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NOTES

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A Digital Marketplace to Improve Cross-Border Payments

Tobias Adrian, Rodney Garratt, Dong He, and
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Abstract	Cross-border payments are expensive, slow, and opaque. These problems reflect multiple frictions, many of which boil down to limited trust among counterparties. Trust plays a central role in exchanging credit-based money. End users need to trust the issuers of money, and issuers must trust users to satisfy financial integrity requirements. Transactions are possible only where trust links exist. Interoperability between different forms of money can thus be conceptualized as the network of trusted links necessary for transactions. Traditionally, across borders, trust links involve exclusive bilateral credit relationships among correspondent banks. However, the fixed costs required to build these links foster an expensive and concentrated system. This paper interprets different payment arrangements in terms of the implied trust structures. It discusses how the tokenization of money alters trust links and allows for a potentially more efficient market structure to exchange money. The paper ends with a suggested global marketplace to trade tokenized money directly across borders.

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Glossary

AML/CFT ... anti-money laundering and combating financing of terrorism
BIS............. Bank for International Settlements
CBDC........ central bank digital currencies
CCP........... central counterparty
CBR........... correspondent banking relationships
DEFI.......... decentralized finance
IOU .... promissory note or loan agreement
KHRC .... Khmer Riel
LP .... liquidity pool
RTGS......... real-time gross settlement
USDC .... USD Coin
XRP .... Crypto Asset by Ripple

Introduction

Cross-border payments are expensive, slow, and opaque, reflecting multiple frictions (FSB 2020; CPMI 2020). These problems are particularly acute for lower-income countries. This paper explains why the frictions related to cross-border payment transactions are so pervasive and explores how digital money may help overcome or mitigate some of the frictions. The paper aims to provide a conceptual foundation for the design of markets and platforms to facilitate the transfer of digital money across borders.

Cross-border payments are difficult because they typically involve multiple currencies and multiple intermediaries. Exchanging one currency for another may not be straightforward, particularly for currencies issued by emerging markets and developing economies, as these markets may be thinner and subject to more exchange rate volatility. Even after the foreign exchange transaction is done, the acquired funds must still be transferred to the intended recipient. Transferring funds across borders involves parties located in different jurisdictions and subject to different laws and regulations. These parties are typically connected through correspondent banking relationships (CBRs).

Trust plays a central role in exchanging credit-based money. Users of money need to trust the issuers of money to not default, and issuers must trust users to satisfy financial integrity requirements. Transactions are possible only when trust exists. Interoperability between different forms of money can thus be conceptualized as the network of trusted links necessary for transactions. Such networks can be established far more simply within jurisdictions thanks to a unitary legal system and the essential role the central bank plays by offering a trusted settlement asset. Across borders, trust links are established bilaterally among correspondent banks. In such cases, the fixed costs required to build trust foster an expensive and concentrated system. In addition, correspondent banking relations are shrinking, especially for lower-income countries, excluding some from international payment networks. Central banks, in some countries, intermediate cross-border payments, but in many cases, they do not trust each other enough to do so. Thus, links between central banks exist mostly for countries that are geopolitically close or share historical connections.

This paper studies how trust networks evolve once money becomes digital—that is, expressed on ledgers commonly available to market participants, such as for stablecoins, tokenized commercial bank deposits, or central bank digital currencies (CBDCs). The paper considers a global clearinghouse that eliminates the need for a complete set of bilateral trust relationships and ends by advancing a model for a marketplace to trade tokenized money directly across borders.

The paper begins by outlining the nature of money and trust networks underpinning domestic payment systems. The discussion is then extended to cross-border payments and analyzes how information or knowledge gaps complicate trust and credit relationships. Then the ways that digital money may help simplify economic relationships across borders are considered. The paper then outlines a conceptual model of trading and transferring digital money across borders, while identifying key efficiency gains, including lower risks and costs as well as greater competition, transparency, and scalability.

This paper complements Adrian and others (2022), which advances a vision for a cross-border payments, exchange, and contracting platform (called XP). The XP platform argues that new technologies — tokenization, programming, and encryption — should be integrated into infrastructure facilitating the cross-border exchange of currencies but also the writing and trading of related contracts such as to manage risks or design auctions to allocated foreign exchange in relatively thin markets. This paper focuses on trust networks essential to exchange money and discusses specifically how the tokenization of money affects such networks and can be leveraged for more efficient trading.

Box 1. What's Different about Cross-Border Payments in Lower-Income Countries?

Recent studies show that correspondent banking relationships (CBRs) have been shrinking in several countries since the global financial crisis (IMF 2016a, IMF 2016b, Rice, von Peter, and Boar 2020). A leading explanation is increased compliance costs associated with new anti-money laundering and combating financing of terrorism (AML/CFT) regulations, including know-your-customer requirements regarding money transfer operators, as well as broader regulatory uncertainty and perceived risks that many banks believe outweigh the benefits of engaging in this activity. Small countries are particularly vulnerable to the withdrawal of CBRs, and there is concern that these events will lead to an increase in the already high cost of remittances. Thus, anything that can be done to reduce regulatory uncertainty and lower perceived risks of making payments is a first-order priority.

Most cross-border payments are settled using US dollar foreign exchange reserves as settlement assets, through CBRs and finally balance transfers on the books of the US Federal Reserve. For the higher-income countries, the network of CBRs among banks works reasonably well in normal times. However, during crises (for example, 2008–09, 2011, 2020), trust can easily erode, even among banks in advanced economies, and the interbank foreign exchange markets could develop serious signs of dislocation.

The lack of trust between advanced economy banks in crisis times is similar to problems faced by lower-income economy banks all of the time. This lack of trust manifests as higher fees and charges for CBR services, higher foreign exchange spreads, and potentially even the cutoff of services altogether. These symptoms reflect many frictions, including the following:

- Some lower-income countries are perceived to have weaker regulatory and supervisory capacities, and as a result credit exposures to their banks are perceived to be riskier.
- Those banks may also face high compliance costs with AML/CFT regulation, as their jurisdictions tend to have lower ratings in Financial Action Task Force assessments.
- Lower-income countries tend to have higher exchange rate volatility (partly due to poor track records in policy credibility), and counterparties tend to worry about low-probability, but high-impact, jumps in exchange rates. For example, 9 currencies of emerging markets and developing economies depreciated by more than 25 percent in 2020, and a further 21 fell by more than 10 percent. Such volatilities tend to be reflected in large spreads in foreign exchange quotes.
- Consequently, many banks in lower-income countries have to pre-fund nostro balances with correspondent banks ("split liquidity"). They cannot rely on their correspondent banks for credit to smooth payments. Even if they can borrow, risk premia/spreads tend to be high.

Money and Trust Networks

Money comes in many forms, including central bank money, commercial bank money, and nonbank money. Central bank money is a liability of the central bank and includes physical cash and electronic balances held by commercial banks at the central bank. Commercial bank money is balances held by depositors in accounts at commercial banks. Nonbank money is balances kept at nonbank financial service providers, including eMoney, stablecoins, and money market funds.

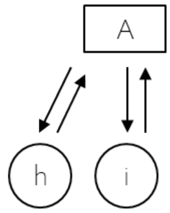
All modern forms of money are based on credit relationships and represent claims and liabilities between related parties. Even central bank money is a liability of the government from the standpoint of a consolidated balance sheet and is ultimately backed by the sustainability of public debt—the net present value of future tax revenue. Inflation from lack of sustainability would undermine the value of central bank money. Commercial bank money represents a credit relationship between the bank and its depositors, and nonbank money represents a claim by the customer on the nonbank issuer. In contrast, unbacked crypto assets, such as bitcoin, are not based on any credit relationship and are not liabilities of any entity.

In the realm of credit-based money, trust plays a key role. The holder of money must trust the issuer to be resilient and well governed, the claim to be legally sound (sometimes across multiple jurisdictions), and the underlying assets or balance sheet to be safe and liquid. And the issuer must trust the holder of money to satisfy AML/CFT and other compliance rules. Trust is therefore a directional concept, from issuer to holder, and vice versa (as illustrated in Figures 1 and 2).

Trust, however, is expensive to establish. It entails paying a fixed and recurring cost, stemming from obtaining and monitoring information. Trust requires prior knowledge of the counterparty and a vetting process that requires special skills and can be time-consuming and imperfect. Public policy can decrease the costs of establishing trust in both directions. Trust in the issuer benefits from public backstops (such as deposit insurance), as well as regulation, licensing, and supervision (which serve to signal that a financial institution is safe) and a legal framework for recourse and enforcement. Trust in the holder of money can be facilitated by national (digital) identity systems, sanctions lists, and the infrastructure to readily access these.

