Research Statement

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Every financial crisis involves leverage. While the focus is often on the borrowers taking on excessive debt, it's equally important to consider who is purchasing the debt and why. Debt of the financial sector is often regarded as a cash substitute, with examples including bank deposits and debt instruments that are commonly held by money market funds. These near-money assets offer lower returns than other assets, even on a risk-adjusted basis. This wedge, commonly referred to as the "money premium", reflects the transactional benefits of holding cash substitutes. Money premium leads to overpricing of debt and excessive leverage (e.g., Stein, 2012). However, the revival of interests in money demand after the Global Financial Crisis (GFC) reduces it to money-in-utility in models of macroeconomy and financial intermediation (e.g., Krishnamurthy and Vissing-Jørgensen, 2015). My research delves into the deeper origins of money demand, showing that the factors driving it stem from secular economic trends, vary endogenously with business and leverage cycles, and result in unintended consequences of policy interventions ([1], [2]).

Money is a not one type of asset but a set of institutions and commonly held beliefs.[1] Payment systems are at the core of monetary system. Bank debt (deposits) is considered as part of money supply because it plays the central role in the modern payment system. However, there is still a lack of understanding of payment systems, especially the implications for banking. There is theoretical literature on why bank liabilities should serve as a means of payment (e.g., Cavalcanti and Wallace, 1999). My research on deposits and payment system is not to rationalize the current institutional setup but to explore its impact on banks. My papers originate from a seemingly mundane observation: to support the functioning of payment system, banks allow depositors to move money freely into and out of their accounts. My research shows that this setup affects bank lending ([3]), their demand for central bank money (reserves) ([4]), the impact of bank leverage regulation ([5]), and the interconnectedness and systemic risk in the banking system ([6]).

Questions about why we need money and who should create it have always been central to economics. Yet, as the world evolves, new questions about the nature of money continue to emerge. In recent years, payment systems have gained enormous attention with the rise of blockchain technology, debates over central bank digital currencies, and the emergence of firms specializing in payment services. I have developed a line of research into cryptocurrencies and their implications for platform economics, financial stability, and regulations ([7], [8], [9]).

In an economy with a perfect credit system, money is unnecessary. People pay for goods and services with IOUs, and every IOU is honored when a payout is requested. In other words, money would not exist in a world with frictionless credit, as assumed in many macroeconomic models.

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[1] While my research focuses on the institutional setup of the monetary system, agents' beliefs are as important. For example, the moneyness of gold results from a long history of conventions and coordinated beliefs.

While money demand drives excessive leverage for part of the economy—i.e., too much debt taken on by the financial sector—the lack of credit is in fact the root of money demand of nonfinancial sectors (Kiyotaki and Moore, 2022). My research examines ways to alleviate credit constraints, in particular, through policy intervention and its unintended consequences ([10]).

My research draws on methodologies from various fields in economics. While my primary focus is on questions in money and banking, my modeling approach often aligns closely with dynamic asset pricing theories. My research interests naturally extend into this area, especially in extracting information on the macro-finance state variables from asset prices ([11]).

My research has consistently focused on the nature of money and the institutions that form the monetary system of the economy. While this overarching theme remains central, the specific research questions are often driven by recent developments, such as the transition toward an intangible-intensive economy ([1]), the scarcity and allocation of central bank money ([3], [4]), deposit influx during the COVID-19 pandemic ([7]), blockchain technology and cryptocurrencies ([7], [8], [9]), credit policies during the Covid-19 pandemic ([10]). Below, I summarize my publications and working papers, highlighting the connections among these research projects.

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1 THE DEMAND AND ENDOGENOUS SUPPLY OF MONEY

Studies on the money demand focus on households rather than firms, guided by the notion that households save and hold money for transactions, often modeled through money in utility, while firms are borrowers. However, in recent decades, the nonfinancial corporate sector in the U.S. turned from a net borrower to a net saver (Quadrini, 2014). Moreover, unlike households whose savings are diversified across assets with different risk and liquidity attributes, firms mainly hold safe and liquid assets (cash substitutes). To analyze money demand and its implications for macroeconomic dynamics, it is important to examine what drives corporate money demand.

The root of firms' money demand is financial constraint. Holding cash would not be necessary if, whenever in need of cash, firms were able to freely raise funds from external sources such as debt and equity markets. Under financial constraints, firms must hold liquidity internally. In the decades leading up to the global financial crisis (GFC), nonfinancial corporations in the U.S. increased their cash holdings significantly. To explain the rising money demand of nonfinancial firms, it is intuitive to consider what causes financial constraints in the production sector.

Fragile New Economy. In my single-authored paper, "*Fragile New Economy: Intangible Capital, Corporate Savings Glut, and Financial Instability*" (accepted at the American Economic Review), I consider the rise of intangible capital in the U.S. economy and its implications on corporate money demand. Intangibles cannot serve as collateral, so as firms increasingly rely on intangibles in production, financial constraints tighten, which in turn incentivizes firms to hold more cash. But what is "cash"? In the real world, there does not exist "storage technology". The "cash and cash equivalents" that firms hold are mostly liabilities of the financial sector, such as bank deposits and money market fund shares that are backed by repo and commercial papers issued in turn by financial institutions. Cash in its most common forms is "inside money", liquid assets held by one group of agents and liabilities of another (mainly financial intermediaries).[2]

The innovation of my paper is to take an equilibrium approach that emphasizes both the demand for money and the endogenous supply. The rise of intangibles drives up firms' incentive to save. As firms increase their demand for cash instruments that are debts of the financial sector, interest rates offered by these assets decline, allowing financial intermediaries to borrow at low costs. The cheap leverage in turn allows financial intermediaries to drive up the prices of collateral assets that back their issuance of near-money liabilities. My paper develops a dynamic (continuous-time) macro-finance model that captures this mechanism and provides empirical evidence. It is the first paper to show that during the transition towards an intangible-intensive economy, several secular trends emerge involving the rising corporate savings, declining interest rates in the money markets, debt-fueled growth of the financial sector, and rising valuation of collateral assets.

