questions including: who would run it, what formula might be appropriate for larger transactions, and how to incentivize participants. We consider all of these below.

1 Members include Singapore, Malaysia, Australia, and South Africa

1 Why fix what's not broken

Digital currencies may allow us to rewrite how FX markets work, but they don't require it. There is no technical reason that CBDC holders could not simply use existing FX spot markets that engage traditional market makers and the order book function. Overall, these are highly efficient markets that could easily incorporate CBDC.

If existing markets work, why spend effort examining alternative structures for liquidity management?

In this section, we discuss three reasons why there is value in considering an additional method for spot FX. Beyond justifications, there is also the fact that the AMM structure has been in operation since 2018, which gives us four years of experience in seeing what works and what does not. AMM has both positive and negative attributes for the use case we look at here. It has been a successful exchange mechanism on public blockchains where liquidity can be challenging, though it functions particularly poorly in times of market dislocation.

1.1 Three reasons to examine alternative structures for liquidity management

The first reason we explore AMM is because FX markets can be inefficient for some types of illiquid currency pairs. Today, FX and liquidity are traded in fragmented markets such as bilateral over the counter transactions (OTCs). Trades require both a buyer and a seller and a way to match them in order to release liquidity. While the markets for highly traded currencies like Japanese Yen and Mexican Pesos are deeply liquid; others, say Fijian Dollars and Ghanaian Cedi, can take much longer to resolve, leading to arbitrage and inconsistent cross-currency rates. The length of time is often related to the need to undertake a bilateral Request For Quotation (RFQ) process where a bank asks partners for bids.

While low-volume currency pairs may be of secondary importance, they are also changing quickly. Today, volumes in Indian Rupee and Chinese Yuan are growing quickly for example.

A second reason to explore new market structures is that there is value for the industry in bringing settlement closer to trading. This is specifically related to the type of market structure we explore in this paper, which effectively collapses these two steps into a single step. Tokens staked to the pool are a form of prefunding, allowing orders to settle immediately on the ledger. This would reduce the cost of settlement, position risk management, and the complexity of the process by freeing up liquidity. Together these would lower the regulatory burden on banks as they can settle closer to the agreed trade time. There is precedent for this type of compression of settlement times. In 2022, **DTCC's Project Ion** platform outlined the value of the acceleration of settlement times. Such value to participants would also accrue in the FX case we explore here.

Related to this second reason is the fact that even as the trading side of spot trading is highly efficient, the settlement side has two sticky problems. The first is that participants need to wait during the two-day settlement period. The second is that settlement relies on either the fee-based correspondent banking network or platforms like CLS which only trade in a small number of currencies and during limited hours.

A third reason to explore new market structures is to take advantage of the opportunity to investigate a new technology. Using traditional markets for CBDC ignores the innovations offered by blockchain. Since CBDC is re-wiring the financial system, why not consider a novel FX mechanism to go alongside that? We believe there are benefits to researching new methods where new technologies provide us the opportunity. This paper is part of that effort.

All three of these justifications do not point us to any specific model. The reason that we are looking into AMM in particular is because it has a history of solving the same issues we expect to find with some CBDC transactions.

1.2 From centralized to decentralized exchanges

Early cryptocurrency markets had to solve the same problem that may be coming to CBDC. As the market size and value of bitcoin grew, there was a lot of liquidity floating around. However the lack of infrastructure to match buyers and sellers meant that It wasn't easy for holders to find each other.

The original solution was centralized exchanges. Exchanges like Kraken or Coinbase commit to buy or sell as much cryptocurrency as you want to move. The exchange plays the role of the market maker, which is common in securities markets today. But the centralized exchanges have two problems. They introduce centralization back into cryptocurrency, which goes against one of the core tenets of its creators. And it makes the exchanges attractive targets for hackers.

Decentralized exchanges have solved these problems in a neat way.

They enable the exchange of cryptocurrencies without a market maker. They replaced the traditional control systems that use individual market makers with an equation (pricing methodology) and smart contracts (for currency matching). The result is self-administering liquidity pools that use automated market making (AMM) to control liquidity.

AMM today is used exclusively in the DeFi ecosystem. It allows the automated creation of liquidity and token exchange. It is more than just automating the function of market markers. It is a pricing protocol that evolved from the intersection of traditional market making and blockchain technology.