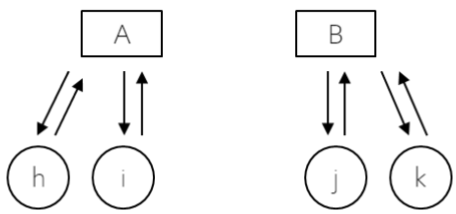
As a result, this paper identifies **a first proposition:** credit-based payment transactions can occur only among people in the same trust network. Absent these ties, the payee would not agree to hold the payer’s money, and the payer’s issuer would not agree to interact with the payee. For instance, two account holders in the same bank can pay each other with money issued by that bank, because both trust the bank and both are trusted by it. This relationship is illustrated in Figure 1. Because trust requires knowledge, the arrows in the figure equally depict knowledge ties between parties, without loss of information.

Figure 1. A mutual trust relationship between bank issuer A and deposit holders h and i



A corollary to this first proposition is that a payment between trust networks is not immediately possible. Indeed, a payment from person i with an account in Bank A to person j with an account in Bank B (as illustrated in Figure 2) is not possible without further arrangements. Person j will not want to hold money issued by Bank A, and Bank A will not want to—nor can it by law—extend a deposit to an unknown person. As illustrated below, the trust networks of people i and j are disjoint.

Figure 2. The lack of a trust relationship between people i and j complicates transactions



A second, more obvious, proposition is that payment transactions can occur only over common infrastructure. In Figure 1, the infrastructure might have involved a proprietary messaging system and a central database containing the bank's internal ledger. However, in a more complex setting involving multiple banks, trust relations may exist where infrastructure links do not, thereby making payments impossible. For simplicity this option is excluded from the remaining discussion. As a result, the arrows drawn in the figures represent a complete characterization of networks, including knowledge and infrastructure links.

The problem of interoperability in payments is thus defined as the transfer of value across trust networks. The next sections demonstrate that solving the interoperability problem is vastly easier for domestic transactions within the same monetary and legal areas. The problem becomes harder across borders, resulting in higher fees and poorer services.

Interoperability in Domestic Payments

Figure 2 shows that, at first glance, person i and person j should not be able to pay each other, yet in reality they do. That is because Banks A and B have solved the problem of interoperability for domestic payments even though each bank issues its own money that the other would not necessarily trust.

The solution lies in Bank A transferring central bank reserves to Bank B, as illustrated in Figure 3. Bank A debits person i's account D_a (D_a, where the subscript denotes currency a) and transfers reserves (R_a) from its account at the central bank to Bank B's. In turn, Bank B credits person j's account (D_a on Bank B's balance sheet).

Figure 3. A domestic transfer from Bank A to Bank B using central bank reserves

Bank A	
R_a ↓	D_a ↓
L_a	E_a

Bank B	
R_a ↑	D_a ↑
L_a	E_a

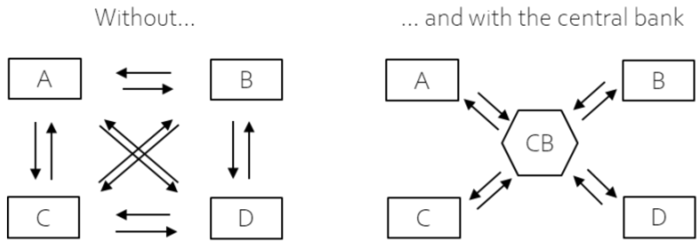
Note: First letters denote asset and subscripts denote currency. Because Banks A and B are in the same country, all assets are denoted in currency a. D = deposits; E = equity; L = loans; R = reserves.

The model rests on two essential pillars: (1) a common settlement asset, central bank reserves in this case; and (2) a common platform, the central bank's real time gross settlement (RTGS) system, which connects with both banks and ensures settlement finality. Both pillars are essential public goods provided by the central bank.

The need to bridge the two banks' trust networks is satisfied in this example by building trust in the central bank. Indeed, both banks trust the money issued by the central bank, which is void of default and liquidity risk and is anchored—ideally—in credible monetary policy and sustainable public debt. And the central bank knows about, and trusts, both banks through supervisory relationships.

As such, the central bank works as a powerful trust-enhancing mechanism. It reduces the costs associated with linking trust networks. Consider a model with multiple (say, *n*) banks and no central bank. Interoperability among banks would require *n(n-1)* bilateral trust relations to be established at significant cost. Instead, the existence of the central bank reduces the trust relations to *2n*, between each bank and the central bank in both directions. These models are illustrated in Figure 4.

Figure 4. The central bank acts as a trust-enhancing mechanism in solving interoperability



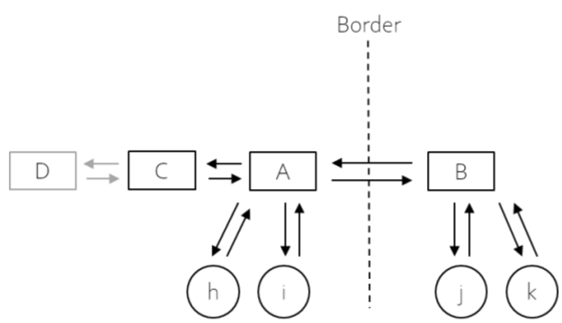
The picture on the left in Figure 4 captures the way many banking systems functioned prior to the introduction of central banks and before the global diffusion of RTGS systems that began during the 1990s (see Bech and Hobijn 2007). Historically, the transfer of reserves did not occur in many banking systems until the end of the day (a practice called *deferred net settlement*), yet the receiving bank would credit the payee's account during the day. This meant that the payee's bank had to trust the payor's bank. Over time, interbank payment values and volumes increased to levels that created uncomfortable intraday exposures, and banks became less willing to acquiesce. Under RTGS, a payee's account is not credited until the transfer of a settlement asset moves from the payor's bank to the payee's bank.

Reality is a bit more convoluted than this stylized model might suggest. In practice, some banks do trust each other and are willing to build modest bilateral exposures by lending each other central bank reserves over intraday money markets to facilitate payment needs. However, the level of trust among banks is volatile and subject to shocks. For instance, interbank money markets nearly froze during the great financial crisis in 2008–09 and 2011. The more cautious attitudes of banks toward credit exposures to foreign banks, as well as balance sheet constraints, even led to violations of covered interest rate parity (Borio and others 2016).

Interoperability in Cross-Border Payments

When person i wishes to send money to person j in another country, the interoperability problem becomes harder to solve. The common settlement platform is replaced by a common messaging system, such as Swift, which allows entities to agree on the terms of settlement but does not actually settle transactions by moving assets as an RTGS system does. Indeed, money does not move across borders. And banks no longer have recourse to a common settlement asset. The central bank, or other government body, is no longer available to bridge the trust networks between Banks A and B. Instead, the banks must build their own bilateral trust links, often at significant expense. The resulting trust network is illustrated in Figure 5, which also shows Bank D without cross-border trust links, having to operate through Banks C and A. In this example, Banks A, B, and C serve as so-called correspondent banks, and Bank C in particular shows how such correspondent banking chains can become long and thus expensive.

Figure 5. The trust networks across borders involve bilateral ties between correspondent banks



In practice, the lack of a common settlement asset held by both Banks A and B requires banks to either extend credit to each other (the credit model) or to pre-fund potential cross-border payment needs (the pre-funding model). Both models build on the bilateral trust relationship established between the two banks:

The Credit Model

In this model, Bank A debits person i's account and extends a promissory note or loan agreement (IOU) to Bank B, which credits person j's account. In essence, Bank B extends credit to Bank A. This IOU, in currency b, requires Bank B to take on counterparty risk and Bank A to take on foreign exchange risk. Neither bank would take on such risks without sound underlying trust links. Figure 6 illustrates this set of transactions.

Figure 6. Cross-border payment through the credit model

Bank A	
R_a	D_a ↓
L_a	E_a
	IOU_b ↑

Bank B	
R_b	D_b ↑
L_b	E_b
IOU_b ↑	

Note: First letters denote asset and subscripts denote currency (either a or b). D = deposits; E = equity; L = loans; R = reserves; and IOU is an "I owe you," namely an extension of credit.