Moreover, by connecting these secular trends in the run-up to the GFC, my model reveals a new source of financial instability. Corporate savings are procyclical. During booms, firms generate earnings and increase savings. Their purchase of debts issued by the financial sector pushes down the debt costs of financial intermediaries; in contrast, households do not benefit because their debts are not deemed money-like. The funding cost advantage makes financial intermediaries the

[2] Outside money accounts for a small share of total monetary assets. One example of outside money is the physical dollar bills that are the owners' assets but not liabilities of any agents. Another example is gold.

natural buyers of assets.[3] The longer a boom lasts, the wider the funding-cost wedge is between financial intermediaries and households. When a negative shock hits financial intermediaries, forcing them to shrink balance sheets, the reallocation of assets to the household sector that has higher funding costs and higher required return causes asset prices to decline sharply. Therefore, the model predicts that the longer a boom lasts, the more severe the next financial crisis will be.

The development of financial markets and institutions has a profound impact on the industrial structure (Rajan and Zingales, 1998). My paper demonstrates that the reverse is also true: the evolution of industrial structure shapes the financial system.

Public Liquidity and Intermediated Liquidity. A key theme of my research is an equilibrium perspective on monetary assets. My paper "*Fragile New Economy*" explores the origin of money demand, but the endogenous money supply by the financial sector is also important in generating financial instability. The emphasis on "inside money"—what firms hold as cash are liabilities of the financial sector—is what distinguishes my paper from the models on corporate liquidity management that assume an exogenous storage technology (e.g., Riddick and Whited (2009); Bolton, Chen, and Wang, (2011); Hugonnier, Malamud, and Morellec, 2015). In another single-authored paper, "*Public Liquidity and Intermediated Liquidity*" (previously titled "*Procyclical Finance: The Money View*", R&R at the Journal of Finance), I explore the different sources of money supply. This paper raises two questions. First, when financial intermediaries cannot supply enough liquid assets ("intermediated liquidity"), can the government issue liquid securities ("public liquidity"), such as Treasury bills, to alleviate the shortage? Second, can increasing public liquidity to crowd out intermediated liquidity solve the problem of financial instability associated with private money creation? The answer to both questions is no.

In the model, financial intermediaries incur costs when transforming risky and illiquid assets into safe and liquid debts (e.g., deposits).[4] Profits earned from supplying liquid assets compensates intermediation cost in equilibrium. When the government issues liquid securities, intermediaries reduce their issuance so that their profits per dollar of liquid assets created remain the same. Therefore, when intermediated liquidity is insufficient, introducing public liquidity cannot fill in the gap as it crowds out intermediated liquidity when intermediation is costly.

Intermediation cost is modelled as equity issuance costs (Myers and Majluf, 1984).[5] A threshold of equity level is optimally chosen below which intermediaries choose to incur the issuance costs and raise equity. As in He and Krishnamurthy (2013) and Brunnermeier and Sannikov (2014), the intermediation cost exhibits countercyclicality. Negative shocks deplete equity. As costly equity raising becomes more likely, the intermediation cost, i.e., the shadow cost of raising equity, rises. In contrast, following positive shocks, equity grows through earnings, so equity raising becomes a more distant event, and the intermediation cost decreases. Under countercyclical intermediation cost, the crowding out of intermediated liquidity by public liquidity is more severe in downturns than in booms. Therefore, in response to the government supplying liquid assets, intermediaries'

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[3] In He and Krishnamurthy (2013), the notion that financial intermediaries are the natural buyer of assets is reflected in the assumption that only intermediaries hold risky assets. In Brunnermeier and Sannikov (2014), the financial sector is the natural buyer of assets because asset productivity is higher when held by intermediaries. My model differs in the reason why intermediaries are the natural buyer of assets: their funding costs are lower than the rest of the economy.

[4] In the model, banks are always solvent and their debts always safe. Safe assets are information-insensitive, which explains why they are liquid and can be freely transferred from sellers to buyers in secondary market without the concern over adverse selection (i.e., information-insensitive assets are money-like).

[5] Banks often have complicated balance sheets. The logic in Myers and Majluf (1984) applies: shareholders incur dilution costs when raising equity, because under information asymmetry, the new shares are underpriced.

leverage becomes more procyclical: they compete with the government in supplying liquid assets (issuing debts) in booms when the intermediation cost is low; in economic downturns, they cut debt issuance and deleverage sharply as they face higher intermediation costs. Public liquidity, by amplifying the procyclicality of intermediary leverage, contributes to financial instability.

In my dynamic model, intermediation cost, which originates form equity issuance costs, causes an undersupply of intermediated liquidity and thus motivates the government to supply liquid assets. However, public liquidity crowds out intermediated liquidity by squeezing profits from liquidity creation. Moreover, the countercyclicality of the intermediation cost implies that public liquidity leads to procyclicality in intermediary leverage. These unique predictions shed light on the complex interactions between public and private supply of money and near-money assets, and these results are distinct from those out of the static models (e.g., Holmström and Tirole, 1998).