The idea appears to have been introduced in 2017 under the description of an "on-chain market maker" by Vitalik Buterin. [2] Uniswap was launched a year later. Decentralized exchanges began to grow in volume once Uniswap paired tokens with ethereum, which was popular enough to attract bigger volumes to the platform.

AMM differs from today's market making structures in three dimensions. These are covered in detail in Table 1 and include: the markets in which they operate, the market makers, and the sources of liquidity.

Table 1: Feature comparison of centralized exchanges vs DEX vs traditional exchanges

	Traditional FX trading	**Crypto exchanges** (centralized)	**Decentralized Exchanges** (DEX)
Examples	NASDAQ, HKSE	Coinbase, Kraken	Uniswap, Curve, Balancer
Assets traded	Securities, derivatives, currency	Crypto, stablecoins	Crypto, stablecoins
How prices are set	Market makers (large institutions)	Market maker (the exchange)	Formula based*
Source of liquidity	Market makers (large institutions)	Market maker (the exchange)	Individual or institutional users
How participants are matched	RFQ, Order book	Order book	AMM (one sided: user interacts with liquidity pool directly)
How liquidity is generated	Incentivising participation of market makers	In-house market makers	Staking rewards

NOTES: *One example is the formula used by Uniswap: x * y = k. The issues around formula choice are treated in Section 3.1 of this paper

An interesting feature of Table 1 is that decentralized exchanges are not simply an iteration of centralized exchanges. Rather, they evolve elements from both traditional markets and centralized exchanges to present a wholly novel way of buying and selling.

2 In an interesting feature, he discusses ways to increase social welfare, which is precisely what central banks would presumably be interested in. https://vitalik.eth.limo/general/2022/12/05/excited.html

2 An alternative way to make a market

The novelty of AMMs is in their execution, not in their function.

In function, they are a near replication of the tasks that have been executed by market makers for decades. One parallel example is from securities markets, where since at least 1987, when the US Securities and Exchange Commission (SEC) required that market makers buy a certain amount of stock from small investors when those investors want to sell. AMM is an alternative way to create a price (vs an orderbook [3]).

In execution, they don't just automate the instructions to buy or sell, but maintain the liquidity rate of the pool at a particular level. This unique function uses the smart contract functionality of centralized crypto markets in a mathematically unique way. They can also operate 24/7.

2.1 Providing liquidity (replace the market maker)

A market maker is a firm that participates in financial market exchanges (specifically, listed instrument exchanges like equities, options and futures). Often, they're banks or brokerage firms or high frequency trading firms and are **FINRA**-registered. Their role is to always be ready to buy or sell securities.

Exchanges like NASDAQ or NYSE could not function without market makers to ensure that someone is always willing to trade even when prices are crashing or soaring. This is also why market makers are often **incentivized** for their services in the **maker-taker model**.

The market making function has digitized over time. For example, foreign exchange markets already use **execution algorithms** (EAs). This has had the benefit of increasing liquidity in the market as it speeds up trading. Yet even EAs use a two-step structure. Trading spot FX is nearly automatic for some currency pairs. But settling FX still often takes 2 days (T+2).

AMM does more than just speed up trading, it collapses two functions: matching of orders and execution of trades. To do this, the role of the market maker can be split into two functions—entities which stake into the liquidity pool, and the algorithm that creates the price. No reconciliation is needed. This could represent a significant change in middle and back office efficiency.

Bringing these two functions together could also address complexity in the spot FX markets today. There are many different mechanisms used for transactions due to the varying depth of liquidity among currency pairs and the relationship trading partners have with each other, which determines capital requirements.

The AMM adjustment to market making will not require disintermediation of market makers. This is for several reasons. First, liquidity providers will still be required to stake into the pool. While the types of entities that provide liquidity may expand, their existence remains necessary. Second, it is unlikely that banks will want or be allowed to enter a market that is only run by an algorithm. While the market maker function could be automated, there is still an entity that will provide a custodial role and which is accountable to operate the liquidity facility. We return to the question of what entity should run the AMM in Section 3.2.

3 An order book is used by CEX to match buy and sell orders together

2.2 Counterparty matching (replace the central limit order book structure)

This brings us to the second feature of traditional market making that evolves under an AMM's structure—use of an order book to match counterparties. Both crypto exchanges and traditional markets use a **matching engine** that operates on a limit order book to match bids with asks.

