

**Implementation Challenges of Central Bank Digital Currencies
- A Blueprint for the Digital Dollar**

Arnav Gupta



Submitted in partial fulfillment of the requirements for the degree of
BACHELOR OF ARTS IN PUBLIC POLICY STUDIES
at **THE UNIVERSITY OF CHICAGO**

Preceptor: Juan Aritz Ardiszone

April 18th, 2022

1 Acknowledgements

Thank you to everyone who provided me guidance throughout the entire thesis project – I couldn't have done this without you! A huge acknowledgement goes to my preceptor Juan Apitz Ardizzone, who provided mentorship and advice from the beginning of the thesis writing process. Your willingness to listen, attention to detail, helpful comments, and nudges to stay on track made this thesis what it is, so thank you so much. Thank you to my mentors and colleagues at BlackRock for introducing me to the topic of Central Bank Digital Currencies and piquing my interest in the financial markets. A special thank you to Prof. Allen Sanderson and Dr. Katherine Baird for your mentorship and support. This thesis wouldn't have happened without Kanit Kuevibulvanich, who taught me about economic policy analysis in a way that I will never forget – you are the best professor I've had at the University of Chicago, and I thank you for making monetary policy interesting and engaging. Thank you to the writing coaches and library staff at the University of Chicago for dealing with my countless requests and clumsiness. And lastly, thank you to my biggest cheerleaders and stress relievers: my mom, dad, and younger brother.

2 Abstract

As the world begins to shift towards technological efficiency, monetary policy is falling behind the curve of digitization; cash continues to decline as a percentage of transactions, is used to propel the underground economy, exacerbates financial inequity, and has huge policy costs. One proposed solution is Central Bank Digital Currencies (CBDCs), a digital token of a country's fiat currency that lives and grows on your smartphone, serving as a convenient and alternate form of payment for transactions in the economy. 87 countries are exploring digital currencies and 9 countries have fully launched a CBDC nationally, leaving the US behind other major economies in the move towards technological efficiency. Thus, I consider whether a central bank digital currency is feasible and desirable in the United States, and how we can use theory and practice to inform successful implementation. I consider the key arguments in the debate, including ethical considerations of privacy and equity as well as economic justifications like costs, efficiency, and digital networks. Weighing these arguments alongside a theoretical macroeconomic model, I recommend, with cautious optimism, a 7-fold plan for the implementation of a digital dollar over the next 10 years.

Contents

1	Introduction & Problem Statement	3
2	Literature Review & Background	7
3	Data Sources & Methods	13
4	Part 1: Laying the Foundation - CBDC Benefits & Drawbacks	16
4.1	Pros: Underground Economy & Finality	18
4.2	Pros: Financial Inclusion	22
4.3	Pros: Data-Driven Monetary Policy	28
4.4	Pros: Cost-Minimization & Seigniorage	33
4.5	Cons: International Financial Inequity	35
4.6	Cons: Privacy Concerns	38
4.7	Cons: Data Security & Cybercrime	41
5	Theoretical Results - A Macroeconomic Model	44
5.1	The Digital-Cash Hybrid Model - Optimization Framework	44
5.2	Policy Lessons & Conclusions	49
6	Part 2: Policy Recommendations	51
6.1	Recc. 1 - Account-Based Retail CBDC	51
6.2	Recc. 2 - An Interest-Growing CBDC Wallet	54
6.3	Recc. 3 - Semi-Centralized Blockchain-Built Ledgers	57
6.4	Recc. 4 - The Private Sector - Account Creation, Authentication, & Transactions	60
6.5	Recc. 5 - Privacy Concerns and Access to Data	63
6.6	Recc. 6 - Expanding Internet Access & Financial Education	66

6.7	Recc. 7 - International Commitments and Aid	69
7	Conclusion - A Gradual, Comprehensive, And Cautious Rollout	71
8	References	72

Implementation Challenges of Central Bank Digital Currencies - A Blueprint for the Digital Dollar

1 Introduction & Problem Statement

As the world begins to digitize, the financial policy side is attempting to understand how best to practically implement technological innovations into complex daily monetary operations. Studies from central banks around the world, fueled by pandemic-era monetary changes, reveal that there are four main inefficiencies associated with how we issue money. First, in a data-driven world, central banks have a shocking lack of data about where the money supply ends up and how cash circulates through the economy. When the federal government buys bonds to increase the money supply, central banks have a fundamental inability to track where cash is transferred and moved, since many transactions happen using physical currency. This lack of data collection also hampers the effectiveness of monetary policy; knowing the precise impact of a singular dollar as it flows throughout the economy can aid with targeted monetary policy and tailored solutions to recession-era dynamics.¹ Second, cash is susceptible to undercover transactions, propelling the underground economy and illicit activity. When currency can't be tracked, it opens the potential for criminal behavior entirely through cash, as well as other more benign transactions that avoid taxation. In fact, the US government estimates that the size of the "underground economy" is around 11-12% of the entire U.S. GDP, or roughly \$2.5 trillion total.² Third, there are fundamental inequities in financial access and inclusion, and these issues are exacerbated by current financial systems and the interactions between public and private institutions. In the status quo, individuals gain access to capital through checkings and savings accounts with commercial banks, but nearly 50 million people in the U.S. don't have access to this luxury.

¹Klement, "A New Form of Monetary Policy?"

²Schneider and Enste, "Hiding in the Shadows: The Growth of the Underground Economy"

People may be unable to physically go to a bank or are unable to own an account because of ID or minimum balance requirements, and are thus forced to turn to sub-prime loans and shady microfinance organizations.³ Finally, issuing physical cash has huge transaction costs. These include various costs, like physical materials, coordination with financial institutions, and private sector buy-ins, among others.⁴ Regardless, the combination of these four factors demands a rethinking and modernization of the central banking system.

Current literature and financial research is beginning to slowly uncover the potential of a digital paradigm for central bank policy, and the limitless potential of e-money. In particular, central bank digital currencies (or CBDCs, as they are referred to in the literature) are slowly becoming the future of redesigning monetary policy in developing and developed countries alike, allowing governments to envision currency in a completely different way. This transformation is already underway. In the private sector, cryptocurrencies and stablecoins are skyrocketing, and in the public sector, the Bahamas have issued the “Sand Dollar,” China is experimenting with a digital yuan, and many nations are developing programs. In the status quo, 87 countries are researching or developing digital currencies, while another 23 have either completely launched one or have begun a large-scale pilot program.⁵ Fundamentally, CBDCs allow central banks themselves to issue electronic currencies through digital wallet accounts, backed by the credit of the government, rather than through traditional fiat currency, or cash. In particular, this paper analyzes the potential of the digital dollar, which would be the United States version of a central bank digital currency.