As counterparty and foreign exchange risks grow, banks will seek to normalize their balance sheets. This may occur automatically if payment flows are balanced between countries. Credit from Bank B to Bank A will be countered with credit from Bank A to Bank B. Alternatively, Bank A may offload its risks by turning to a bank more specialized in holding open foreign exchange positions, such as a foreign exchange dealer. Bank A will transfer currency a reserves to the dealer through its domestic RTGS system. And in turn the dealer will transfer currency b reserves it holds in a foreign subsidiary to Bank B through the foreign RTGS system. As a result, Banks A and B will have extinguished their IOU and, with it, counterparty and foreign exchange risk. But these risks do not disappear; they are merely transferred to the dealer bank, which bears foreign exchange risk and liquidity costs associated with warehousing foreign currency.[1]

The credit model naturally leads to a concentrated market structure for correspondent banking. Establishing bilateral trust links between Banks A and B requires substantial and repeated sunk costs associated with obtaining information on counterparties and monitoring these to evaluate their safety. It also requires investment in capacity to (partly) hedge risks through financial markets. Finally, while the above discussion emphasized costs associated with trusting the issuers of money, trusting the sender and recipients of money also raises costs. Especially across borders, customer due diligence and other compliance procedures may differ significantly. Trusting the holders of money boils down to trusting the intermediary running the checks—thus further raising the sunk costs associated with cross-border payments.

The number of banks willing to bear these costs, and able to cover them with sufficient business, will naturally be small (see Sutton 1991 for a discussion of sunk costs and market structure). In addition, the larger the banks, the more diversified their balance sheets, and thus the less risky they will be perceived by their counterparties—an additional factor inducing market concentration. For example, the concentration ratio of the biggest four banks by turnover stayed above 80 percent throughout the 2010s in the correspondent banking market for the euro (ECB 2019).

[1] Reference to "the foreign exchange dealer" is an attempt at simplifying the model without loss of generality. In practice, the foreign exchange dealer in the above discussion can be made up of several institutions taking part in the foreign exchange market. Note that economically the foreign exchange dealer is just another "correspondent" bank, though specialized in providing liquidity to the foreign exchange market. If the foreign exchange dealer has access to both currencies and RTGS systems, it can be thought of as a correspondent bank with two subsidiaries that provide credit to each other.

The Pre-Funding Model

This model resembles the credit model, though tipped on its head, because Bank A initially builds up deposits in Bank B and draws these down when making a cross-border payment. The model is illustrated in Figure 7.

Figure 7. Cross-border payment through the pre-funding model

Bank A	
R_a	D_a ↓
L_a	E_a
W_b ↓	

Bank B	
R_b	D_b ↑
L_b	E_b
	W_b ↓

Note: First letters denote asset and subscripts denote currency (either a or b). D = deposits; E = equity; L = loans; R = reserves; and W = wholesale credit extended by Bank A to Bank B.

In this model, Bank A first pre-funds a wholesale account (W_b) at Bank B. It does so either by building up funds from Bank B customers seeking to pay Bank A customers or by transferring funds to a foreign exchange dealer, which will deposit reserves in Bank B much as discussed above. When undertaking a cross-border payment, Bank A debits person i's account (D_a), while Bank B debits Bank A wholesale deposits (W_b) and credits person j's account (D_b).

In this case, Bank A incurs liquidity costs, as well as foreign exchange and counterparty risks associated with maintaining funds in Bank B. And again, Bank A must know and trust Bank B, leading to a concentrated market structure for correspondent banking.

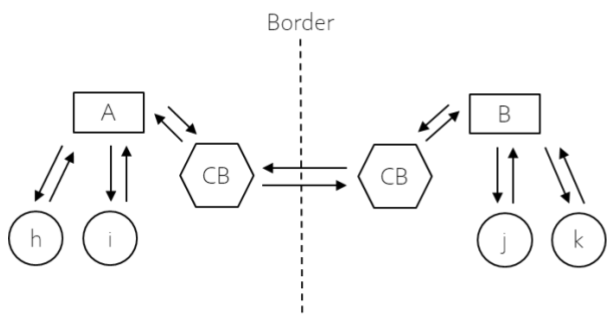
Likewise, the foreign exchange market embedded in both models is often concentrated. Few currencies will actually be traded, as correspondent banks and foreign exchange dealers attempt to limit currency warehousing costs and risks. Figures 6 and 7 depict scenarios in which payment obligations from country A to B are met by converting currency a to currency b. In fact, foreign exchange transactions tend to be channeled through fewer vehicle currencies than those involved in underlying payment transactions. Krugman (1980, 1984) explains how larger market volumes lead to less delay in finding currency matches or an improved trade-off between currency stock size and the probability of a stockout for market makers, and hence lower spreads. At the same time, concentration into vehicle currencies is reinforced by strong network effects. From a dynamic perspective, once a currency gets established as a vehicle currency, its dominance tends to be self-justifying (He and Yu, 2016; Gopinath and Stein, 2021), to the extent that reduced transaction costs outweigh the costs of indirect exchange (Devereux and Shi, 2013).

A Role for Central Banks

Coordination failures may stop commercial banks from investing in bilateral trust relations. For instance, net private benefits (revenue from offering correspondent banking relations versus costs and risks) may be much lower than the net social benefits of doing so (including effects on growth and financial inclusion). And commercial banking relations can break down in stressed times. However, in normal times and among advanced economies and a few emerging market economies, commercial banking ties work well and facilitate payments and foreign exchange market liquidity.

But where and when commercial banks fail to establish trust links necessary to support cross-border payments, in some cases central banks step in to offer equivalent services—to the extent they know each other and sufficiently trust each other. The resulting trust network is isomorphic to the one presented earlier, except that central banks replace Banks A and B in providing settlement services and access to foreign exchange (Figure 8).

Figure 8. Central banks can operate as correspondents

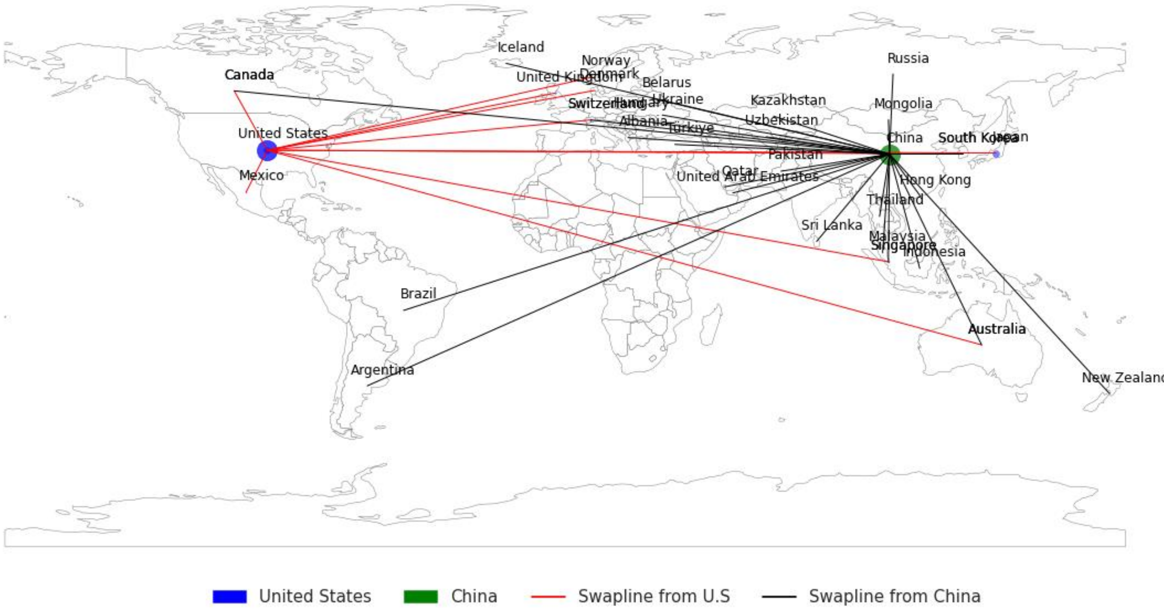


In this role, central banks replicate the same two models identified above to facilitate payments across borders. The credit model is replicated through swaps between central banks—essentially collateral-backed IOUs. And the pre-funding model is replicated through foreign exchange reserves held by central banks with their foreign counterparts (usually at the Bank for International Settlements, or on accounts managed at the foreign central bank, very much like the earlier example).