The part of the process that changes in a decentralized world is the limit order book, not the **matching engine**. The matching engine in either case is an algorithm that can use a variety of attributes for matching (these can include first-in first-out, price-time priority etc).

Central Limit Order Book (CLOB) may not work for some currency pairs, with low liquidity, which is our concern here.[4] The result is often that parties revert to a bilateral trade rather than use the CLOB. This situation reduces visibility into market price discovery. It's difficult to get efficient execution when prices are unclear. This leads to problems like:

- Slippage, which occurs when insufficent liquidity exists at a given price. Slippage is lower when liquidity is higher.
- Lack of clarity about whether traders have achieved the best execution for their clients across a market.

Even if we wanted to replicate this existing structure, it cannot be efficiently architected using smart contracts and decentralization.

AMM has two benefits in this situation. First, it does not require a central limit order book because it does not match peer-to-peer, instead the buyer or seller interacts with the liquidity pool directly. The second is that it allows all that fragmented liquidity in the market from bilateral trades to be put into a single pool. This reduces the difficulty of finding multiple counterparties.

A potential third benefit comes from the fact that the pool is the counterparty which reduces settlement risk. Though this has the additional challenge that the pool must then assume liability. In a pool, each contributor assumes a proportional market risk, which is an uncommon set up in the non-AMM market. In this case, pricing of the AMM for pool contributors will be a critical consideration.

4 Anonymous CLOB is also a problem for some high liquidity pairs where exposure during settlement is large and so counterparty risk is a driving concern.

3 Configuring AMM for CBDC

If we look at AMM in action today, it is used for very specific activities that are not in line with the types of transactions we might expect a central bank to make. There are many adjustments that could be made to make this more suitable for the CBDC use case.

In this section we cover three ways that AMM would need to be configured to suit CBDC. These include which formula could be used, who should run the AMM, and how to incentivise participation.

3.1 Choosing an AMM formula

We begin by discussing the technical features of the AMM formula. This is complex, but critical starting point because the formula is central to the concept of AMM. The pool in an AMM is a smart contract which is operated by users calling functions on it. This means that the formula used by the pool to balance funds is key to the functioning of the bilateral FX market.

In our discussion here, we assume that the pool will be operating as a two-token pool. There are also examples of multi-token pools, which may be of interest to central banks.

There are three known formulas in use for AMM. These include: a constant product function, a constant sum function, and a hybrid function, which is a combination of the first two. Each formula has pros and cons, though over time the ecosystem has developed some mitigants that could be considered for the CBDC case as well. Table 3 summarizes the main formulas.

Table 2: Summary of AMM functions

	Constant Product Market Makers (CPMM)	Constant Sum Market Makers (CSMM)	Hybrid Function Market Makers (HFMM)
Formulas	X*Y = K	X+Y = K	Various combinations of CPMM & CSMM possible
Price	Price determined by the supply & demand in the liquidity pool	Price is stable and equal to 1:1 face value	Price is the derivative of the function
Price slippage	High price slippage	Zero price slippage	Low price slippage
Known problems	• Large trade exacerbate slippage • Require significant amount of liquidity to avoid slippage • Hard to scale	• Corner equilibrium—possibility of token drained out • Suffer from arbitrage activity	• Less suitable for volatile tokens
Liquidity performance	Infinite Liquidity	Finite Liquidity	Provide some liquidity like CPMM

SOURCE: Automated market makers and decentralized exchanges: a DeFi primer

The constant product function (CPMM) is the most common formula today and is based on the model:

x * y = k

x= quantity of one token in the bilateral set
y = quantity of the other token in the bilateral set
k = constant value

Using this formula, the liquidity in the pool always remains the same. k is a measure of the liquidity in the pool.

Prices are determined by the supply of tokens in the pool. That is, there are a range of prices either token can take depending on its supply. When the supply of token x increases, the supply of token y decreases to maintain the constant value k. As the quantity of token y falls, its price will increase.

CPMM is the basic AMM mechanism powering the majority of decentralized crypto trading. Decentralized Financial Exchanges (DEX) such as Uniswap, Pancakeswap, and Sushiswap employ this function to offer infinite liquidity.