CBDCs, with the caveat of proper implementation, remedy all four of the major problems with our current central banking system. First, it would enable central banks to track how money flows from account to account in a centralized fashion, allowing them to precisely tailor quantitative easing and other monetary tools.⁶ Second, the data available from centralized

³FDIC, “How America Banks”

⁴United States Mint, “2021 Annual Report”

⁵CBDC Tracker

⁶Nelson, “The Benefits and Costs of a Central Bank Digital Currency for Monetary Policy”

ledger access would help the government track transactions in the underground economy and limit illicit behavior happening through U.S. dollar.⁷ Third, retail CBDCs go directly to people without going through traditional banks, so individuals have CBDC accounts directly on the central bank core ledger on their smartphones. This would improve financial inclusion by letting people access and transact with money through a simple and convenient digital wallet application.⁸ Finally, after the fixed costs are internalized, digital money is more cost effective and reduces transactional costs associated with buying and selling government bonds and issuing fiat money. There are, however, many concerns to grapple with when crafting an overhaul of the financial and monetary system. Some of these problems include cybersecurity issues, privacy concerns, research and maintenance costs, international inequity, and various regulatory headaches.⁹

Through a combination of qualitative and quantitative work, I will attempt to understand the material effects of implementing CBDCs on a national scale in the United States. The paper will attempt to answer the question: **Is central bank digital currency feasible and desirable and if so, how can research from theory and practice be used to craft a model for the implementation of the digital U.S. dollar?** As such, the first part of this paper will focus on weighing the pros and cons of central bank digital currencies. Then, the second part of the paper will focus on how to create a model for effective policy implementation using research from other countries and institutions, as well as lessons from macroeconomic theory. With a task and question as large as this, the number of questions to be grappled with are endless, many of which this paper will deal with directly: What kind of implementation and logistical challenges are involved with implementing nationwide CBDCs? How would it coexist with existing monetary policy, and could it exist in conjunction with traditional cash? Would it require large-scale infrastructure and cybersecurity costs? Are the long-term benefits worth the physical and logistical costs?

⁷Zhang and Oh, "Central Bank Digital Currency and Informal Economy."

⁸Koulayev et al, "Explaining adoption and use of payment instruments by US consumers"

⁹Williamson, "Central bank digital currency: Welfare and policy implications"

By analyzing how to best use central bank digital currencies effectively, my research can help craft a policy that minimizes inefficiencies and maximizes impact. When considering the pace of technological adoption in other industries, it is only logical that monetary policy should follow similar steps. However, a hasty and under-researched implementation process could create huge national problems in areas like information security, capital access, inflation management, growth industries, and many more. Therefore, well-researched theoretical and empirical evidence is needed to create strong public policy and remedy the aforementioned problems with the status quo. My 7-fold implementation plan for the digital dollar can be used as a blueprint for gradual implementation over the next 10 years. CBDCs can step in and, if implemented correctly, provide huge advantages in financial inclusion, crime control, effective data-driven monetary policy, and cost minimization.

2 Literature Review & Background

As we consider the rapid changes that have occurred from technological innovation and an increasingly globalized world, the financial sector is no different. Recent payment innovations have greatly advanced our infrastructural capacity to transfer money throughout various parts of the economy and bring financial systems towards a more interconnected model. Examples of these include recent advancements in end-to-end encryption in digital payments, apps like Venmo and CashApp, the existence of smartphone apps to securely store banking information, and more.¹⁰ While technology has continued to keep pace in many instances, there is a fundamental demand and supply-side shift rippling through the United States economy. Exacerbated by the coronavirus pandemic, cash transactions are slowly becoming obsolete, and more citizens are using digital payments as their preferred mode of financial payment. This, coupled with increases in online shopping and decreases in brick-and-mortar sales have created an environment where the digital economy is beginning to outpace the physical economy.¹¹

The Federal Reserve (or the Fed) is the central bank of the United States and it crafts monetary and financial policy. Since its founding in 1913, its role in the economy has increased exponentially. The goal of the organization is to "analyze domestic and international economic and financial conditions, and to lead committees that study current issues, such as consumer banking laws and electronic commerce."¹² The Federal Open Market Committee, creates policy designed to promote stable prices, constant inflation, and GDP growth, as well as the money supply that circulates through the economy.¹³ However, the current monetary system fails to keep pace with increasing costs of issuing currency, creating new forms of experimental policy, and tracing transactions that happen through cash.¹⁴ Along

¹⁰Dhar, Dusek, and Tiwari, "Technology-led shifts and opportunities in card-based payments"

¹¹Prasad, *The Future of Money: How the Digital Revolution Is Transforming Currencies and Finance*

¹²Federal Reserve Education, "The Structure and Functions of the Federal Reserve System"

¹³ibid

¹⁴Chiu et al, "Bank Market Power and Central Bank Digital Currency: Theory and Quantitative Assess-

with this, cryptocurrencies have sprung into the mainstream, and is being used to facilitate many transactions. However, currencies like Bitcoin are decentralized and are used for transactions that are meant to be entirely anonymous. Along with that, Bitcoin creates huge emissions and the energy footprint gives it very little redeeming qualities for a nationwide implementation scheme.¹⁵ Its coexistence with other forms of mainstream payment methods is still feasible.

What is necessary is a middle ground - a way to propel digital currencies into the Federal Reserve banking system while simultaneously ensuring some level of control and centralization towards the benefit of the economic system. Hence, there has been a trend towards more countries exploring the potential of central bank digital currencies (CBDCs). Central bank digital currencies offer a unique opportunity to move money into a digital age and offer a host of benefits in conjunction with them. If designed with public welfare and interest in mind, CBDCs have the potential to create innovative changes throughout the monetary system, create more efficient policymaking, and advance equity throughout the population.¹⁶

What is a CBDC, or a digital dollar? A CBDC is a virtual token of the United States dollar, and lives as an official record of our country's official currency. The record is stored in the form of a centralized "ledger," which is a centralized hub which stores all data about digital currency movement, including identities and transaction amounts. It would be a currency that is centralized, which means the power and information about its regulation lies in the hand of the Federal Reserve and the U.S. government. The central bank thus has the ability to insure the currency and regulate its supply using its own monetary tools. Fundamentally, digital currencies fulfill all three of the principles that are necessary for money to have worth, which is that they function as a unit of account, store of value, and medium of exchange for daily transactions.¹⁷ The goal of CBDCs is to give U.S. citizens more

ment"

¹⁵Investopedia, "What's the Environmental Impact of Cryptocurrency?"

¹⁶Federal Reserve, "What is a Central Bank Digital Currency?"

¹⁷Deloitte, "Are CBDCs the money of tomorrow?"

convenience and security through a well-regulated and reserve-backed currency controlled by the federal government. For the purposes of clearly defining CBDCs in the paper, I will use the definition provided by Kumhof and Noone. They defined CBDC as electronic central bank money that "(i) can be accessed more broadly than reserves, (ii) has functionality for retail transactions, (iii) can be interest bearing (with a rate different from that on reserves), and (iv) has a separate operational structure relative to other forms of central bank money."¹⁸

In practice, it looks as simple as an application on your smartphone that you can use to access your CBDC "digital wallet." Once you access this wallet, you have access to your fiat currency and can choose to use it wherever you would traditionally use cash, transfer it to others digital wallets, or keep it there while it earns the prevailing nominal interest rate like a savings account.¹⁹ When you do something with those funds in the CBDC wallet, the information is anonymized and sent to a centralized ledger that is stored by the Federal Reserve. While the idea is to slowly remove cash as a secondary or tertiary mode of payment, implementation of a CBDC does not imply removing all cash immediately from the economy. Instead, the convenience, settlement finality, liquidity benefits, and widespread usage of the digital wallet can eventually phase out cash and move the economy towards more efficient monetary tools.²⁰