2 DEPOSITS AND PAYMENT SYSTEM

The money view of banking emphasizes the role of deposits as means of payment, the liability side of bank balance sheet (e.g., Friedman and Schwartz, 1963). The credit view focuses instead on the asset side: bank loans are important sources of financing for firms and households (e.g., Bernanke, 1983). The credit view has become dominant since the 1990s, especially for analyzing the role of banks in the macroeconomy (e.g., Gertler and Kiyotaki, 2010). Moreover, research on deposits in the recent decades is no longer about deposits serving as means of payment but rather focuses on bank runs (e.g., Goldstein and Pauzner, 2005). In line with my research interests in money demand and endogenous money supply, my papers on banking revisit the money view.

2.1 PAYMENT OUTFLOWS AND LIQUIDITY RISK

Deposit contracts allow depositors to freely take money out of their deposit accounts. The right to withdraw has been the focus because of interests in bank runs (depositors front run one another to withdraw money in fear of bank failure). While runs often occur and have severe consequences, most deposit withdrawals are due to payments. When Alice makes an electronic transfer to Bob, money is withdrawn from Alice's bank and deposited in Bob's bank. Alice's withdrawal is not driven by her fear of bank failure. It is the use of deposits for payment. In Fedwire (the major payment settlement system in the U.S.), weekly payment volume easily surpasses the U.S. GDP.

Some may argue that in the example above, Alice's bank loses deposits, but it can borrow from Bob's bank that gains deposits. Given that deposit outflow at the payment sender's bank is often matched with inflow at the recipient's bank, interbank markets can smooth out such liquidity shocks (Bhattacharya and Gale, 1987). However, both theoretical and empirical studies on interbank markets have shown various frictions that limit its role in liquidity sharing.

Payment Risk and Bank Lending. In my working paper, "Payment Risk and Bank Lending: Reassessing the Bundling of Payment Services and Credit Provision", we use data from Fedwire to quantify the liquidity risk that banks face due to depositors' payment activities. Therefore, our first contribution is to quantify liquidity risk that is tied to the monetary role of deposits.[6]

[6] Quantifying the risk of funding stability can be very challenging. The Basel III definition of net stable funding ratio relies on rather ad hoc weights to funding sources. For example, retail deposits are assigned 100%, and bonds with a maturity of at least one year are assigned 85%. It is unclear how these percentages are calculated.

We find that our measures of payment liquidity risk are strongly and negatively correlated with bank lending. Depending on the payment risk measure, 10% to 20% of the standard deviation of loan growth can be explained by a bank's exposure to payment liquidity shocks. Intuitively, a bank that faces heightened risk of deposit outflows is reluctant to invest in illiquid loans. We find that the negative impact of payment liquidity risk on bank lending is more pronounced when the interbank market exhibited stress or when banks faced aggregate liquidity drain (e.g., liquidity transfer from the banking system to the US Treasury). In the cross section, the sensitivity of bank lending to payment risk is higher among smaller banks and banks that are undercapitalized.

Our findings highlight the tension between the two key functions of banks, lending (loans on the asset side of balance sheet) and payment services (deposits on the liability side). It is the first paper that provides empirical evidence on the connection between bank credit supply and the liquidity risk of deposits driven by payments. Liquidity mismatch is a classic theme in banking literature. Our focus is on liquidity risk inherent in the role of deposits as a means of payment.

Our findings echo the surging interests in reserve scarcity (e.g., Copeland, Duffie, and Yang, 2021; Acharya, et al., 2023). After the GFC, banks' reserves increased through several channels (e.g., quantitative easing). If reserves are abundant, banks would not be concerned with deposit withdrawals that drain reserves, and their lending would not be impacted by liquidity exposure from payment settlement. Our paper demonstrates that this is clearly not the case.

Bank Money Demand and Interbank Liquidity Sharing. Payment liquidity risk motivates banks to hold cash (reserves held at the central bank) beyond what is required by regulations because banks use reserves to cover deposit withdrawals due to payment outflows. In "Network Risk and Key Players: A Structural Analysis of Interbank Liquidity" (editor's choice at the Journal of Financial Economics), our goal is to understand how exposure to payment liquidity risk drives banks' money demand, i.e., reserve holdings. This question is increasingly important nowadays because the debate on the proper size of central bank balance sheet, which is directly relevant for the operations of quantitative easing (QE) and tightening (QT), is really about the adequate amount of reserves (central bank liabilities or M0) that should be supplied to banks.

As discussed in "Payment Risk and Bank Lending", banks may share liquidity and undo the liquidity shocks from depositors' payment activities. Specifically, the payment recipients' banks may lend to the payment senders' banks, allowing the latter to replace the lost deposits with interbank borrowing. Interbank credit transactions take place in an OTC (over the counter) market with search frictions where a network structure emerges that determines the odds of transactions between banks. The extent to which a bank can rely on interbank borrowing to smooth out payment shocks (rather than hold reserves themselves) depends on its location in the network.

In this paper, we develop a structural model that explains banks' reserve holdings with the entire network structure of interbank borrowing and lending as a key input together with a variety of payment-system variables, bank characteristics, and macro variables. The model is estimated with proprietary data on payment settlement and interbank credit from the Bank of England.

In our model, the interbank credit network can generate either strategic complementarity in banks' reserve holdings or strategic substitution. When neighboring banks on the interbank credit network hold more reserves, a bank can rely more on interbank borrowing rather than its own reserves to cover payment outflows. This free-riding incentive gives rise to strategic substitution. Strategic complementarity arises through the propagation of economic activities underlying payments. When neighboring banks on the interbank credit network hold more reserves, a bank has more accessible liquidity and thus supports more payment activities, for example, by issuing more demand deposits. An increase in depositors' transactions triggers more economic activities that may in turn stimulate more transactions, for example, through input-output linkages. This causes the bank to hold more reserves in anticipation of more payment activities.