This formula is not suitable for a central bank use case without adjustment. The mBridge project called out the problems associated with the constant product formula. Specifically that it is retail-focused and thus optimized for low-valued transactions. Large transactions tend to suffer from volatility and high price slippage due to the nature of this function.

A second common function is the constant sum function (CSMM). It is based on:

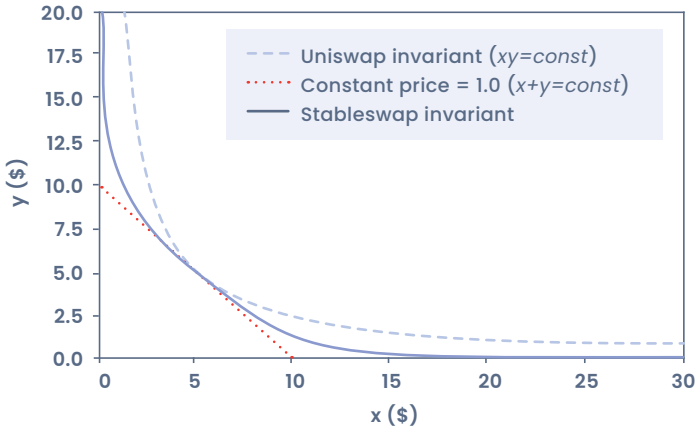
x + y = k

The price is constant (equal to 1:1 face value), and tokens trade on a one-to-one basis. Under this pricing formula, the price ratio of one asset in relation to another is always one. This model makes sense for stablecoins for example, since they should in theory, always trade at a one-to-one rate.

This model differs from the constant product in the way that it provides zero slippage since the tokens can be traded at a stable relative price. Yet, it provides a finite liquidity pool, which means that arbitrage activity can entirely drain the liquidity pool of one token. That means that if, for example, the external market price changes, arbitrageurs can take advantage of the price differential in two markets and drain pool reserves out (resulting in a corner equilibrium). Thus, this formula is not widely adopted in DeFi and also not suitable without adjustment for the CBDC case.

The third function is the hybrid function (HFMM). This uses a combination of features from both constant product and constant price functions. This model allows investors to trade assets at lower price slippage while maintaining liquidity for transactions. For instance, **Curve** AMMs (stableswap invariant) employ this function to provide low-price-impact swaps between tokens and maintain relatively stable at a one-to-one exchange rate. The HFMM adjusts risk exposure for liquidity, offers less penalty for large transactions, and has low price slippage.

Figure 1: Comparison of curves used for constant product, constant price and hybrid (stableswap)



SOURCE: Egorov, 2019

A visual comparison makes it clear how the hybrid function fits in with the constant product and constant price formulas. In Figure 1, the stableswap invariant curve (hybrid model) is flat in the middle where liquidity is deep (similar to CSMM which is completely flat to maintain a fixed exchange rate) and curves (similar to CPMM) at other points of value where there is some imbalance. This allows the price to remain stable in the middle of the curve while maintaining liquidity at the limits. This is one, but not the only, way to combine CPMM and CSMM.

The outstanding question with HFMM design is whether the liquidity provider makes active or passive decisions about liquidity provisioning. Curve v2 gives the liquidity providers a passive role with dynamic fees. That is, the algorithm redefines the curve at different points of liquidity in the pool. The alternative Uniswap v3, gives liquidity providers the ability to decide the range to which they will contribute.

Box 1: Mitigants of formula problems: concentrated liquidity

Liquidity pools in the DeFi ecosystem continue to suffer from high price slippage and impermanent loss risk. This means that any application will either require a wholly new formula, or mitigating measures for future usage. All CBDC projects have raised these issues during their AMM research.

There are some deployments that have addressed these issues, one is concentrated liquidity. The introduction of concentrated liquidity aims to address the deficiency in the CPMM formula by allocating the liquidity to a price interval (Uniswap v3), or adding dynamic fees for the liquidity provider (Curve v2).

The method of concentrated liquidity was introduced by **Uniswap v3**. The defining idea of this concept is that liquidity is allocated within a price range. This differs from CPMM platforms (such as Uniswap v2) where liquidity is distributed uniformly over the price range from 0 to infinity ('infinite price range liquidity provision'). In Uniswap v3, capital is concentrated within the range where most of the trading activity occurs as a way to boost the capital efficiency. This allows liquidity providers to achieve considerably higher returns (relative to the other approaches) across a tight range for token pairs.