Many central banks are currently doing research into the value and potential of central bank digital currencies, and most of the outlook is positive. Out of the four largest central banks in the world (EU, US, Japan, and the UK), the United States is the farthest behind in terms of research and implementation.²¹ This puts the US far behind many other countries - 9 countries have fully launched a digital currency. Nigeria is the latest country to launch a CBDC, the e-Naira, and many countries in the Caribbean have implemented it as well. Another 14 have pilots programs, including the People's Republic of China. Currently,

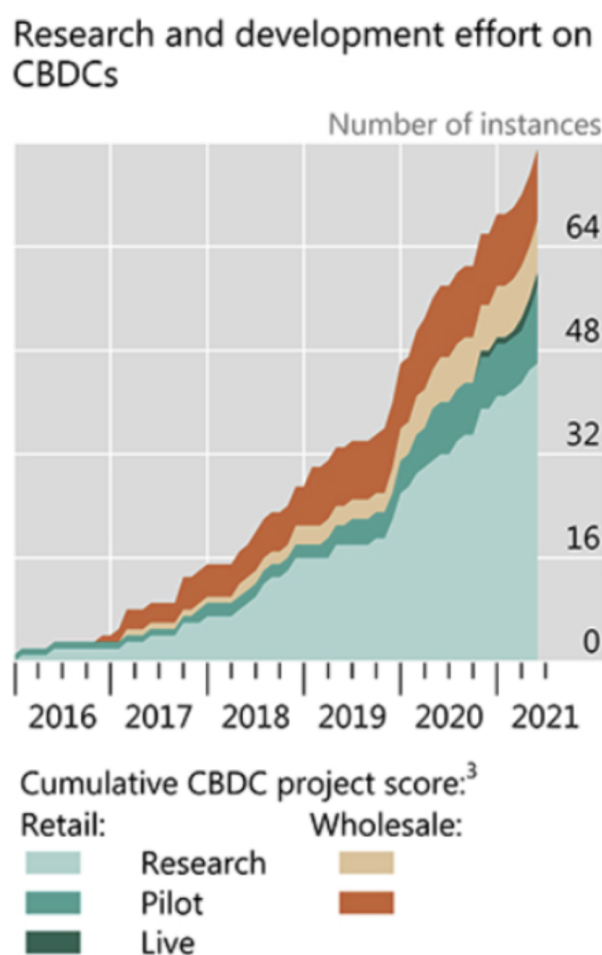
¹⁸Kumhof and Noone, "Central bank digital currencies — design principles and balance sheet implications"

¹⁹Barrdear and Kumhof, "The macroeconomics of central bank issued digital currencies"

²⁰Federal Reserve, "Money and Payments: The U.S. Dollar in the Age of Digital Transformation"

²¹CBDC Tracker

according to the CBDC tracker, over 87 countries (representing over 90 percent of global GDP) are exploring a CBDC. In May 2020, only 35 countries were considering a CBDC, proving the exponential growth of the field in recent years.²² The trend is set to continue as information sharing accelerates and global infrastructures are created. While many countries agree that CBDCs are the way forward, hasty and subpar implementation could exacerbate many existing problems and ruin fiscal and monetary equilibrium across the economy.²³ The following graph from the Bank of International Settlements reveals the increasing instances of research and development efforts on central bank digital currencies.²⁴:



There are a few major themes within existing academic literature which highlight the

²²Atlantic Central Bank Digital Currency Tracker

²³Shin, "Central bank digital currencies: an opportunity for the monetary system"

²⁴Boar, Codruta, and Wehrli, "Ready, steady, go?"

important Federal Reserve considerations. An overwhelming number of central banks are researching the potential for a CBDC, with estimates ranging from 85-87%.²⁵ Information about current literature is interspersed throughout the paper, first in the data sources section and second throughout the paper, where central bank studies and academic literature are quoted and referenced.

There are three areas within current academic literature that my paper attempts to fill in. Ozili identifies, in his literature review of CBDCs, that there is a lack of design frameworks for CBDCs that "meet multiple competing goals."²⁶ This means that policy frameworks are rife with tradeoffs. For example, a CBDC that wants to increase payment efficiency could trade off with data security and cybercrime, since quickness in transactions would require less encryption techniques. Reducing financial crime requires a tradeoff with the amount of privacy offered to citizens. A CBDC that increases financial inclusion can make it difficult to detect fraud because you have to reduce standards for account signup (since unbanked adults often fail to meet documentation requirements or don't have official ID.) Finding a tradeoff between user happiness and aggressive monetary policy is always a balance that the Central Bank grapples with. My paper attempts to create a blueprint and design that achieves multiple objects simultaneously. Second, there are not many papers that step outside of the realm of pure theory or pure decisionmaking - instead, because of the lack of topic information, papers in the area tend to focus on specific subparts of CBDCs rather than holistically analyzing the benefits and drawbacks. This paper attempts to quantitatively and qualitatively analyze all of the factors within parts of the literature, including considerations for privacy, financial inclusion, data privacy, cybercrime, seniorage, international collaboration, and more. As such, it serves as a blueprint for the digital dollar and answers the fundamental question about its feasibility and desirability simultaneously. Finally, Ozili also identifies that there is a lack of studies that are "country and region-specific." This paper, rather than

²⁵Boar, Codruta, and Wehrli, "Ready, steady, go?"

²⁶Ozili, "Central bank digital currency research around the World: a review of literature"

consider digital currencies in a vacuum, considers a blueprint for a specific US version of a CBDC, with special emphasis on the characteristics that make this country unique.

3 Data Sources & Methods

A challenging yet intriguing aspect of studying CBDCs is the lack of widely available academic literature. Many scholars have attempted to study this field from a quantitative perspective and found that there is a severe lack of data and research methods that can be used to study the issue. This is mainly due to a few core problems that I identified while attempting to find sources myself. First, digital currency infrastructure is a new field of research, with most countries operating in the research phase and very little long-term proof of concept. For those that have implemented pilot versions of CBDCs, more years are needed to study the long-term macroeconomic effects of these policies and understand the level of usage and engagement. Blockchain technology, additionally, is relatively new, and until recently, most central banks could not consider large scale infrastructural expansions to their monetary systems. As open data sharing efforts ramp up, analysis will become more widely available and global information sharing can help guide implementation strategies. Research and development efforts on CBDCs have continued to ramp up as more countries explore retail and wholesale options for their countries, a trend shown by this graph in an annual BIS survey of central banks.²⁷:

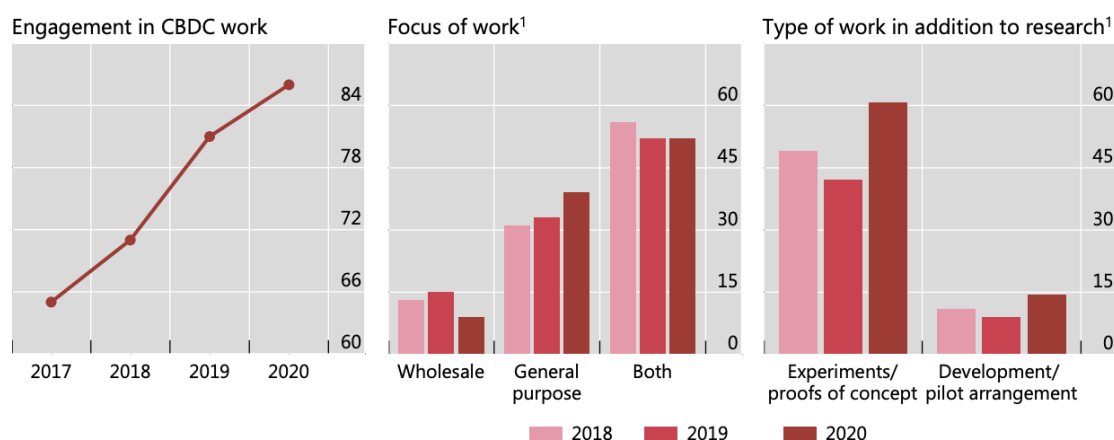


Figure 1: Exponential Growth of CBDC Research

²⁷Boar, Codruta, and Wehrli, "Ready, steady, go?"

Second, a common problem with analyzing macroeconomic policy issues is establishing statistical causality. Since there are hundreds and thousands of factors affecting the economic health of a country, it is difficult to precisely pinpoint the causal effect of a specific policy intervention. For example, while it is possible to subtract levels of banking access pre and post-CBDC implementation, there are many confounding variables such as increases in economic prosperity, financial literacy education, commercial bank marketing, and more.²⁸ Third, the limited number of existing databases are used privately by national governments, either because the research occurs behind closed doors or the data has confidentiality restrictions. Since financial data includes sensitive private information about transaction amounts and identities, most databases can only be used by authorized organizations with strict confidentiality regulations. As a result, most of the research on the topic is happening behind closed doors with classified data. Because of the combination of these three factors, much of the existing literature is largely theoretical in nature, whether through macroeconomic models or logical reasoning and case studies from small pilot programs.

In particular, this paper will use a combination of methods to illustrate the benefits and drawbacks of CBDCs to add to the existing literature. This paper uses important available datasets on the topic: namely, international fund data, CBDC tracker information, preliminary data from other countries, as well as using Venmo as a proxy for how digital currency is used in the status quo. In addition, I conducted anonymous interviews with three members of economist team at the Federal Reserve to understand digital currency efforts and learn about how the US government is conducting research in the status quo. The Federal Reserve employs 400 Ph.D. economists who produce working papers and work on cutting-edge research for the Federal Reserve to drive future policy efforts.²⁹ Unfortunately, due to the somewhat sensitive nature of proprietary security work, as well as the relatively public nature of current publications, the conversations did not illuminate information that

²⁸Kuevibulvanich, "Economic Policy Analysis - Lecture Notes"

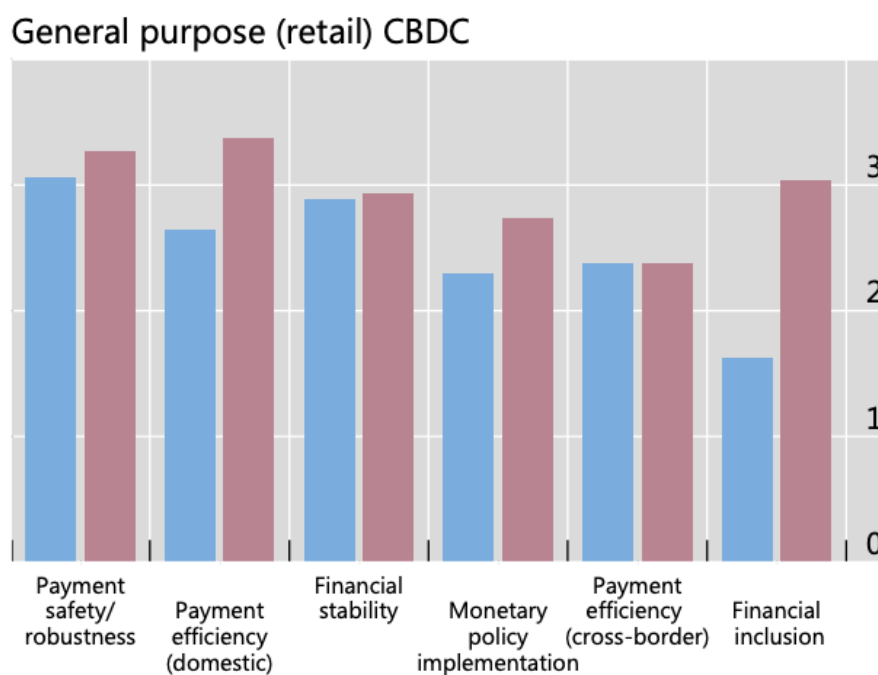
²⁹Federal Reserve, "Meet the Economists"

was not already readily available through Federal Reserve working papers.

The paper is divided into two core sections. The first part of the paper considers the pros and cons of central bank digital currencies using available data. The second part of the paper eventually argues in favor of CBDCs in the United States, using information from a theoretical macroeconomic model to craft a 7-fold implementation blueprint for the digital dollar.

4 Part 1: Laying the Foundation - CBDC Benefits & Drawbacks

To begin the analysis of CBDCs, it is important to consider the general motivations that are driving central banks around the world and understand their points of emphasis during research and pilot phases. The Bank for International Settlements (BIS) conducts yearly surveys with top-ranking central bank members in each country that are directly involved with monetary policy creation.³⁰ For the US, that is most likely a representative from the Federal Reserve that is directly involved with the research operations of the organization on the Board of Governors. The following figure reveals the key motivations for CBDC implementation from the BIS survey in 2020; in blue are the countries that are classified by the UN as "Advanced Economies," and the pink bar is countries classified as "Emerging Market Economies." 1 = not so important; 2 = somewhat important; 3 = important; and 4 = very important.



³⁰Auer et al, "CBDCs beyond borders: results from a survey of central banks"

The survey reveals that payment safety and efficiency, as well as financial stability and effective monetary policy rank as the 4 largest motivating factors for CBDC implementation. It's important to note that the equal-sized bars indicate that emerging markets and developed economies are motivated by similar factors *despite their vastly different economic and social characteristics*. This points to a trend of CBDCs as, potentially, an international system that can be implemented across a wide range of countries regardless of GDP or technological advancement. The one key exception, however, is financial inclusion, which is of larger concern for emerging market economies than developed economies. This is a logical conclusion - in places where internet and smartphone access is low, governments have legitimate concerns that CBDCs could be inaccessible to a wide swath of their population. In this way, improper implementation could, in fact, exacerbate income inequality, with urban elites in poorer countries being the only group with reliable access to this new form of banking. In addition, these countries tend to be places where transactions occur primarily in cash or other traditional forms of payment, as well as societies that are organized around agrarian or community-based living.³¹

The first part of this paper will, using these motivations as a guiding force, compartmentalize the important issues in the CBDC debate and attempt to do a robust cost-benefit analysis of the digital dollar.

³¹Fernandez-Villaverde et al, "Central bank digital currency: Central banking for all?"