These approaches are not unheard of among central banks, though they remain expensive and involve risks—similar to those identified for correspondent banks. Swap lines are used among a growing number of central banks, albeit mostly as backstops to access foreign exchange and only between central banks that highly trust each other. For instance, swap lines with the US Federal Reserve were sought during the great financial crisis in 2008–09 and 2011 but turned down for many countries.[2] Today, swap lines exist in regional clusters around central banks in a few countries, such as the United States, European Union, and China (Figure 9). And in many emerging markets and developing economies, the only source of foreign exchange for payments is from the central bank's foreign exchange reserves.

[2] Marple (2021) argues that social similarity between central banks may be a driver of the decision to extend swap lines, which can depend on historical connections such as colonial history.

Figure 9. Global map of swap lines in existence in 2020



This paper offers some empirical insights into the impact of swap lines. In brief, where swap lines exist, cross-border payments tend to be cheaper, suggesting that central banks can play an important role in overcoming market frictions. An empirical investigation confirming that swap lines are associated with lower bid-ask spreads in foreign exchange markets is found in Annex A. And, in turn, evidence that lower spreads are correlated with lower costs of remittances—one important application of cross-border payments—is described in Annex B. The cost of remittances from the United States to foreign countries increases in the bid-ask spread. Both the level and volatility of the bid-ask spread matter for the cost of remittance: for a $200 remittance, a 10 percent increase in the bid-ask spread *level* is associated with a $0.15, or 2.4 percent, higher cost of remittances. And a 10 percent increase in the bid-ask spread *volatility* is associated with a $0.19, or 3.0 percent, higher cost.

Options to Improve Cross-Border Payments

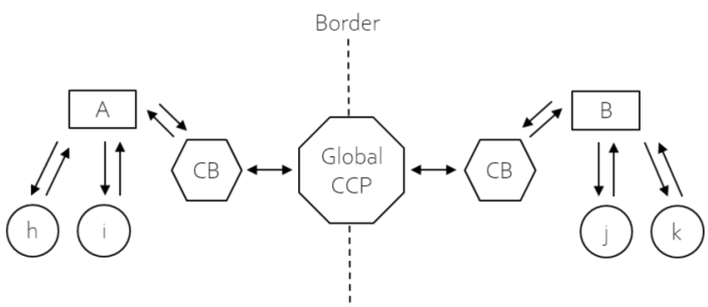
This section suggests that a global clearinghouse to reduce the costs of establishing trust links would offer a marginal improvement to the current correspondent bank-based arrangement. It then considers how the tokenization of money affects trust relations and advances a model for a global marketplace to more efficiently exchange tokenzed money across borders. The model remains exploratory and is intended to lay an initial blueprint to encourage further scrutiny and debate.

A Means to Enhance Swap Lines?

The analysis in this paper suggests that swap lines among central banks effectively reduce foreign exchange spreads and as a result decrease the costs of cross-border payments, so the question naturally arises—why not make greater use of them? Potter, Nemeth, and Choi (2020) make this recommendation, while noting the increasingly important role of banking and custody relationships between central banks since the global financial crisis. In this paper's framework, the question boils down to finding ways to enhance trust among central banks engaging in mutual swaps.

One option is to draw on the earlier example of a central trust-enhancing entity limiting the need for costly bilateral relationships. In this case, the entity would resemble a global clearinghouse to intermediate swap arrangements between central banks, as sketched in Figure 9. The option finds inspiration in Duffie and Zhu (2011).

Figure 10. A global central counterparty (CCP) clearinghouse to intermediate swap arrangements between central banks



The entity could reduce trust-related costs in two fundamental ways. First, it would reduce the number of bilateral trust relationships needed to create interoperable payment networks, since each central bank would have to trust just the global clearinghouse. Second, the clearinghouse could reduce overall risks, and thus require less trust to start with. It could net swaps to the extent possible, hold loss-absorbing capital, require participating central banks to post collateral, and pool risks among its members.

However, in practice, significant hurdles are likely to arise. First, political backing can be difficult to obtain for risk-sharing arrangements among sovereigns. Few such arrangements exist globally, and even multilateral lending organizations such as the IMF have strong governance and conditions to limit risk-taking. Second, more practically, collateral requirements of such central clearinghouses may be prohibitive to trade currency pairs less liquid than today's reserve currencies. More investigation of the feasibility, as well as costs and benefits, of this solution are needed.

Moving to Tokenized Money: Basic Building Blocks in Domestic Transactions

Tokenizing money means inscribing and trading property rights to a currency on a common ledger (in this case a permissioned ledger among known nodes).[3] In other words, the holder of a token is presumed to be its owner, and ownership is transferred by transferring the instrument. However, unlike bearer instruments, tokenized money is not associated with anonymity. The identity of token owners and the nature of transactions can still be monitored by appropriate parties. Stablecoins, for instance, are vying to create token representations of currencies—dollars, euros, and pesos. Commercial banks are also exploring ways to tokenize their deposits, though models differ—some foresee tokens as messages that trigger more traditional underlying clearing and settlement among bank accounts (see Garratt and Shin, forthcoming). And central banks are actively evaluating and piloting central bank digital currencies (CBDC).

When money is tokenized, the trust required for transactions and settlement changes drastically, while that related to the value of money and compliance does not. Trust in the validity of transactions and the authenticity of the money received no longer lies with the institutions and counterparties involved in the transaction (Kahn and Roberds 2009). Once one receives the private keys to a token, one becomes the rightful and sole owner of it—to the extent that the technology and governance of the underlying network are sound and resilient. Settlement thus requires trust only in the network, no longer in the transacting parties. That is because a monetary transaction is no longer the result of an *exclusive* bilateral credit relationship needing the involvement and consent of both parties.

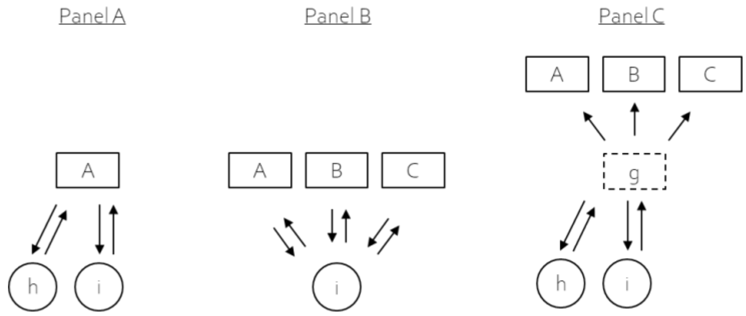
However, money remains credit-based in nature, so the two key trust relationships discussed in this paper related to value and compliance must still be satisfied. First, the recipients of funds must be assured of the stability of the money they receive, relative to the local unit of account. In essence, can the money be redeemed for cash at face value in any state of the world and at any time? Adrian and Mancini-Griffoli (2019) call this the "redemption criteria," which hinge on the assets backing the money as well as the governance, legal, and operational frameworks, including safeguards for cybersecurity.

Second, the recipients of funds must be trusted to satisfy financial integrity requirements. End users must be subject to customer due diligence, and the transactions must be monitored.[4] These trust relations are depicted in Panel A of Figure 11, where i and h represent end users, and *A* is a form of tokenized money.

[3] The key ingredient of tokenized money is the electronic ledger, not the full decentralization as in distributed ledger technologies. In fact, we envision a permissioned network, that is, one that is not fully decentralized, but rather where ledger entries are permissioned by one or several central nodes for the sake of a more efficient and scalable network.

[4] In practice we might expect that the standards applied by the gateway would be determined by an international body such as the Financial Action Task Force.

Figure 11. Trust networks to hold and transact tokenized money



Costs of establishing these trust links can be high—in fact, higher at first glance than in the more traditional banking world described to date given the number of potential relationships with issuers of money. Competition among private (and potentially public) issuers of money could lead to multiple monies that users can potentially hold all at once. Holding each additional money entails paying additional sunk costs to establish and maintain trust links. Costs can rapidly rise, in proportion to $2ni$, where n represents the number of monies held, and i is the number of end users, as illustrated in Panel B of Figure 10, where *A, B,* and *C* represent monies of different issuers.

However, entities can arise to reduce trust-related costs in the tokenized world. These new entities—generally called gateways—are likely to play an essential role in tomorrow's world of digital money. Gateways can be digital wallet providers that stand in between the issuer of money and end users (though issuers can own and provide wallets).