This measure may contribute insights into the currency band used by central banks or governments. A currency band allows the currency to flow between a specified range of prices, which share a similar approach with **concentrated liquidity**. For instance, China has a controlled currency policy that only allows the Chinese Yuan (CNY) to move up or down +/-2%. And, the concentrated liquidity might be interesting for the foreign exchange market as well since evidence suggests it's more appropriate for stablecoins.

For a detailed description of the impact of introducing concentrated liquidity, see **Mohan, 2021**.

3.2 Who will run the AMM?

All of the decentralized exchanges (DEXs) in existence today were initially set up and run by the private sector. More specifically, startups. Because of their venture capital status, jurisdictional oversight is light. As an example, the Uniswap protocol was originally started by a 23 year-old mechanical engineer and is now governed by those who own the governance tokens (UNI) issued by the protocol, 21.5% of which are owned by VC-funded Uniswap (the company), which is located in Brooklyn NY.

Since CBDCs will be issued by central banks, we assume that they will prefer to run them on permissioned networks which they manage. Permissioned networks have a governance structure in place, specifically one which requires a business network operator. Were these to be used to build the AMM for CBDCs, some formal entity would play this role. This leads us to ask the question of what entities should run AMMs?

When we ask who will run the AMM, there are two potential functions: governance and liquidity provision. Both are required for this mechanism to function, and both may be provided by different entities.

For a CBDC exchange with AMM functions, we explore four potential operator types, both public and private. The operators we explore include: existing exchange groups, investment banks, central banks, and other actors.

Desirable characteristics of a CBDC AMM operator might include: a history of resilience, auditability, and trusted partnership with participating central banks. The last characteristic is particularly important. For any systemically important currency pair, the operator must be recognized and trusted by both central banks. We do not consider specific country cases where, for example, the currency may not trade outside of the country as with the Indian rupee. Country pairs in this case will have separate requirements for an AMM operator.

These characteristics limit what types of entities are competitive options. Importantly though, we expect that the desirable characteristics of a CBDC AMM exchange operator may change over time. Once there is a history of running an AMM, it is conceivable that the universe of acceptable entities could expand.

We explore the pros and cons of each of these options for the running of bilateral pools in full shortly.[5]

3.2.1. Existing exchange groups

For our use case of an exchange using AMM for FX for immediate delivery in CBDC-to-CBDC transactions, we believe that the most likely candidates are existing trading exchanges. Examples of this category include big exchanges like LSEG, NYSE, SGX, CME Group, or the Japan Stock Exchange.

We expect that this category of operator will provide governance but would not participate as a liquidity provider.

The reason that existing exchange groups are a good fit is because they already have the operational and regulatory frameworks in place to run a trading venue. They also have an infrastructure advantage over many other candidates since they could leverage their existing connections to the commercial banking network. This infrastructure is already used and considered to be secure.

5 In this paper we only consider the case of bilateral pools. However there are other configurations as well. Project Mariana in particular has 3 bilateral pools that interact on a supra-regional network. In either case, we suggest that the operator would need to have a close working relationship with the central banks of each currency pair.

Another point in favor of an existing exchange group as the exchange operator is that Project Mariana specifically suggests that AMM protocols could form the basis of a **new generation of financial infrastructures**. Though in that case, they call out a supra-regional network as the hub.

There are drawbacks to using such well-established entities. They would need to be incentivised to set up entirely new exchanges without being able to accurately estimate the potential returns since variables like the velocity and uptake of CBDCs is not yet known. They may also be reluctant to move into a new area given that their existing business model is lucrative in today's financial system. There is also market risk in participating in both fiat and CBDC foreign exchange markets since the degree and cost of fungibility between them is unknown.

A final drawback of this option is that many—though not all—exchanges are deeply rooted to their domestic jurisdiction and so would not begin with the trust of both central banks in a bilateral AMM. Euroclear is one example of a multi-jurisdictional exchange, illustrating that there are some exchanges that might be a more natural fit in the early days of an AMM.

If existing trading venue operators to take on this role, they would need to build a number of new pieces onto their already extensive infrastructure. This includes things like setting up new exchanges that are separate from existing exchanges, creating new operational controls and rules around CBDC trading.