4.1 Pros: Underground Economy & Finality

One of the largest drawbacks of cash, along with its inability to be traced for monetary policy purposes, is its lack of tracking potential when transferred to the underground or informal economy. When a dollar bill moves from your pocket to someone else's pocket in an untraceable manner, that creates huge gaps in tax collection, causing huge discrepancies in our calculations of yearly gross domestic product (GDP) and aiding financial crime. The underground economy also fuels problems in the labor supply market, since those hired and paid using cash are not required to receive worker compensation, health insurance, other forms of insurance, or legal protection benefits.³² According to economic estimates, the Internal Revenue Service (IRS) suggests that the underground economy is around 11-12% of the U.S. GDP, valued at around \$2.25 to \$2.46 trillion. A study in the same year by the International Monetary Fund (IMF) concluded that "countries with relatively low tax rates, fewer laws and regulations, and a well-established rule of law tend to have smaller shadow economies," implying that effective policy is a deterrent against the untraceability of cash.³³ The US Department of Justice estimates that the largest components of the underground economy that occur through cash transactions are non-reporting of labor income, drug trade and purchases, illegal services like loan sharking, fraud arson, gambling, and prostitution.³⁴

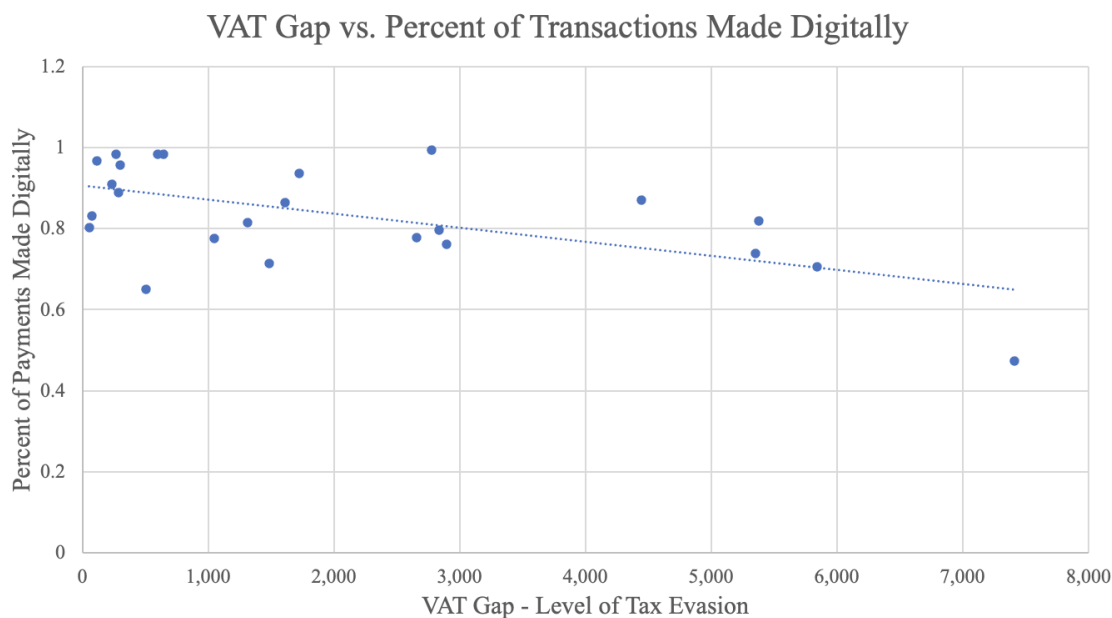
Naturally, the first thing to establish is a statistically significant link between tax evasion and the size of the informal economy. An interesting proxy that can be used to calculate the size of the informal economy (since the current numbers in the US are pure approximations) is the VAT Gap. The VAT Gap is a data point collected in the European Union that calculates the difference between the Value Added Tax (VAT) due versus how much each country actually collects in VAT. Thus, the VAT Gap is viewed amongst economists as one of the strongest indicators of lost revenue and tax evasion and is comparable to the size of the

³²McDonald, "The "Underground Economy" and BLS statistical data"

³³Schneider and Enste, "Hiding in the Shadows."

³⁴Simon et al, "Underground Economy"

informal economy. Each year, the European Commission collects information and publishes it for broader use.³⁵



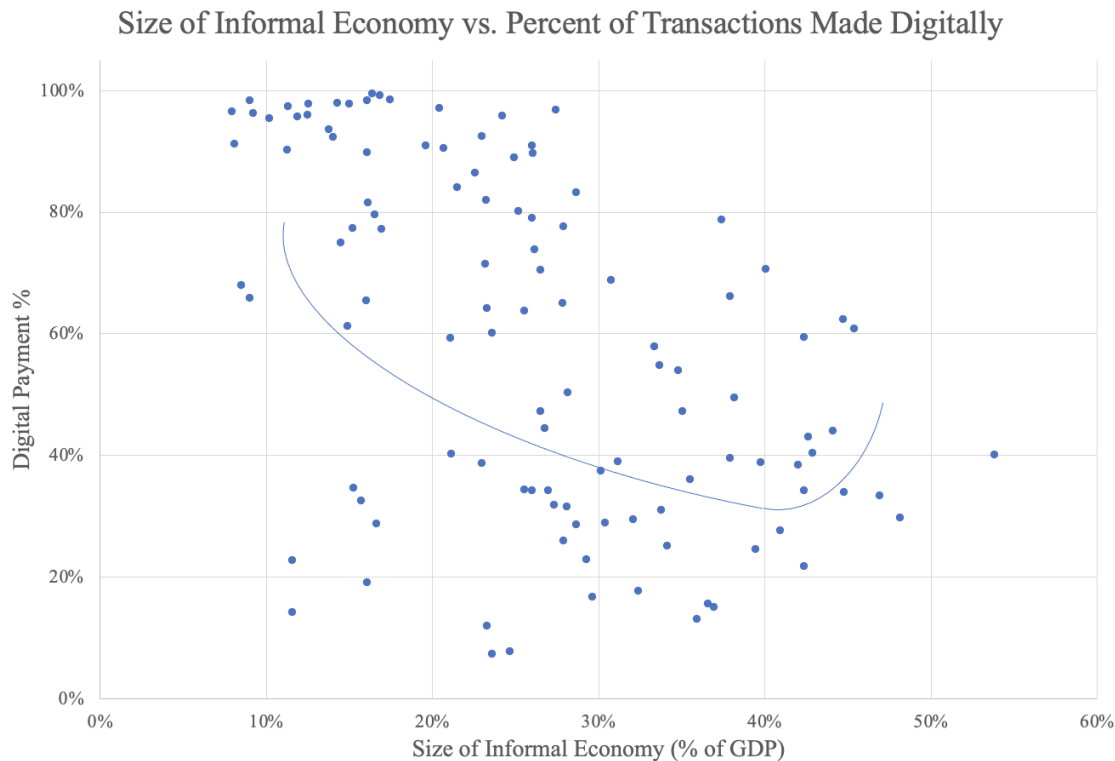
One drawback of this dataset is the small sample size of 27 countries (the size of the European Union), but regardless, we can see a trend emerge amongst this group of countries: the smaller the VAT Gap, the larger the % of payments happening digitally. Clearly, and to a degree of statistical significance, digital payments reduce the amount of tax evasion and the size of the informal economy - a clear downward sloping trend reveals that a higher frequency of digital payments is associated with lower tax evasion. From running this regression, the slope coefficient is statistically significant, implying that a 3% increase in the percentage of payments made digitally corresponds to a 1% decrease in the level of tax evasion within a country. The next regression shows the calculation of the "informal economy" which now includes all countries in the world based on approximations from relative governments, merged with data about the percentage of payments that happen digitally.^{36,37}