Gateways can reduce trust-related costs by giving their stamp of approval to particular coins, thus eliminating the need for each end user to evaluate the stability of each issuer. That is, the gateway fulfills the important task of *mutualizing trust*. Gateways can establish trust links with each issuer of money, but end users need to build trust links to only a single (or few) gateways. In turn, gateways verify that users satisfy financial integrity. As a result, costs of the trust network decrease to $2(i + n)$ from $2ni$ in the case of a single gateway, as illustrated in Panel C of Figure 10. In reality, more gateways are likely, though sunk costs associated with establishing trust links should keep that number low.

Moreover, costs of the trust network can be reduced further by public policies. These include licensing requirements and supervision of money issuers and gateways. These policies help lower the costs for gateways to trust issuers of money and for end users to trust gateways. Moreover, if the tokenized money is issued by an already closely regulated institution or central bank, trust costs decrease further.

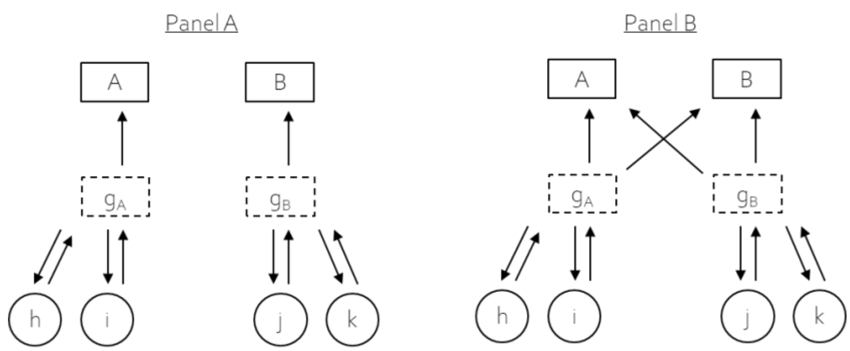
A useful analogy for the role of gateways is how banks hold foreign currencies in conventional financial systems. An entity that wants to directly hold a foreign currency (not a nostro account at a foreign bank) typically has to establish a branch in the foreign country. That branch is then regulated by the host country. In this instance, issuers of a currency must accept the regulatory and supervisory standards of the gateway. That is analogous to a bank in country A holding balances of the currency of country B, with country B accepting the regulatory standards applied to bank A by country A. This is not unprecedented. Switzerland allows banks domiciled in foreign countries to maintain Swiss franc accounts and exchange value through their Swiss Interbank Clearing system.

The Cross-Country Marketplace Model, with Tokenized Money

One possible model to enhance cross-border payments is to establish a marketplace on a digital platform to trade tokenized money across borders. For the purposes of exposition, the proposal can be divided into two parts: interoperability and foreign exchange. The interoperability part entails transferring money to a recipient initially on a different trust network—and can be illustrated in a domestic or cross-border context. The foreign exchange part is instead unique to the cross-border context as it entails exchanging one currency for another before transferring it to the final recipient.

The interoperability problem begins much in the same way as this paper did: with banks issuing their own liabilities. Person i holding money of issuer A (A-coins) wants to pay person j holding B-coins. Each person knows and trusts his or her respective issuer, through gateways g_a and g_b, and vice versa, as illustrated in Panel A of Figure 12.

Figure 12. The interoperability problem with distributed ledger technologies–based digital coins



However, the earlier solution of interposing a central bank with a common settlement asset and infrastructure no longer holds. Suppose, for instance, that issuers *A* and *B* are well-regulated stablecoins —which is the harder case relative to CBDC—that all end users equally trust. Stablecoins have neither a common platform nor a backing asset to ensure settlement. A-coins may be backed with three-month government bills, for instance, and B-coins with one-week government bills and cash to compensate for their lower liquidity. If issuer A had to liquidate assets and send the cash equivalent to issuer B—through the banking network using central bank reserves as a settlement asset—and issuer B had to reconstitute a portfolio of three-month bills to back the newly created money in person j's possession, the payment would be slow, expensive, and cumbersome—and would not have evolved much relative to today's model! The approach of destroying private liabilities, transferring a common settlement asset, and issuing new private liabilities worked well to ensure interoperability among domestic banks, but it is not generally applicable to digital money.

A new model is needed, dubbed the "multiownership model," which finds roots in the basic property discussed earlier that tokenized money is no longer an exclusive bilateral relationship. Simply put, person j can receive money from person i in the form of A-coins. Moreover, to the extent that person j trusts those coins to satisfy the redemption criteria, or—more simply—that his or her gateway trusts those coins, person j should be indifferent to holding either A- or B-coins. And so the transaction should be able to go through.

In short, this setup solves the two criteria initially identified for interoperability: a common trust and an infrastructure network. To the extent that persons i and j belong to the same trust network, by way of a common gateway or gateways that trust the same set of coins, and to the extent that gateways or end users can hold the keys to both assets, then money can be transacted directly and becomes interoperable. The setup is illustrated in panel B of Figure 12.

The equivalent arrangement in the world of traditional bank accounts, recounted earlier, would have been unthinkable. Person j would have had to open an account in Bank A in order to receive money from person i—an unrealistic solution given the substantial bilateral sunk costs of establishing the necessary trust relationships. In the traditional banking world, rooted in exclusive bilateral credit relationships, an end user has a trust relation with a single bank (or a few banks), whereas in the digital world an end user can have a trust relationship with multiple issuers of money, by means of its gateway.

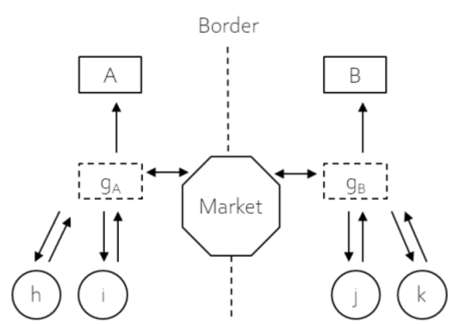
The multiownership model holds domestically just as much as it holds across borders. Figure 11 would not be any different if a border were drawn between the trust network of person i and that of person j. To the extent that each person, or their respective gateway, trusts the other coin and could hold the keys to it, direct transactions should be possible. In practice, aligning regulatory frameworks to allow the ownership of foreign coins makes the cross-border case more complex, though feasible and easier in the extension discussed below of a global marketplace for digital money.

If the A- and B-coins were respective CBDCs in each country, establishing trust links would be even more straightforward. The more numerous the issuers and the less information there is about them, the more expensive the trust network, even if gateways serve to mutualize trust. CBDCs would do well on both counts—with fewer and more trusted issuers. However, conceptually, the multiownership model still applies.

In addition to the interoperability problem discussed above, the cross-border context involves the foreign exchange problem. That is, person j must be able to convert the coin received in A-currency to her domestic B-currency. Spending the coin locally would otherwise be difficult.

A global marketplace for digital money could potentially overcome the foreign exchange problem. Person i would be able to exchange her coin for one denominated in B-currency and accepted by person j's wallet (say B-coins). The setup is illustrated in Figure 13.

Figure 13. A cross-border market for digital money



The simplest foreign exchange transaction is the *coincidence of wants* example. Person i may encounter a coincident order, namely by person k wanting to sell an equivalent amount of B-coins for A-coins to pay person h. Thus, person i merely sends A-coins to person h, while person k sends B-coins to person j. The marketplace ensures these payments are perfectly coincident through smart contracts (such as hash-time locked contracts).

Alternatively, and more realistically, a market maker with access to both A- and B-coins and respective gateways may need to step in if transactions are not naturally coincident. The market maker would take the inverse of person i's trade, that is, receive A-coins and pay out B-coins. The relative demand and supply of A- and B-coins would set the exchange rate on the marketplace. And the market maker would need to warehouse both A- and B-coins.

In practice, the marketplace would combine the interoperability and foreign exchange parts of the cross-border transaction, thereby yielding further advantages. To start, the marketplace offers a trust-enhancing mechanism. Person i and her gateway do not need to trust B-coins, as neither hold B-coins in the transaction. Person i merely sends A-coins to the market maker, through the marketplace, which then sends B-coins to person j from its own portfolio. In a way, market makers specialize in trusting foreign coins and can receive and send both coins since money is no longer rooted in an exclusive bilateral credit relationship. Person i and her gateway need only trust the marketplace.