Since we're discussing existing trading venue operators, it is also conceivable that existing AMM operators in the DeFi space could operate a CBDC AMM, given their deep knowledge of the digital currencies space. Uniswap for example has experience operating in this area and, to our knowledge, has had no known attacks that have destabilized the pools. DeFi operators would in fact potentially be more efficient due to their technical capacity. However we expect that central banks will require the operator to be regulated and have some history of interaction with both or all involved central banks.

3.2.2. Investment banks

Another private sector option for an AMM operator includes investment banks that are heavily involved in FX markets today. This includes entities such as Goldman Sachs, Barclays, Standard Chartered and Deutsche Bank among others.

This category of operator could both provide governance and liquidity.

As dominant liquidity providers in today's FX markets, they have both the experience and potentially the incentive to operate an AMM. Most of these operators are dominant liquidity providers for particular currency pairs in FX markets. We can envision a world where their clients provide liquidity into the AMM pool.

The drawback of banks operating liquidity pools for CBDC pairs is that banks are a business. If the returns from running such a pool are not sufficient to justify continued operation, they are likely to simply shut down this service. This could be disruptive to markets.

3.2.3. Central banks

If we turn to the public sector, there are several reasons that two or more central banks might set up their own AMM operations.

Were the operator to be a central bank, the traditional role would focus only on governance since they do not participate in marketplaces for foreign exchange. However, we might imagine a case where a central bank might want to provide liquidity to balance a pool if the level of liquidity is weak.

The first reason that a central bank might be selected to run the AMM relates to their **evolving role as providers of public liquidity**. Since the global financial crisis, during which they functioned as **market maker of last resort**, there has been discussion about this as a possible role for them. This is largely restricted to the securities markets, but should not be ignored.

A second reason is that some central banks have reported considering new functions in FX markets. In a survey among 66 central banks, **14% of responding central banks are considering taking on operational roles, most notably in FX conversion**. Responses to the survey indicate that central banks could take on several roles: including providing CBDC liquidity, and facilitation and monitoring the smooth operation of FX conversion.

A third reason central banks might take on the role of operator is that in DeFi, the issuer often plays a role in the liquidity pool that is set up. In the case of CBDC, the central bank would be the issuer, so it follows that they might also want to function as the AMM operator.

If the AMM becomes a systemically important venue for foreign exchange, it would makes sense that a central bank would want to directly stake into the pool to influence or support that currency.

All this aside, there are significant governance hurdles that would need to be overcome for a central bank to play this role. There is no case for a purely domestic DEX, so two or more central banks would need to agree that one runs the FX market for both of their currencies.

In the case of central banks, the regulation already exists, but the infrastructure is wholly absent. This is potentially helpful in that it might be easier to start from scratch rather than trying to implement complex application changes such as AMM to existing multi-currency systems.

3.2.4 Other trusted parties

One characteristic we expect will be required of an operator is that they have the trust of both or all central banks involved. This is particularly tricky because most deeply-trusted infrastructure providers in one jurisdiction are unknown outside of it.

The parties we've covered so far are the most obvious. However, it is certainly possible that other entities in a given country or region or trade corridor could run an AMM. Early pilots have focused on specific currency corridors which means that there are likely to be regional actors that hold trust in both economies. Examples of this could include development banks or EX-IM banks.

For these cases, we expect that such an operator will only participate in governance and not liquidity provision.

One example is that if the AMM were operating in the African market only, the African Export-Import Bank might play such a role. They count central banks and financial institutions in 50 African member countries among their members and they are a trusted intermediary among those entities. They also already play a cross-border role and have the governance set up for such activities.

The drawbacks are of course many. These actors have no existing role in FX markets and it is unclear what jurisdiction the exchange should sit in. Finally all operations and infrastructure would need to be created from scratch.

The purpose of this section was to consider some AMM operators within the universe of potential options. There is no obvious candidate, though the private sector is likely to be able to set up such a structure with

the least cost, if they can be convinced to do so.

3.3 Incentives for participation

The third key configuration in an AMM design relates to staking and incentives. In DeFi, participants stake into the liquidity pool in order to capture yield. There are rewards for staking. How can a central bank modify staking rewards to cover risk of impermanent loss and attract participants to stake in that pool over holding fiat currency? This is a fundamental question for AMM and will be key in the ability of central banks to run or oversee an AMM structure for CBDCs.