The type of equilibrium on the network varies over time. In the run-up to the GFC, strategic complementarity is the dominant force, suggesting that the propagation of economic activities underlying payments is strong. As a result, the interbank credit network amplified (payment-driven) liquidity shocks to banks' reserve holdings. During the GFC, strategic complementarity weakened, and the liquidity free-riding incentive strengthened. Strategic substitution eventually became the dominant force as the Bank of England started its QE in 2009. By then, the interbank credit network has turned from a shock amplifier pre-crisis to a shock-absorbing mechanism.

We develop a framework to identify systemically important banks. The advantage of having the entire network as input (rather than several network statistics as often done in reduced-form network analysis) is that we are able to fully utilize the information on network nodes and edges in our measures of systemic risk. We demonstrate that systemically important banks are not necessarily the largest ones. Banks' contribution to systemic risk depends on network topology.

2.2 THE BURDEN OF PAYMENT INFLOWS

Research on deposits typically focuses on deposit outflows as bank runs have been at the center of banking literature. My papers above emphasize a different type of outflows that are driven by payments. Banks must deal with payments on a daily basis and in large magnitudes. A payment perspective on deposit flows also reveals interesting insights regarding payment inflows. Deposit accounts entitle depositors to receive payments unconditionally. The first instinct is that this is beneficial for banks, especially given that deposit rate is typically below the market rate.

In "Dynamic Banking and the Value of Deposits" (accepted at the Journal of Finance), we show that payment inflows often pose a great challenge for banks. We develop a continuous-time model of a bank's dynamic balance-sheet management. The stock of deposits, which is the key state variable, loads on both positive and negative shocks as depositors receive and send payments. A sequence of positive shocks resembles what U.S. banks experienced during the Covid-19 pandemic: from Q4 2019 to Q1 2020, JP Morgan Chase had an increase of 18% of its deposit liabilities, and the deposits at Citigroup and Bank of America increased by 11% and 10%, respectively. During this period, bankers consistently complained about deposit influx and some even went out of their way to persuade depositors to move money out of their accounts. This is inconsistent with the conventional wisdom that deposit inflow is beneficial (i.e., the marginal value of deposits from bank owners' perspective, or the "deposit marginal q", should always be positive). Moreover, banks did not increase lending following the deposit influx.

The key to understanding these phenomena is the combination of bank leverage regulation and equity issuance cost. Deposit influx forces a bank to increase leverage, and if the bank violates the regulatory cap on leverage, it must incur issuance costs to raise equity. Therefore, deposit inflows, by pushing the bank close to the regulatory boundary of equity raising, can decrease bank shareholders' value. Moreover, as the likelihood of costly equity raising increases following deposit inflows, the bank becomes increasingly cautious in risk-taking as negative shocks to earnings would deplete equity and further increase leverage. Therefore, in response to deposit influx, the bank may even cut lending. Since the bank cannot perfectly control the liability side of its balance sheet due to payment-driven deposit flows, it chooses to de-risk the asset side.

We introduce a zero lower bound on deposit rate and show that a low-interest rate environment is detrimental to banks.[7] The bank adjusts deposit flows via deposit rate. Once the deposit rate hits zero, the bank loses its ability to counteract deposit inflows through reductions of the deposit rate. In our model, the bank earns a spread between the market rate, **r**, and deposit rate. When it is well capitalized (away from the boundary of costly equity raising), the bank raises the deposit rate to attract deposits as a cheap source of funds, and importantly, to gain slack so that when it becomes undercapitalized in the future, there would be more room to cut the deposit rate and deleverage before hitting the zero lower bound. Therefore, when **r** is high, the bank has more flexibility in raising deposit rate when it is well capitalized without squeezing too much the spread between **r** and deposit rate. The distance between **r** and zero essentially determines the degree of flexibility to control deposit flows. A low **r** makes it more difficult for the bank to manage deposits.

The way we model deposits allows us to sharply distinguish between deposits and a bank's short-term debts. With short-term debts, the bank can always choose to stop borrowing at maturity, and therefore, does not face the problem of unwanted leverage. In contrast, deposits are in effect long-term contracts without a well-defined maturity (Drechsler, Savov, and Schnabl, 2021; Jermann and Xiang, 2023). Deposits leave the bank only when depositors withdraw funds. We show that when the bank is well capitalized, it issues short-term debts to obtain additional financing for lending. Following negative shocks to bank earnings, the bank deleverages by first reducing its short-term debts. When the bank becomes severely undercapitalized and approaches the boundary of costly equity issuance, it switches from issuing short-term bonds to holding risk-free bonds issued by other entities (e.g., the government), thereby de-risking the asset side of its balance sheet, given that the risk on the liability side (deposits) cannot be fully controlled.

Deposit contracts allow depositors to freely put money in and take money out of their accounts, which is necessary for the seamless operation of the payment system. The consequence is that banks cannot perfectly control their deposit liabilities. The bank's inability to fully control the size of its liabilities gives rise to a balance-sheet management problem that is conceptually very different from that of non-depository intermediaries and nonfinancial firms.

2.3 INSIDE MONEY CREATION AND THE PAYMENT NETWORK

In "The Network Structure of Money Multiplier" (working paper), we conducted a systematic analysis of payment inflows and outflows and demonstrate how the network structure of payment flows between banks is crucial for understanding the intermediation capacity of banking sector.