The second figure shows a quasi-parabolic relationship between the share of digital pay-

³⁵European Commission, "Study and Reports on the VAT Gap"

³⁶Elgin et al, "Informal Economy Database"

³⁷Demirgüç-Kunt et al, "World Bank - The Global Findex Database"



ments and the size of the shadow economy, indicating that countries with less informal transactions have more digital payments, but such effects become less important at higher levels of the shadow economy, namely amongst countries that constitute more than 40% of informal economic activities.³⁸ This result is supported in other studies as well. Using card payments as a proxy, a study by Caixa Bank Research found that an increase of 100 euros per capita per year in card payments reduces the shadow economy as a percentage of GDP by as much as 3.5 percentage points.³⁹ The IMF also cites research that greater use of simple electronic payments alone cut the size of the shadow economy significantly.⁴⁰

CBDCs, by having all financial information stored in a centralized ledger, would drastically reduce the number of transactions that occur in the underground economy. This allows the Federal Reserve and IRS to track transactions that happen through official digital currency, including labor income and person-to-person transactions for illegal goods and

³⁸Zhang and Oh, "Central Bank Digital Currency and Informal Economy."

³⁹Ruiz, "The Shadow Economy"

⁴⁰Schneider and Enste, "Hiding in the Shadows."

services. For the purposes of tracking smaller benign payments and salaries, the ledger offers a data hub to track tax collection and ensure worker benefit compensation. For larger illegal transactions, in many countries now, CBDCs are anonymous in small transactions, but an algorithm flags suspicious transactions when the amount reaches a particular threshold. Repeat transactions, unknown accounts, or patterns of suspicious payment amounts can be easy triggers for a computer algorithm, thus ensuring no human involvement is needed in places where privacy is a concern.⁴¹ No matter how CBDCs are implemented however, advocating for the complete removal of cash immediately is an unwise decision. Based on insight about usage, accessibility, and efficiency, a large rollout of electronic money would simultaneously occur with a gradual phasing out of cash.

Countries are well aware of this prime benefit of CBDCs and are collaborating with technology providers and crime-fighting organizations to spur research efforts. To quantify this, we can extend our analysis and look at the relationship between the size of the underground economy and the level of research happening on CBDCs; this means merging information with the international database collected annually that benchmarks the level of CBDC research and implementation across the globe.⁴² In the CBDC Progress Index, the regimes are labeled as such: no work being done on CBDCs (0), preliminary or advanced research stage (1), established pilot program launched (2), or a live implementation of retail, wholesale, or government-controlled CBDCs (3).⁴³ The table below summarizes the results from multivariate probit regressions performed on CBDC project indices regressed on the shadow economy index. The results are displayed here, with sample sizes and R-squareds:

⁴¹WEF, "Privacy and Confidentiality Options for CBDC"

⁴²Elgin et al, "Informal Economy Database"

⁴³CBDC Tracker

Dependent Variable - Probit Regression	CBDC Project Index	Retail CBDC Index
<i>Informal Economy (% of GDP)</i>	0.031*	0.0445***
SE_{InfEc}	(0.0189)	(0.011)
R^2	0.251	0.264
<i>Sample Size</i>	105	100

***/**/* indicates significance at 1/5/10% level

Not only is the informal economy larger where digital payment percentages are higher, but *work on CBDCs is more advanced where the informal economy is larger*, consistent with the notion that CBDCs, by creating a data trail for transactions, help formalize informal activities. While it seems like the development status of a country is a confounding variable, the BIS survey can dispel this notion and establish causality. Formalizing informal activity is one of the main motivating factors for CBDC implementation regardless of economic status, with over 70% of countries saying it is a top 5 motivation for pursuing a digital FIAT currency.⁴⁴

4.2 Pros: Financial Inclusion

Underbanking is a massive problem in the United States and one that receives very mainstream media coverage. The regulatory definition of "underbanked" is an individual that has a bank account but relies on alternative financial services such as "money orders, check-cashing services, and payday loans" because they lack access to "convenient, affordable banking services."⁴⁵ Unbanked individuals, on the other hand, have no bank accounts, meaning they do not use any mainstream financial services and rely primarily on cash, payday lending, or check-cashing services. Being unbanked is a huge financial and time cost - those who are unbanked have to rely on unregulated services like predatory lenders if they do

⁴⁴Boar, Codruta, and Wehri, "Ready, steady, go?"

⁴⁵Investopedia, "What Does Underbanked Mean?"

not have access to traditional types of financing. These loans can pile up interest payments fast and often prey on those with lower income and less financial literacy. Not having a bank account also means going through more lengthy and time-consuming processes for basic financial transactions, including using check-cashing as a proxy for direct deposit and money orders for bill and rent payment. Those who only use cash "can face annual costs of around \$199 for check cashing and money order services." Data collected by the US government reveals that around 20% of American adults, or 60 million adults, are either unbanked or underbanked, a trend that is slowly improving but remains incredibly problematic.⁴⁶

CBDC accessibility is, inherently, conditional on the availability of key infrastructure including, but not limited to, high-speed internet access, electricity penetration, reliable cellular network coverage, smartphone ownership, and digital ID systems.⁴⁷ And, if access to these services is sparse, CBDCs may exacerbate financial inequality, since not everyone has access to a phone with internet service. That is a valid concern for a significant number of countries with low GDPs and high levels of poverty, where low internet penetration, lack of smartphone ownership, and inadequate electrical grids are legitimate challenges. This graph, presented at the ITU-WB Digital Regulation Conversation in Geneva using Global Findex data, shows information about smartphone account ownership, a proxy and precondition for digitally advanced economies.⁴⁸ For example, many poor African nations have extremely low smartphone ownership.

While a solution for the global accessibility of CBDCs is necessary and addressed later in the paper, the trends in the United States are glaringly different. And, since this paper begins by establishing a blueprint for the digital dollar, it is worthwhile to understand the fundamental challenges facing the American financial system. A fact that very few people are aware of: the percentage of adults classified as 'underbanked' in the United States is *lower*

⁴⁶FDIC, "How America Banks"