But does the market maker simply reproduce the earlier correspondent banking model? To some extent, yes—any intermediary in a foreign exchange transaction can be viewed as a correspondent bank. However, the digital marketplace model lowers costs and instills greater competition in correspondent banking services in two key ways.

First, the market maker is no longer wedded to a bilateral credit claim that is expensive to manage. While the market maker in the above example holds A-coins, it can dispose of these freely on the marketplace by leveraging the multiownership model. It can sell these to another party, swap them into another currency, or net out exposures to A-coins with another issuer, for instance. It does not need a payment going in the opposite direction to reverse the bilateral position. In brief, managing liquidity, credit, and foreign exchange rate risks should be much easier on the marketplace.

Second, market making can be made more competitive since coins (in this case from issuer A) are akin to standardized contracts that any market maker can bid to hold. Market makers do not need to have a preferred bilateral relationship with issuer A in order to do business with it, unlike in the earlier correspondent banking model. Market makers merely need to be connected to the marketplace. Greater participation and active bidding for market making business should help lower costs of foreign exchange trading for cross-border payments. This is related to the arguments by Catalini and Gans (2019) that blockchain networks have advantages over traditional marketplaces by reducing the cost of networking and cost of verification.

Extensions and Further Considerations

First, the marketplace model is agnostic about which types of coins are traded. The objective of the above discussion was to lay out a general conceptual framework applicable to any type of coin. However, the trading of CBDCs on the marketplace has significant advantages. First, it should support market liquidity as more market makers would be willing to hold these safer coins. Moreover, the trading of CBDCs would lower settlement risks and ensure fungibility of money at par, given the riskless nature of CBDCs. A marketplace trading only privately issued monies would be riskier, though possible.

Second, the marketplace model is equally agnostic about which currencies are traded. The choice of currencies is likely to evolve endogenously. The above example assumed a direct exchange between coins in a- and b-currency. However, another model is for the marketplaces to gravitate toward trading fewer currency pairs. For instance, a third currency, c-currency, could become the vehicle currency on the marketplace. In this case, person i would trade a-currency for c-currency through one market maker, which would then turn to another market marker to trade c-currency for b-currency. The additional step would occur on the marketplace and could reduce overall costs by trading more liquid currency pairs. The marketplace model can easily extend to multiple trades in a transaction chain. Importantly, each would be run competitively with open bidding for market making as discussed earlier.

Third, and relatedly, liquidity in the foreign exchange market is a key factor of success. The currency pairs traded on the marketplace will naturally gravitate to those offering most liquidity. Moreover, central banks could participate in the foreign exchange markets to provide further liquidity, especially where markets are thinner to start with. Also, the foreign exchange market can be designed to draw lessons from decentralized finance (DeFi), such as building liquidity pools (see Box 2 for a discussion) in order to broaden participation. The particulars lie outside the scope of this paper but are investigated in other ongoing work.[5] Finally, foreign exchange trading could be run using specially designed auctions to maximize liquidity, a topic explored in Adrian and others (2022).

Fourth, foreign exchange trading in the marketplace must not fragment foreign exchange markets globally. A tradeoff seemingly arises. The more liquidity rises on the digital marketplace, the less liquidity may exist on other, more conventional foreign exchange markets. And markets could become fragmented in the sense of trading the same currency pairs at different prices. The simple solution is ensuring that the digital marketplace is open to market makers that also take part in more conventional foreign exchange markets, so they may efficiently arbitrage any price deviations away. Indeed, a key characteristic of the marketplace is its openness to participants of any size given the low trading costs and significant transparency.

Fifth, an important question is who builds and operates such a marketplace, and which rules will govern it. International financial organizations could do so, since they already have well-established governance standards and some experience in making international transfers to and from central banks. Another question is whether the public or private sectors should be—or will be—involved. While the most efficient or socially desirable setup may be debated, the private sector is rapidly building this infrastructure.

[5] Project Mariana of the BIS Innovation Hub is building a platform that exchanges CBDCs through a liquidity pool. https://www.bis.org/about/bisih/topics/cbdc/mariana.htm.

Three models arise: a private settlement asset and marketplace, such as Ripple's XRP; an open-source marketplace such as the Stellar Foundation's or, more recently, DeFi networks; and a marketplace and settlement asset based on unbacked crypto assets, such as Strike, which leverages Bitcoin and the Lightning Network. However, a public solution (potentially run by a regulated private entity) has key advantages such as (1) tackling the coordination problem around centralizing participation and liquidity provision, (2) offering clear and trusted governance and operational stability, and (3) providing full compatibility with financial integrity standards.

Box 2. Liquidity Pools

Suppose a manufacturer in the United States is purchasing rubber from Cambodia. The manufacturer has USD Coin (USDC), but the supplier wants payment in the tokenized version of Cambodia's Khmer Riel (KHRC). Assume that the current exchange rate people expect from over-the-counter market trades is such that 1 USD equals 4,000 KHR.

A liquidity pool for these two tokens would be established by having liquidity suppliers (holders of both tokens) add amounts of USDC and KHRC in the ratio of 4,000 KHRC per 1 USDC to the liquidity pool smart contract. This ensures that the pool has an equal dollar value (or Khmer Riel value) of both currencies. In exchange for doing this, liquidity providers receive Liquidity Pool (LP) tokens in proportion to their contribution size. For example, providers might receive 1 LP for every 1,000 USD (or equivalent in KHR) contributed. Once the pool is established, whenever a trade occurs a 0.3 percent fee is then proportionally distributed among all of the token holders. When a liquidity provider cashes out, she receives her initial liquidity contribution and burns her tokens in exchange for the accrued fees.

The US manufacturer obtains its desired amount of KHRC by performing a swap with the liquidity pool. Suppose it needs to obtain 40m KHRC. The exchange rate it gets is determined by the following pricing formula:

QUSDC * QKHRC = constant.

Where QUSDC is the amount of USDC, and QKHRC is the amount of KHRC. This means that whenever someone wants to swap either currency for the other, they have to put in and take out quantities that preserve the constant value. Suppose that at the time the US manufacturer initiates the swap, the constant equals 40t and the pool holds 100k USDC and 400m KHRC. To obtain 40m KHRC, the manufacturer has to contribute X USD, where X solves this formula:

$$(100k + X) = \frac{40t}{400m - 40m}.$$

The required contribution of USDC is 11,111.11 plus fees for an implied exchange rate of 3,600 KHRC to 1 USDC.

The difference between the realized exchange rate and the initial proportions of the pool is called slippage. The larger the size of the pool, relative to the size of the swap, the less the slippage. For instance, if the pool was 100 times larger (multiply the amounts of each token by 10), then the required contribution of USDC needed to maintain the constant value while swapping out 40m KHRC is 10,101.01, an implied exchange rate of 3,960 KHRC to 1 USDC. Generally, as the size of the pool increases the slippage goes to zero; see Figure 2.1.

Box 2 Figure 1. Slippage as a percent of the initial exchange initial ratio (4,000).

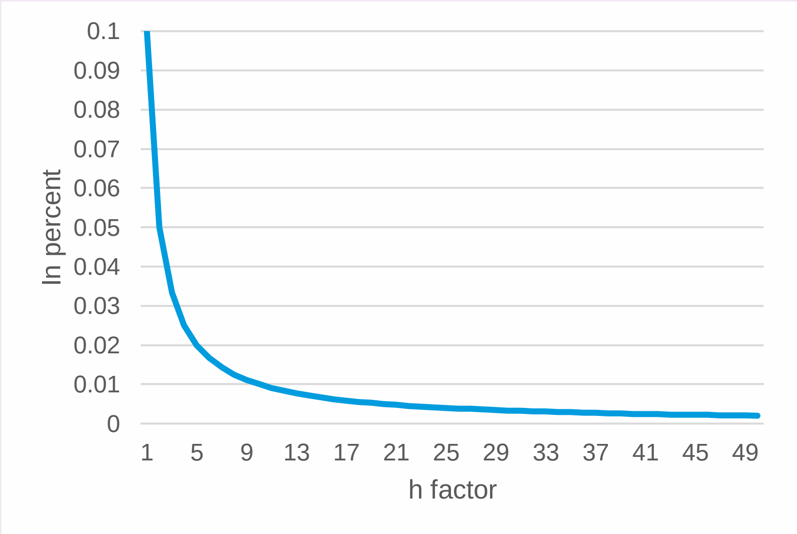


Chart shows percent slippage as the initial liquidity pool token amounts are multiplied by a factor h, where h varies from 1 to 50.