Depositors' payments reallocate both deposits and reserves among banks. When Alice makes a payment to Bob, Alice's bank loses deposits to Bob's bank, and under the current protocol of real-time gross settlement (RTGS), Alice's bank must transfer an equal amount of reserves to Bob's bank to settle the payment. Therefore, the payment recipient's bank expands its balance sheet, adding deposits on the liability side and reserves on the asset side.

Liquidity condition improves for the payment recipient's bank. While it carries more deposits now and must hold reserves in anticipation of potential withdrawals, the bank does not need to cover the new deposits with reserves on a one-to-one basis as the deposits will not be withdrawn

[7] The bunching of deposit rates at zero is a salient empirical feature (Heider, Saidi, and Schepens, 2019).

immediately. Only a fraction of reserves the bank receives is needed to buffer the liquidity risk of these new deposits, and the rest of the newly received reserves is extra liquidity that the bank gains because its depositors have received payments (Parlour, Rajan, and Walden, 2022).

In this paper, our first contribution is to quantify such liquidity spillover and map out its network structure with payment settlement data from Fedwire. Why is this network important? We show that it is a key determinant of the equilibrium money multiplier, that is the ratio of banks' deposit issuance backed loans to the aggregate amount of central bank liquidity (reserves or M0).

When extending loans, a bank conducts a debt swap: it acquires the borrowers' debts (loans) and issues its own debts (deposits) to the borrowers. This process of inside money creation—banks issue deposits to pay for asset purchase—is how money supply (M1) grows. It may appear that banks possess the ability to create money ex nihilo. However, the ratio of loans funded by deposit issuance to a bank's reserves, i.e., the money multiplier, cannot be overstretched. When the newly issued deposits are withdrawn, often as a result of the loan borrowers making payments, the bank cannot liquidate the illiquid loans and must use reserves to cover the deposit outflows. In other words, payment liquidity risk imposes a constraint on banks' money creation through lending.[8]

One bank's money creation through lending has ripple effects through the network of depositors' payment flows. After a bank issues deposits to finance lending, the subsequent payments drive deposits and reserves to other banks. As previously discussed, such liquidity spillover improves liquidity condition of the payment recipients' banks, so with extra liquidity, these banks become willing to issue deposits to finance lending. The resultant payment liquidity spillover then triggers another round of money creation through bank lending, where the payment recipients' banks in the previous round become the payment senders' bank in this round.

In summary, banks rely on reserves to cover deposit withdrawal due to payment outflows, but this liquidity constraint is relaxed by payment inflows from other banks. An immediate result is that banks' decisions to create money (issue deposits) to fund new loans are strategic complements. In our model, a bank's decision depends on the net interest margin (spread between loan rate and deposit rate), reserves, and, importantly, its position in the payment-flow network. In equilibrium, the money multiplier depends on the topology of the entire network. After structurally estimating the model and analyzing banks' positions in the network, we are able to identify the systemically important banks that drive the aggregate fluctuation of credit and money creation. These banks are not necessarily the largest ones, but their liquidity shocks strongly impact the capacity of the banking sector to conduct liquidity transformation (i.e., extending loans funded by deposits).

This paper contributes to several strands of literature on money and banking. Bank lending and liquidity percolation via payments are known to be the key ingredients of money multiplier, but little has been done in modern literature to formalize the mechanism. Our paper fills in the gap. Recent studies on money and near-money assets focus on quantities and prices, i.e., estimating the money demand curve and the money premium (e.g., Krishnamurthy and Vissing-Jørgensen, 2012; Lucas and Nicolini, 2015; Nagel, 2016). Our paper goes beyond quantities and prices to analyze the circulation of money and its network structure. Finally, we show that the payment

[8] Our notion of money multiplier differs from the traditional deposits-to-reserves ratio. What matters is not the amount of deposits issued, but the liquidity property of assets funded by deposits. Issuing deposits to acquire liquid assets does not create liquidity mismatch and is not subject to liquidity constraint, because payment outflows can be covered by selling the newly acquired assets. In contrast, issuing deposits to fund loans requires the bank to have other (liquid) assets that buffer payment outflows as loans are illiquid.

system redistributes reserves among banks. The fact that such redistribution affects the aggregate liquidity transformation by the banking sector suggests reserves are not abundant.

3 CRYPTOCURRENCIES

Economic activities are increasingly shifting to the digital space, as evidenced by the boom in e-commerce. On e-commerce platforms, transactions are settled using fiat currencies, with payment still relying on the bank- and deposit-centric system. In theory, platforms—much like countries—could introduce their own currencies, as both provide the infrastructure that supports economic activities. A platform could develop a payment system where its own currency serves as the settlement asset, and all the forces driving money demand discussed in this article would apply.

If there is a demand, what prevents a platform from introducing its currency? The issuance can be excessive as the marginal cost of producing more digital currency units is zero. Countries face the same problem and solve it through commitment, for example, to an inflation target, and they set up institutional arrangements (e.g., central bank independence) to enable such a commitment.

Blockchain technology makes commitment feasible for digital platforms. Any changes made to the rules of money supply must receive consensus among the currency users. In recent years, many platforms have introduced cryptocurrencies. Some platforms aim to become a universal payment system that supports trade of all products and services, including financial services. Examples include the Ethereum blockchain and Solana blockchain. Some platforms serve niche markets, such exchanging digital storage space (Filecoin) and facilitating online advertising (Basic Attention Token). Research interests also surged in this area.

As shown in the opening paragraphs, drawing an analogy between platforms and countries—where economic agents gather and trade—proves to be a fruitful approach. I believe that understanding new phenomena in emerging financial technologies through the lens of classic financial economics, rather than "reinventing the wheel," is generally more productive. This perspective also helps identify what is truly innovative in fintech. In the following, I summarize my work on cryptocurrencies. My research applies insights from the literature on money and banking and modeling frameworks from the macro-finance and asset pricing literature.