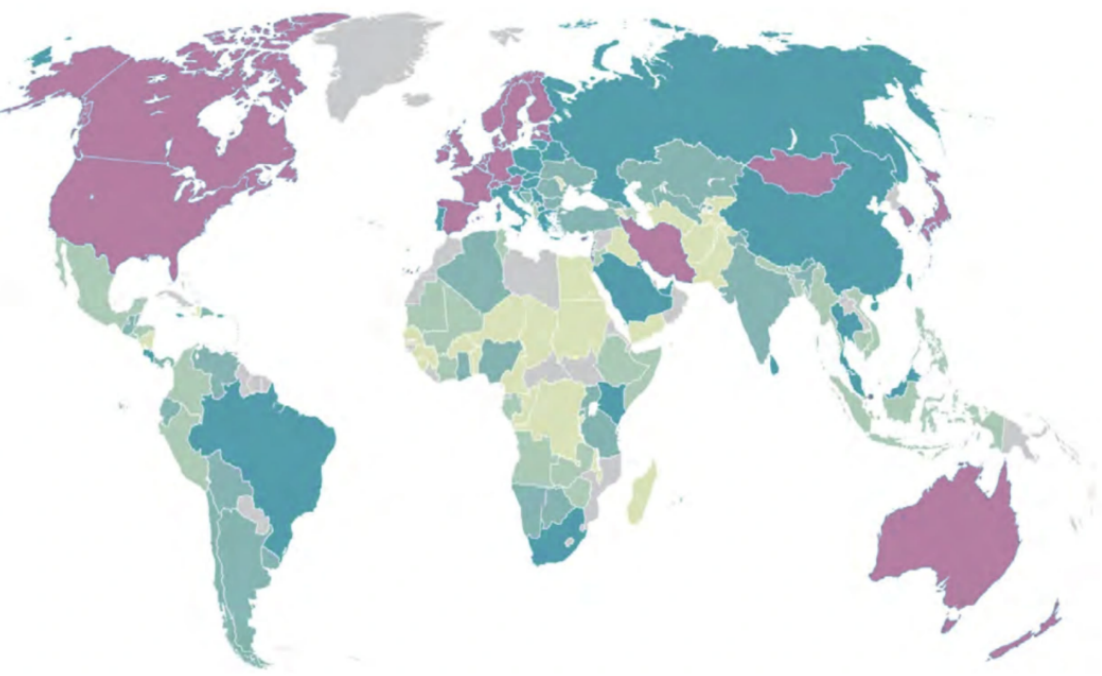
⁴⁷Schilling, Fernández-Villaverde, and Uhlig, "When Price and Bank Stability Collide"

⁴⁸Macmillan, "Digital Financial Services: Regulating for Financial Inclusion"

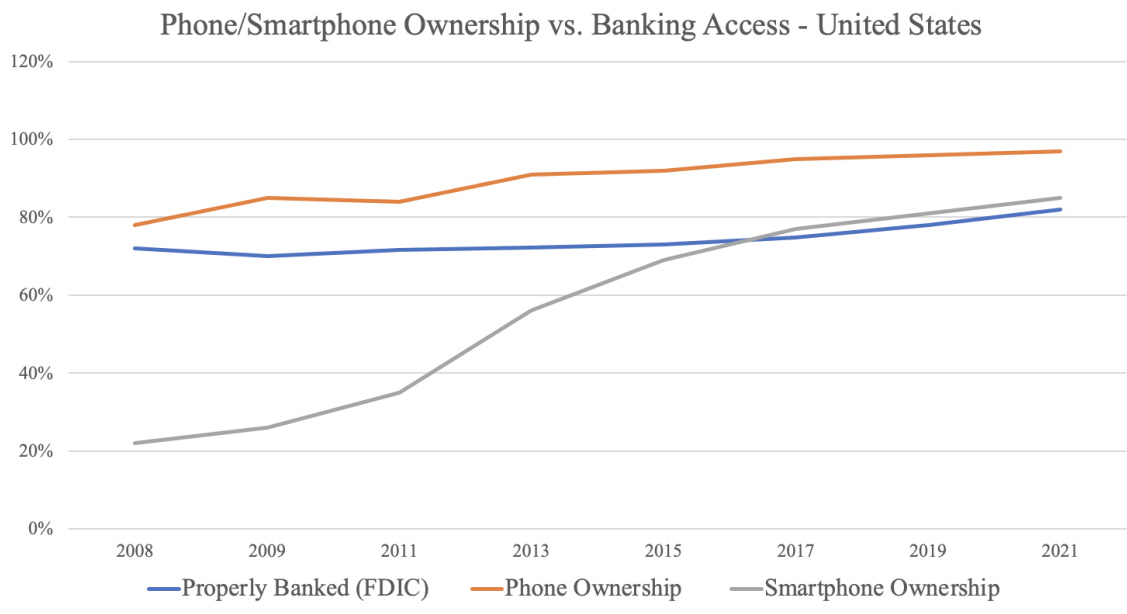
MAP 1.1
**Account penetration
around the world**
Adults with an account (%), 2014

- 0–19
- 20–39
- 40–64
- 65–89
- 90–100
- No data available

Source: Global Findex database.
IERD 41559 | APRIL 2015



than the percent of adults who own a smartphone. The data gathered below comes from merging datasets from comprehensive biennial surveys from the Federal Deposit Insurance Corporation (FDIC) and the Pew Research Center about technological progress and banking trends in the United States.⁴⁹⁵⁰



⁴⁹FDIC, *How America Banks*
⁵⁰Pew Research Center, *Mobile Fact Sheet*

Last year's data reveals that the percentage of adults that own a smartphone hovers around 85% and the percentage of adults that own any type of phone is close to 97%. In contrast, 81.9% of Americans in 2021 were classified as underbanked or unbanked. As of 2016, the percentage of Americans who owned a smartphone has surpassed the percentage of Americans who have access to proper banking services, a trend that has been consistently sustained for the past 6 years. This reveals a natural conclusion: giving people access to their money on a smartphone greatly increases the accessibility of money and makes banking easy for those who do not have accounts with commercial banks. When banking is expensive and inconvenient, either because of geography or time/income constraints, digital infrastructure can help close the gap and promote financial inclusion. Other requirements for digital currencies like reliable electricity already exist in the United States; the U.S. Energy Information Administration reports that 100% of the US population has access to electricity as of 2021.⁵¹

How do CBDCs resolve the problem of underbanking? There are three fundamental reasons. First, CBDCs provide access to digital currency for populations that do not have access to traditional commercial banks or e-money operators. While commercial banks, in theory, are meant to be inclusive of all, there are large barriers to entry that CBDCs can help resolve. A recent FDIC survey, for example, reveals that the most commonly cited reason for remaining unbanked is that people feel they do not have enough disposable income to "meet the minimum balance requirements for a bank account."⁵² According to the same survey by the FDIC, the average minimum balance requirements for accounts with no interest was \$622, and the average minimum balance for accounts with interest was a whopping average of \$7,123. If you fail to meet the threshold, the average maintenance fee for non-interest bearing accounts was \$5.61 a month and \$15 a month for checkings accounts with interest payments.⁵³ Fees for a low-balance bank account can continue to pile up, and unreasonably

⁵¹EIA, *Electricity Data*

⁵²FDIC, *FDIC Survey of Household Use of Banking and Financial*

⁵³ibid

high monthly payments compounded with historically low interest rates prey on low-income populations. Nearly 1 in 4 people who do not have a bank account are interested, but find it geographically/logistically inconvenient or are deterred by other structural factors. The other most commonly cited structural reasons include poor credit scores, insufficient capital to warrant the creation of an entire account, lack of knowledge about credit services, or lack of physical access to a reputable national bank within 10 miles.⁵⁴ A CBDC wallet circumvents many of these issues by providing a government-authorized, convenient solution for storing currency and conducting transactions throughout the economy. With a wallet that grows at some nominal interest rate and no minimum balance fees/barriers to entry for those who are not located near a physical branch, CBDCs promote financial inclusion for the unbanked and underbanked. Transferring money to your digital wallet can occur either by directly linking your e-wallet to your commercial account; for those without access to e-money, a digital wallet would include direct deposit from employers or government assistance programs, online check photo depositing as well as dropoffs at post offices, town halls, or other physical infrastructure. While other savings mechanisms like stock market investing, cryptocurrencies, savings accounts, or credit card rewards may seem difficult to someone with less financial knowledge, digital currency gives convenient and easy-to-understand access to interest-growing accounts for all.