The design of fees and incentives will be complicated. Higher trading fees benefit liquidity providers, but discourage arbitrage. Normally, the operator of the pool would determine the staking rewards. Current DeFi AMMs provide liquidity providers with trader fees as a base yield and additional UNI, SUSHI, etc to compensate for impermanent loss. The design of incentives might further include **dynamic fees for rebalancing**.

But, in a CBDC pool, central banks may want visibility and therefore influence over who participates in the pool. If they have this, they may be able to offer interest rates to attract participants.

4 Liquidity provisioning with an additional system

Beyond technical considerations, any application of an AMM should include a consideration of how the reaction of existing intermediaries will affect the availability of liquidity in the overall landscape of the financial system. We offer a conceptual framework here, though much more research is needed on this topic.

In our treatment of AMM, we assume that it will be a complement to the existing FX system for a new type of digital currency. Existing FX markets work well for the majority of currencies and transactions. We do not propose that AMM be considered for them. Rather, this explores AMM as an innovation that could improve the existing market for "the rest" of transactions and currencies for which existing markets are costly and complex.

But, even if the AMM is deployed only for this limited use case, it may have spillover impacts. In particular, an additional source of liquidity in the market might be expected to reduce the amount of transactions covered by traditional market makers, and change overall system volatility.

4.1 Profitability of existing system participants

One of DeFi's value propositions is that it democratizes liquidity. By extension, it creates liquidity without requiring involvement of established market makers.

On the one hand, having more participants can lead to more overall liquidity in the system. Corporates and other excess capital holders could invest their holdings in decentralized liquidity pools. Allowing the participation of new types of participants could improve overall market efficiency.

But then, will new participants reduce business for traditional market makers? And if it will, how will this affect the cost of liquidity? Central banks have already made it clear that they do not intend to take measures that will disintermediate existing participants in the financial sector. And as we note earlier, these entities may choose to transform themselves into operators of decentralized liquidity pools or developers of AMM. This is not so different from how firms adjusted their activities in response to electronic trading.

4.2 Relative volatility

A second channel through which existing liquidity provision might be impacted by the creation of an AMM is via relative volatility between the systems. We assume that the AMM will have a different volatility profile than traditional markets, particularly on initial deployment.

Existing crypto-only liquidity pools show a great deal of price movement. Some of this is the result of new token issuance which may result in underfunded pools. Some of it is due to the fluctuations created by normal adjustments of the liquidity pool as investors react to speculation and hype.

In situations of market dislocation, AMMs also perform particularly poorly. Since central banks are responsible for financial stability, this is a consideration that needs to be incorporated into any analysis. In particular because given the novelty of CBDC, we might expect similar volatility at least in the beginning of CBDC issuance.

Volatility in a CBDC pool could impact the overall lending rate in the economy. Institutions might be motivated to shift deposits to liquidity pools because of opportunity cost.

5 Conclusions

It is important to remember that today's foreign exchange markets work well for large institutional players and most currency pairs. This is why we are not suggesting that AMM should replace or displace any part of this existing process.

However we cannot ignore that FX can be problematic for individuals, smaller clients and illiquid currencies. There is an obvious lack of transparency and cost for these transactions. There are also some participants in the market who are more concerned with transparency and efficiency rather than price optimization. For these participants, AMM would be a useful addition.

There are several design issues that we believe will be critical for the proper functioning of an AMM for CBDC that we did not treat in this paper. One issue is the distribution of regulator and operator risk. If a pool is expected to have a private sector operator, this balance will need to be established before it is set up. Another is **how to combine bilateral AMMs into networks**.

Another design issue is the creation of policies around how to manage arbitrage and potential negative disruption, such as maximum lending rates. It is likely that the on-chain exchange rate will differ from off-chain transactions in the traditional market. Others have considered how to design arbitrage approaches to make the on-chain and off-chain exchange rates consistent (e.g. **Lipton, Sila, and Bank, 2021**) but more work is needed.

Finally, as financial services transition to Web 3.0, the role for decentralized liquidity pools and AMM becomes more generic. This ongoing Web 3.0 transition shines a brighter light on the critical importance of research and regulation around this topic.

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