Dynamic adoption and valuation. In "Tokenomics: Dynamic Adoption and Valuation" (editor's choice at the Review of Financial Studies), we develop a dynamic model of money demand on a platform to address two questions. First, how to value a cryptocurrency ("token") based on users' transactional demand? Second, how does introducing a platform currency affect the growth of user base on the platform? Agents hold tokens in anticipation of transaction opportunities on the platform. If the user base grows on the platform, the transactional benefit from holding tokens becomes greater, which reflects the network effect of user adoption. Therefore, a key input of token valuation is user-base dynamics. Next, we show that token price dynamics in turn affect user adoption. These two key endogenous variables must be jointly determined in equilibrium.

The trade-off in theories of money demand is between transaction needs and the carry cost for holding money. As previously discussed in this article, means of payment (e.g., bank deposits) often deliver inferior returns relative to other financial assets. This is also true for tokens as they do not generate a stream of dividends. However, the expected token price appreciation may compensate the carry cost and thereby stimulates user adoption of the platform and its currency.

Our analysis focuses on a promising platform with growing productivity.[9] Productivity represents the quality of the platform and the variety of trade it supports. The prospective growth of user base driven by productivity growth leads agents to expect more users in the future and a stronger demand for tokens. Given a fixed token supply, which is a commitment enabled by blockchain technology, the expected user growth translates into expected token price appreciation. Therefore, user growth exhibits intertemporal complementarity: the expected growth of future user adoption makes holding tokens now more attractive, simulating the current user adoption.

Introducing tokens also stabilizes user adoption. A negative productivity shock reduces users' transactional benefit from holding tokens and thus discourages user adoption, lowering the user base. This negative effect is mitigated by an increase in the expected token price appreciation (which encourages adoption), because a lower level of current adoption implies more users can be brought onto the platform in the future and thus a greater expected token price appreciation.

Our paper is the first to clarify the role of tokens in capitalizing endogenous platform growth, and thereby, reducing agents' effective carry cost of holding means of payment. In our model, the prominent adoption problem in the literature on payment platforms (e.g., Rochet and Tirole 2006) is naturally connected with the trade-off between transactional benefit of money and its carry cost (e.g., Baumol 1952; Tobin 1956). And, compared with traditional user subsidies, we demonstrate the advantages of tokens in accelerating and smoothing adoption. This new solution is enabled by blockchain technology that allows the rules of token supply to be credibly fixed and thereby anchors the token price to the platform users' transactional demand.

Token-based platform finance. In "Token-Based Platform Finance" (published on the Journal of Financial Economics), we develop a dynamic model of token ecosystem: the token demand side is modeled following "Tokenomics: Dynamic Adoption and Valuation", and the token supply side involves several decisions about the platform's "monetary policy". The platform issues tokens for investing in productivity growth or for rewarding its owners. It can also buy back tokens from the market using externally raised funds, subject to a financing cost. Our first contribution is to provide a unified framework for analyzing endogenous token price and token-supply policies. Our model delivers several insights on the economics of tokens and platforms.

First, tokens are akin to durable goods but defy the prediction in Coase (1972). Even though the marginal cost of producing token is zero, the equilibrium price can be positive. The owners' concern over the franchise (continuation) value can generate incentive against over-supply and even induce the owners to buy back tokens. The endogenous growth of platform productivity and the resulting growth of user base and token demand are the ingredients that distinguish our model from standard models of durable goods and stationary demand (e.g., Stokey, 1981).

Second, under-investment arises from conflict of interest between the owners and users. Token-financed investment in productivity increases the token supply, but the impact on productivity is random. If productivity is improved, it benefits both the owners and users; if not, the downside is mainly borne by the owners. While they realize capital loss as the token price decreases, such risk was fairly priced when they bought the tokens. The owners care about the franchise value of the platform and, to maintain user base, may choose to support token price by buying back the token supply in excess (relative to platform productivity). The buyback is externally funded and thus costly. Such asymmetry in exposure to investment risk between the users and owners discourages

[9] Platforms with declining productivity and even frauds exist. Those are beyond the scope of our paper.

the owners from token-financed investing (and tilts token issuance towards payout to the owners), which in turn reduces the users' welfare, the token price, and the value of owners' token payouts.

The root of the under-investment problem is the owners' time inconsistency. If the owners were able to commit against under-investment (and against excessive payout), the users would have demanded more tokens, which increases the token price and the value of owners' token payouts. However, the predetermined rules of token-financed investment can be deemed sub-optimal ex post when the conflict of interest between the users and owners arises. Blockchain technology can address this problem by enabling commitment to predetermined rules. We find that the owners' value is improved under the predetermined rules of token supply and investment in productivity.

Stablecoin: Debasement trap and volatility paradox. The volatility of cryptocurrencies limits their usage as a means of payment. Stablecoins are cryptocurrencies whose exchange rates with a fiat currency (e.g., US dollar) are pegged to one. The amount of stablecoin issued has skyrocketed to meet the rising demand for blockchain-based safe assets. The space is dominated by Tether (the issuer of USDT), Circle (the issuer of USDC), and MakerDAO (the issuer of DAI). Tether and Circle are traditional corporations that aim to be narrow banks, holding safe assets to back safe liabilities. They issue stablecoins on various blockchains. In contrast, MakerDAO is a set of codes ("smart contracts") built on the Ethereum blockchain. The codes operate as a securitization robot: a user posts cryptocurrencies (e.g., Ether) as collateral whose value is split into a certain amount of DAI (the senior tranche) and the user's equity. When the user uses DAI in a payment, the newly issued DAI enters circulation. If the prices of collateral assets fall and the user's equity is wiped out, the smart contracts liquidate the collateral and use the proceeds to buy back DAI from the market and destroy ("burn") them. The idea is to always over-collateralize. However, due to sharp price movements of collateral assets or the price impact of collateral liquidation, the proceeds from collateral liquidation may not be sufficient, in which case MakerDAO uses its own cash holdings to buy back DAI and even issue equity ("governance tokens") to raise cash.