Conclusions

Modern forms of money depend on credit relationships that require trust. Difficulties associated with making cross-border payments can be better understood by factoring in the importance of these trust relationships, which can be particularly difficult to establish and maintain between counterparties located in developing economies. Within countries, central banks act as a trust-enhancing mechanisms across market participants by eliminating the need to maintain costly bilateral trust relationships. This is done by providing a common settlement asset and a common settlement platform.

In cross-border payments, a common settlement asset or common settlement platform does not exist, because different countries use different currencies and have different banking systems. In this environment, bilateral credit relationships between transacting parties become essential, but these relationships are typically scarce and costly. Central banks can and have intervened by providing liquidity through swap lines, but bilateral trust relationships between central banks that are necessary for the creation of swap lines are often missing.

This paper offers two possible improvements for cross-border payments. First, there is the possibility of a global clearinghouse that eliminates the need for a complete set of bilateral trust relationships. However, various practical hurdles may arise, such as obtaining political backing to mutualize risks from swap lines. Second, this paper advances a more promising model for a marketplace to trade tokenized money directly across borders. A shift toward digital money may reduce the need for bilateral trust relationships and foster more efficient and competitive market making. But the proposal must be further discussed, including to explore models to enhance market liquidity and establish sound governance.

Annex I: Swap Lines and Foreign Exchange Spreads

During the 2007–08 financial crisis, the United States Federal Reserve started to establish swap lines with central banks around the world. These were agreements between central banks to exchange US dollars for local currencies, which were designed to address dislocations in foreign exchange markets. Annex Table 1.1 shows the dates and institutions with which the Fed made swap line agreements. The last swap line agreement occurred on October 10, 2018. The peak amount totaled $620 billion as of September 29, 2018.

Annex Table 1.1. Authorized Amounts of USD Liquidity Swap Lines (USD Billions)

Total	24	36	62	67	247	277	290	620	As Demanded	As Demanded	As Demanded
Dates	12/12/07	3/11/08	5/2/08	7/30/08	9/18/08	9/24/08	9/26/08	9/29/08	10/13/08	10/28/08	10/29/08
European Central Bank	20	30	50	55	110	110	120	240	as demanded	as demanded	as demanded
Swiss National Bank	4	6	12	12	27	27	30	60	as demanded	as demanded	as demanded
Bank of Japan					60	60	60	120	120	120	120
Bank of England					40	40	40	80	as demanded	as demanded	as demanded
Reserve Bank of Australia					10	10	10	30	30	30	30
Sveriges Riksbank						10	10	30	30	30	30
Danmarks Nationalbank						10	10	30	30	30	30
Norges Bank						5	5	15	15	15	15
Reserve Bank of New Zealand						5	5	15	15	15	15
Banco Central do Brazil											30
Banco de Mexico											30
Bank of Korea											30
Monetary Authority of Singapore											30

Sources: Federal Reserve; and IMF staff calculations.

We analyze the effects of the swap line agreements on foreign exchange bid-ask spreads using a panel data event study following the empirical strategy proposed by Clarke and Tapia-Schythe (2021).[6] The bid-ask spread is presented in the equation (A1):

[6] Bahaj and Reis (2022) also analyze the effects of swap lines on banks' funding costs.

$$Spread_{i,t} = \frac{Bid_{i,t} - Ask_{i,t}}{\frac{Bid_{i,t} + Ask_{i,t}}{2}} \quad \text{(A1)}$$

where $Bid_{i,t}$ is the point at which a buyer is ready to buy and $Ask_{i,t}$ is the point at which the seller is ready to sell. Bid and ask data are obtained from Thomson Reuters at daily frequency, and following equation (A1) we calculate the variable $Spread_{i,t}$. To capture the effect weeks before and weeks after for close announcement dates, we convert the daily series to a weekly series. Out of the 11 swap line deal announcements we consider those that occurred in the same week as one event—thus we have 7 events in total.

The methodology proposed by Clarke and Tapia-Schythe (2020) is an extension of the differences-in-differences model or two-way fixed effects model, which allows for dynamic leads and lags to the event of interest to be estimated, in this case the swap line agreements, while also controlling for fixed factors by country and time. Consider a panel covering a country indexed as i and time periods t. We are interested in estimating the impact of the swap line announcement, which may occur at different times in different countries. We will denote as Swapline a variable recording the time period t in which the swap line is announced for country i. Denoting the impact on bid-ask spreads as y_{it}, the panel event study regression is presented in equation (A2):

$$y_{i,t} = \alpha + \sum_{j=2}^{J} \beta_j (Lag\ j)_{i,t} + \sum_{k=1}^{K} \gamma_j (Lead\ k)_{i,t} + \mu_s + \lambda_t + BX'_{i,t} + \epsilon_{i,t} \quad \text{(A2)}$$

where μ_s and λ_t are the country and time fixed effects, $X'_{i,t}$are the control variables (including trading volumes and volatility of the exchange rates) added to the model, and $\epsilon_{i,t}$ is the error term. In equation (A2), lags and leads to the swap line announcements are defined as follows:

$$(Lag\ J)_{i,t} = 1[t \leq Swapline_i - J], \quad \text{(A3)}$$

$$(Lag\ j)_{i,t} = 1[t = \ Swapline_i - j]\ for\ j \in \{1, \dots, J-1\}. \quad \text{(A4)}$$

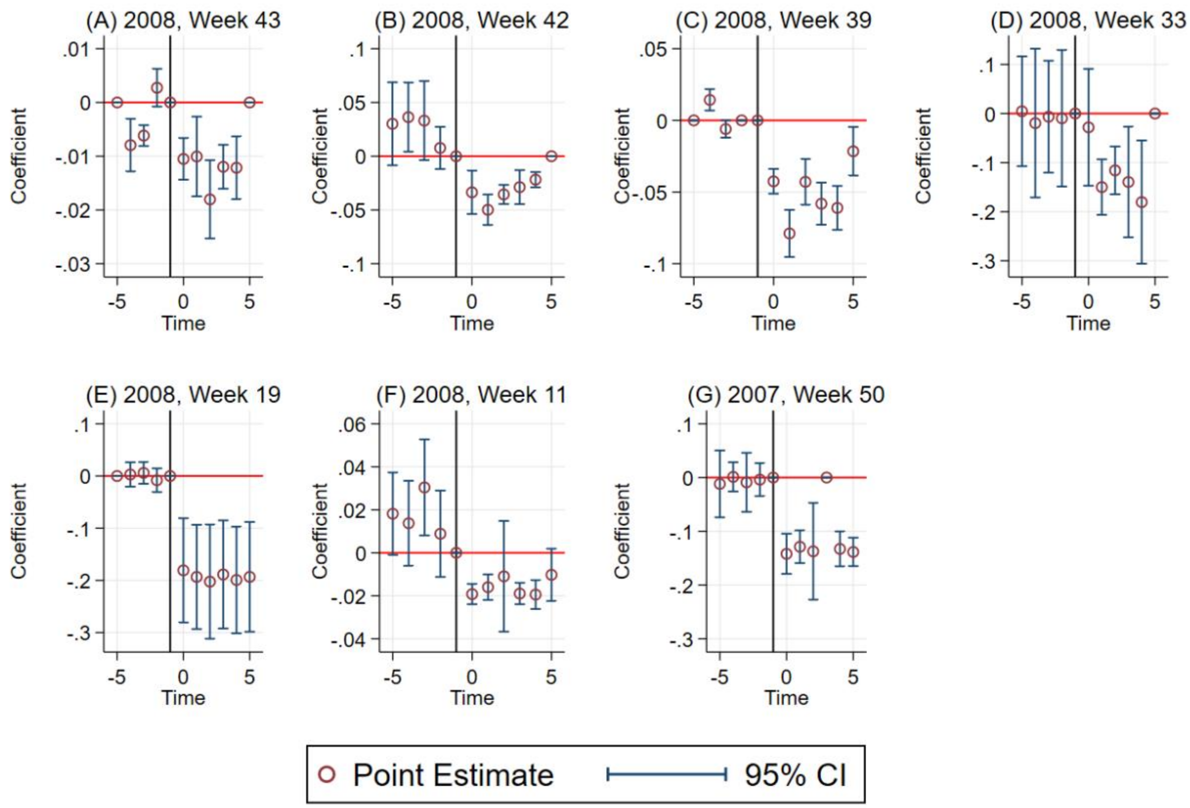
$$(Lead\ k)_{i,t} = 1[t = Swapline_i + k]\ for\ j \in \{1, \dots, K-1\}. \quad \text{(A5)}$$

$$(Lead\ K)_{i,t} = 1[t = Swapline_i + K] \quad \text{(A6)}$$

Lags and leads are thus binary variables indicating that the given swap line announcement was a given number of periods away from the event of interest in the respective period. *J* and *K* lags and leads are included respectively, and as indicated in equations (A3) and (A6), final lags and leads “accumulate” lags or leads beyond *J* and *K* periods. A single lag or lead variable is omitted to capture the baseline difference between countries where swap lines did and did not occur. In specification A2, as standard, this baseline omitted case is the first lag, where *j* = 1.