In "Money Creation in Decentralized Finance: A Dynamic Model of Stablecoin and Crypto Shadow Banking", we develop a dynamic model of stablecoin issuer. Our model applies not only to MakerDAO but also to Tether and Circle as their assets are not perfectly safe. For example, USDC debased during the collapse of Silicon Valley Bank (SVB) as the market is concerned about Circle's exposure to SVB. In the following, I highlight two contributions of this paper.

First, we find that the system exhibits a bimodal distribution of states: a stablecoin can stay pegged for a long time, but once debasement happens, the system gets stuck in the "debasement trap". Following positive shocks to the collateral assets, the margin of over-collateralization increases. As the peg to US dollar holds, the demand for stablecoins allows the issuer to gain revenues from charging fees (akin to the deposit spread that banks earn). As a result, the issuer's equity grows, and the margin of over-collateralization grows further.[10] This is a virtuous cycle. Negative shocks trigger a vicious cycle. As collateral value declines, the collateralization margin deteriorates. As it becomes increasingly likely for the issuer to recapitalize (raise equity) and incur financing costs, the issuer becomes effectively more risk-averse and optimally debases the stablecoin to share risk with the stablecoin users. Debasement depresses the stablecoin demand, reducing the issuer's fee revenues and thereby slowing down the rebuild of the issuer's equity.

[10] In an extension where both the issuer's equity and the users' equity are at stake for buffering shocks to the collateral assets as in the case of MakerDAO, we show that our mechanisms hold.

Our second contribution is the discovery of volatility paradox: a decrease in the riskiness of the issuer's assets increases (rather than decreases) the probability of debasement. As the collateral assets become safer, the issuer optimally creates more stablecoins per unit of equity, increasing the leverage. A key implication is that a relatively safer asset portfolio, as often emphasized by Tether and Circle, does not translate into a more robust stablecoin.

In recent years, regulators in the U.S., the European Union, and several countries in Asia have devoted significant attention to stablecoins, recognizing them as central to the future of cryptocurrency application and regulation. Our paper presents a cautionary perspective on the promise of stablecoins and offers new insights for both practitioners and regulators on how to achieve stability. For instance, we demonstrate that implementing standard capital requirements or leverage restrictions can significantly reduce the likelihood of debasement. In contrast, as implied by the volatility paradox, restricting riskiness of collateral assets amplifies instability.

4 Relaxing Credit Constraints

Credit frictions are the reason why money exists (Kiyotaki and Moore, 2002). Spot payments would not be necessary if agents could commit to repay any debt and make purchases with their IOUs.[11] Under credit frictions (e.g., limited commitment), agents must conduct spot transactions: the buyer must hand the seller something valuable on the spot, i.e., certain means of payment. This is particularly evident in the online world of anonymous agents, as it is difficult to develop a credit system based on reputation, proof of income and wealth, and contract enforcement.

My research extends beyond the monetary system to explore credit constraints. A key friction in this context is limited commitment (i.e., the inability to commit to repayment). The government, however, holds a unique advantage: its commitment to repay can be supported by institutional and legal arrangements, and the government can enforce repayment from those that borrow from it. Thus, the government may act as a credit intermediary (Lucas, 2016).

Credit intervention has grown in size and become more direct. The programs during the GFC injected liquidity primarily through the banking sector. During the Covid-19 crisis, not only the GFC-era programs were promptly reinstated, but central banks and governments across the world initiated new programs that lent directly to nonfinancial firms. In light of this trend, it's important to consider: what are the long-term effects of direct credit support for nonfinancial firms, and in particular, what causes credit intervention to grow in scale from one crisis to the next? In "Firm Quality Dynamics and the Slippery Slope of Credit Intervention" (R&R at the Review of Economic Studies), we answer these questions from the perspective of firm quality dynamics.

In our model, firms differ in productivity. High-quality firms have larger debt capacity than low-quality firms. They can borrow more and thus are more likely to survive in crises. Thus, crises exhibit a cleansing effect: the economy emerges from crises with a greater fraction of firms being high-quality. Funding from the government dampens the cleansing effect because, unlike private-sector creditors, the government is unable to differentiate firms by their productivity.

Therefore, credit intervention alleviates the decline of aggregate output but reduces the average firm productivity. A slippery slope of intervention emerges: the economy enters into the next crisis with lower average productivity and thus requires a greater scale of intervention to sustain

[11] Models without financial frictions all assume perfect credit systems (e.g., real business cycle models).

the output. In our calibrated model, increasing the scale of intervention in the current crisis by one dollar per unit of firm capital leads to an increase of 4 cents per unit of capital in the next intervention should another crisis happen in ten years. Given that capital stock grows over time, the inter-crisis pass-through rate by the total dollar amount is even larger.

A key feature of our model is the trade-off between quantity and quality. Optimal intervention in crises strikes a balance between distorting the firm quality dynamics and preserving the overall production capacity. We show that ignoring the distortionary effects on firm quality dynamics results in a more aggressive intervention that almost doubles the welfare-maximizing amount.

5 ASSET PRICING

My research integrates methodologies from different areas, for example, structural estimation of network models that is primarily used in areas beyond financial economics. While the focus of my research is on money and banking, my modeling approach often aligns with dynamic asset pricing theories, and my research interests also extend into this area.

In "Slicing an Asset to Learn about Its Future: A New Perspective on Return and Cash-Flow Forecasting", we develop a new method for forecasting the returns and cash flows of financial assets. Asset pricing theories suggest a great variety of state variables that drive asset prices through expected cash flows and expected returns (discount rates). These state variables reflect different parts of the economy, such as consumption, production, financial intermediation, and government policies. With numerous signals available, data-driven approaches have become popular for forecasting (e.g., Kelly, Malamud, and Zhou, 2024). We propose a simple alternative that does not require a large set of signals ("big data") or state-of-art statistical models.

We show that slicing an asset by payout horizons unseals information about its future returns and cash flows. In particular, we slice the S&P 500 index into dividend strips (Binsbergen, Brandt, and Koijen, 2012). The valuation ratios of these strips, i.e., the logarithm of strip prices scaled by realized dividends, span the underlying state variables (Lettau and Wachter, 2007).

Our paper provides four findings. First, by analyzing the strip valuation ratios, we find the state space of equity index has a low dimensionality. These valuation ratios form a term structure. The level and slope span all the valuation ratios (state-variable proxies), and for forecasting dividend growth and return of the index, we only need these two variables. The level is the log price-dividend ratio of the index (pd). The slope is the difference between pd and valuation ratio of one-year strip. While many economic forces affect the equity price through expected cash flows and discount rates, the level and slope of its valuation term structure summarize these forces.

Second, the slope alone is sufficient for forecasting return. It delivers an in-sample R^2 of 24.8% and an out-of-sample R^2 of 14.6% and subsumes the predictive power of the level (pd). The slope outperforms other predictors in the literature. Augmenting the slope with other predictors does not improve the forecasting performances. It also outperforms machine learning algorithms that aggregate many predictors nonlinearly (Kelly, Malamud, and Zhou, 2024).

Third, return predictive power of the slope has a simple interpretation: market participants have limited information on cash flows beyond the very next year; therefore, when the valuation term structure steepens, it is not driven by an improving expectation of long-term growth but due to a lower discount rate that benefits the valuation of long-duration cash flows more than that of nearterm cash flows. Theoretically and empirically, we demonstrate a tight connection between return predictor power of the slope and market participants' lack of information on long-term growth.

Lastly, we find the role of price-dividend ratio (pd), i.e., the level of valuation term structure, in spanning the state space is not to predict returns (as the slope subsumes its predictive power) but to augment the slope in forecasting cash flows. Both the level and slope predict annual dividend growth poorly on a standalone basis, but together, they deliver an in-sample R^2 of 38.6% and an out-of-sample R^2 of 31.9%. Since news on the expected return and expected cash flows can be correlated, when forecasting cash flows, it is important to control variation in the expected return (via the slope). The literature has coalesced around using pd to predict returns. For this reason, it has been included as a state variable in empirical asset pricing and macro-finance models (e.g., VAR models). We show that the slope of valuation term structure actually corresponds to the expected return, while the level forecasts dividend growth when we control for the slope.

Our paper illustrates a new method of identifying and combining information for forecasting returns and cash flows of financial assets. An asset has many valuation ratios, its own valuation ratio and its valuation term structure, i.e., the valuation ratios of its payout strips. By slicing an asset along payout horizons, we obtain the strip valuation ratios as state-variable proxies. We are extending the framework to extract information on the secular trends in the macroeconomy from prices of equity and debt payouts at different horizons. Our goal is to develop a framework to test theories on the long-term dynamics, such as those emphasized in my other papers ([1]).

LIST OF PAPERS AND WORK IN PROGRESS

[1] Fragile New Economy: Intangible Capital, Corporate Savings Glut, and Financial Instability, accepted at the *American Economic Review*.

[2] Public Liquidity and Intermediated Liquidity (previously titled "Procyclical Finance: The Money View"), under revision (R&R) at the *Journal of Finance*.

[3] Payment Risk and Bank Lending: Reassessing the Bundling of Payment Services and Credit Provision, with Yi Li, working paper.

[4] Network Risk and Key Players: A Structural Analysis of Interbank Liquidity, with Edward Denbee, Christina Julliard, and Kathy Yuan, the *Journal of Financial Economics* (lead article), Volume 141 Issue 3, September 2021.

[5] Dynamic Banking and the Value of Deposits, with Patrick Bolton, Neng Wang, Jinqiang Yang, accepted at the *Journal of Finance*.

[6] The Network Structure of Money Multiplier, with Yi Li and Huijun Sun, working paper.

[7] Tokenomics: Dynamic Adoption and Valuation, with William Lin Cong and Neng Wang, the *Review of Financial Studies* (editor's choice), Volume 34 Issue 3 March 2021.

[8] Token-based Platform Finance, with William Lin Cong and Neng Wang, the *Journal of Financial* Economics, Volume 144 Issue 3 June 2022.

[9] Money Creation in Decentralized Finance: A Dynamic Model of Stablecoin and Crypto Shadow Banking, with Simon Mayer, working paper.

[10] Firm Quality Dynamics and the Slippery Slope of Credit Intervention, with Wenhao Li, R&R at the *Review of Economic Studies* (resubmitted after second-round minor revision).

[11] Slicing an Asset to Learn about Its Future: A New Perspective on Return and Cash-Flow Forecasting, with Chen Wang, working paper.

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