We estimate the model with the 13 central banks listed in Annex Table 1.1 as the treatment group, and we compare it with 55 countries that did not have any swap lines. The results of these estimates are presented in Annex Figure 1.1.

Annex Figure 1.1. Event-Study Graphs



Source: IMF's staff estimates.

We find that all announcements had significant negative impact on the spreads; that is, immediately after the announcements, the spreads became narrower, as shown in Annex Figure 1.1. The panels show that the negative impact on spreads was large in certain episodes, to the order of 15 to 20 percent after the announcement in week 50 of 2007 and in week 19 of 2008. During other swap line announcements, although there were negative and significant effects, they varied over the weeks.

These results help to demonstrate that central bank interventions by setting up swap lines during episodes of market dislocation facilitated foreign exchange market functioning. One caveat of this type of event study is that we are not able to demonstrate whether the effects are persistent. However, as we argue in the main text of this paper, conceptually enhanced credit relationships between central banks, particularly between reserve currency issuing central banks and emerging market and developing economies' central banks, could enhance foreign exchange market efficiency. Lower expected volatility in exchange rates would likely lead to narrower spreads and, ultimately, lower costs for cross-border payments such as remittances.

Annex II: Foreign Exchange Spreads and Cost of Remittances

In this exercise we demonstrate that the bid-ask spread, which measures liquidity in foreign exchange markets, is positively correlated with the cost of sending remittances. The dependent variable is $CostOfRemittances_{i,t}$, which is the cost of sending $200 remittances from the United States to country i in period t. This variable is obtained from *Remittance Prices Worldwide* of the World Bank and is available on a quarterly basis. The variable $Spread_{i,t}$ (as defined in Annex 1) is transformed to the quarterly level. Other control variables included in the model are $Economic\ Growth_{it}$, $Inflation_{it}, External\ Debt_{it}, Current\ Account\ Balance_{it}\ and\ International\ Reserves_{it}$. The data are available for 30 countries from 2011:Q1 to 2020:Q2. Annex Table 2.1 presents a statistical description of these variables.

Annex Table 2.1. Descriptive Statistics

Variable	Observations	Mean	Standard Deviation	Minimum	Maximum
Cost of Sending $200 Remittances (%)	910	6.22	2.08	–4.5	14.22
Bid-Ask Spread (Mean) (%)	910	0.25	0.38	–0.01	2.71
Bid-Ask Spread (Volatility) (%)	910	0.09	0.17	0	1.93
Economic Growth (%)	460	3.46	4.37	–30.41	17.67
Inflation (%)	833	5.47	5.46	–21.82	68.03
International Reserves ($ billions)	763	219.53	691.32	1.71	4055.81
Current Account (% of GDP)	485	0.54	5.22	–19.89	55.55

Sources: World Bank; Thomson Reuters; and IMF staff calculations.

The regression is presented in the equation (B1):

$$CostOfRemittances_{i,t} = \alpha + \beta_{i,t}Spread_{i,t} + BX_{i,t} + \mu_{i,t}, \quad \text{(B1)}$$

Where α is the constant term, $X_{i,t}$ is the vector of control variables for country i in period t, and $\mu_{i,t}$ is the error term. The regression results from equation (B1) are presented in Annex Tables 2.2 and 2.3:

Annex Table 2.2. Panel Regression Results of the Bid-Ask Spread on the Cost of Remittances

Variable	(1)	(2)	(3)	(4)	(5)	(6)
	Cost of Remittances ($200)	Cost of Remittances ($200)	Cost of Remittances ($200)	Cost of Remittances ($200)	Cost of Remittances ($200)	Cost of Remittances ($200)
Bid-Ask Spread	0.000	0.014*	0.010	0.014*	0.015*	0.016*
	(0.25)	(2.28)	(1.62)	(2.09)	(2.19)	(2.18)
Economic Growth		0.061***	0.060***	0.065***	0.059***	0.063***
		(4.25)	(4.16)	(4.13)	(3.75)	(3.83)
Inflation			0.036*	0.042	0.033	0.043
			(2.00)	(1.93)	(1.51)	(1.84)
External Debt				0.007	0.004	0.005
				(1.01)	(0.56)	(0.76)
International Reserve					–0.006*	–0.005*
					(–2.27)	(–2.04)
Current Account						0.026*
						(2.25)
Constant	6.210***	6.098***	5.988***	5.867***	7.420***	7.328***
	(102.15)	(57.28)	(50.15)	(43.89)	(10.66)	(9.32)
N	910	460	460	415	415	374
Adj. R^2	–0.034	0.009	0.015	0.029	0.039	0.057

Source: IMF's staff estimates. Note: *t* statistics in parentheses, *p < 0.05, **p < 0.01, ***p < 0.001. This table shows estimates using Panel Data with Fixed-Effects. The dependent variable is cost of sending $200 from the United States to the country, and the level of bid-ask spread is the independent variable. All error standards are robust.

Annex Table 2.3. Panel Regression Results of the Bid-Ask Spread Volatility on the Cost of Remittances

Variable	(1)	(2)	(3)	(4)	5)	6)
	Cost of Remittances ($200)	Cost of Remittances ($200)	Cost of Remittances ($200)	Cost of Remittances ($200)	Cost of Remittances ($200)	Cost of Remittances ($200)
Spreads Volatility	–0.001	0.019**	0.016*	0.019**	0.020**	0.021**
	(–0.18)	(3.00)	(2.49)	(2.77)	(2.88)	(2.89)
Economic Growth		0.060***	0.059***	0.063***	0.057***	0.061***
		(4.16)	(4.11)	(4.04)	(3.64)	(3.74)
Inflation			0.034	0.040	0.032	0.040
			(1.95)	(1.91)	(1.49)	(1.72)
External Debt				0.007	0.004	0.006
				(1.10)	(0.64)	(0.87)
International Reserve					–0.006*	–0.005*
					(–2.31)	(–2.07)
Current Account						0.026*
						(2.30)
Constant	6.226***	6.161***	6.030***	5.943***	7.515***	7.426***
	(137.56)	(74.97)	(56.81)	(48.53)	(10.85)	(9.48)
N	910	460	460	415	415	374
Adj. R^2	–0.034	0.017	0.023	0.037	0.047	0.067

Source: IMF's staff estimates. Note: *t* statistics in parentheses, $*p < 0.05$, $**p < 0.01$, $***p < 0.001$. This table shows estimates using Panel Data with Fixed-Effects. The dependent variable is cost of sending $200 from the United States to the country, and the volatility of bid-ask spread is the independent variable. All error standards are robust.

The results suggest that there is a positive association between the bid-ask spread and the cost of sending remittances. The cost of remittances from the United States to foreign countries increases in the foreign exchange spread. Both the level and volatility of the foreign exchange spread matter for the cost of remittance: A 10 percent increase in the bid-ask spread level would on average raise the cost by $0.14 to $0.16 for a $200 remittance. And a 10 percent increase in the bid-ask volatility would on average raise the cost by $0.17 to $0.21 for a $200 remittance. As the average cost of a $200 remittance is 6.22 percent, a 10 percent increase in the level of spreads would raise the average cost by 2.4 percent. And a 10 percent increase in the volatility of spreads would raise the average cost by 3.0 percent.

These results suggest that foreign exchange market liquidity matters greatly for the cost of cross-border payments. This is consistent with survey results. For example, McKinsey and Company (2016) estimates that costs of an average cross-border transaction can be broken down into Nostro-Vostro or trapped liquidity (34 percent); foreign exchange risk management (15 percent); compliance (13 percent); and claims, treasury, and other operations (38 percent). The first two components are closely related to foreign exchange market liquidity and the determination of bid-ask spreads.

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