Second, as previously mentioned, CBDCs become an extremely useful mechanism for governments to make stimulus payments to individuals even if they do not have a bank system setup, thus ensuring the population receives money quickly and efficiently during time-sensitive periods. Even in a country as digitally sophisticated as the US, millions of Americans, disproportionately the unbanked and underbanked, had to wait months to receive their \$1200 stimulus payments. For example, those without bank accounts do not have direct deposit information that they can easily provide to the government databases

⁵⁴ibid

for coordination of stimulus payments.⁵⁵ CBDCs can help set up a uniform program by eliminating financial intermediaries like check-processors and commercial banks during times of required economic stimulus, helping collect data about how low-income communities are using digital money, and reducing the cost and time needed to transit checks and money door-to-door.

Third, there is a robust set of literature theorizing that CBDCs would promote digitization of common peer-to-peer and business-to-business payments and create value chains for those who are unable to efficiently conduct transactions now.⁵⁶⁵⁷ This is similar to the economic concept of "network effects," whereby people simply benefit from an inclusion standpoint when those around them adopt technologies and they become commonplace around various parts of the economy. Free open banking frameworks help link people and make transactions more efficient, similar to the way that Venmo and PayPal help foster interoperability within financial services and payment services. Having a legally-regulated and universally accepted legal tender gives CBDCs a crucial leg-up from other third-party software, allowing for digitization in various parts of the economy. This includes international and domestic supply chain distributors, producers, and enterprises of all sizes, along with consumer transactions that can happen efficiently and affordably.

Finally, CBDCs can become a strong catalyst toward granting universal access to broadband Internet and data.⁵⁸ While low Internet penetration is an extremely pressing issue within rural and low-income communities and counties, a nationwide digital currency would require government investment in Internet Service Providers (ISPs). For example, Biden's recent infrastructure plan allocates significant funds towards expanding the range of ISPs and providing grants for local investments.⁵⁹ More detail about this issue is addressed in

⁵⁵House Hearing, 116 Congress

⁵⁶Allen, Esser, and Cooper, "CBDC and Financial Inclusion"

⁵⁷Raghuveera, "Central bank digital currency can contribute to financial inclusion"

⁵⁸Pantuliano and Tyson, "Can Central Banks Digital Currencies deliver for people in poverty?"

⁵⁹President Biden's Bipartisan Infrastructure Law

Section 6.6. Even in areas with low internet access, CBDCs could implement workarounds to “operate in low-bandwidth areas such as DCEP’s “touch and touch” functionality, allowing users to make peer-to-peer transfers by physically touching their mobile devices together.”⁶⁰

4.3 Pros: Data-Driven Monetary Policy

In the status quo, there is a shocking lack of information being used when evaluating monetary policy interventions like open market operations and adjustments to various interest rates across the economy. Since many financial transactions occur in ways that the federal government has difficulty tracking (like cash and underground operations), the Federal Reserve is unable to draw causality or track how a singular dollar bill moves through the economy. A core component of tracing the effectiveness of monetary policy is the ability to understand how dollar bills flow; without an ability to track the velocity of money and craft an accurate estimate for the money multiplier, economists struggle to establish causality and pinpoint effectiveness with any degree of granularity.

More robust benevolent data collection and analysis from the central ledger would not only increase the efficiency of existing policy levers but also open up experimental possibilities for a new era of Federal Reserve policy. These new policy tools can help expand the portfolio of options available to the Federal Reserve, since adjustments to the interest rates are constrained by the zero lower bound and newer tools like quantitative easing propels inflation.⁶¹ Given that a variety of macroeconomic indicators are flashing red, including record-high inflation, historically low interest rates, and foreign policy instability, a paradigm shift may be necessary.

A digital dollar opens up the potential for a whole host of targeted monetary policy tools and levers that would’ve otherwise been impossible. This could create a completely new

⁶⁰Yeung, “Digital Currency”

⁶¹Klement, “A New Form of Monetary Policy?”

form of monetary policy stimulus that is impossible to achieve with our current financial system, allowing the Central Bank to target interventions with pinpoint precision.⁶² The fundamental problem relies upon a consistently disproven notion of trickle-down economics, which is the belief that providing money and tax breaks to the rich tends to increase the velocity of money and boost productivity for the general economy. However, this theory has been debunked repeatedly in academic literature.⁶³⁶⁴ Even during the coronavirus pandemic and the recent decrease in the corporate tax rate, money was saved or reinvested by those with higher incomes, meaning it fails to move through the economy and cuts the money multiplier short. Those who already have high-income levels find it most convenient to save money or capitalize on low prices in the stock market because they have the luxury of disposable income during recession periods.⁶⁵ Cash, checks, and traditional bank accounts exacerbate the problem and occur in a way such that the government has difficulty doing granular analysis of spending/stimulus patterns.

While there are many potential tools, four theoretical policies can highlight the limitless flexibility and potential of digital money. First, to achieve short-term stimulus, the central bank can create money with time limits and set a demurrage fee on digital currency stored for long periods of time during recessions.⁶⁶ For example, the Fed could require that, during times of extreme economic distress, granted money must be spent within a certain time period or it disappears from the digital wallet. A percentage demurrage fee on currency could reduce the face value of a dollar stored in the digital wallet, acting as a tax for making a conscious decision to save during recessionary economic times. Second, the Central Bank could implement progressive demurrage fees. Not only would these fees increase with income, but they could also increase with respect to your savings amount. For example, someone in the highest tax bracket could face a significantly higher depreciation rate on their digital

⁶²ibid

⁶³Hope and Limberg, "The Economic Consequences of Major Tax Cuts for the Rich"

⁶⁴Arndt, "The "Trickle-Down" Myth

⁶⁵ibid

⁶⁶Klement, "A New Form of Monetary Policy?"

wallet during economic recession times should they choose to hold large amounts in their e-wallet. Similarly, saving larger amounts of money or a greater percentage of the stimulus money could elicit a higher demurrage rate.⁶⁷ Third, the Federal Reserve could issue currency that would be targeted towards spending on specific items like durable goods to create targeted monetary interventions. A sub-par usage of this policy lever would be to assign permanent fees if money is used for "productive" (gyms, food, rent) versus "unproductive" goods (gambling, alcohol, luxury goods). A better method would be setting conditions on spending in broad categories during recessionary periods, ensuring the money is spent on essentials or actual "items" and not vessels for saving.⁶⁸ Finally, the central bank can institute across-the-board negative nominal interest rates on CBDC wallets to solve the zero lower-bound problem.⁶⁹ This issue is discussed in more detail with policy implementation recommendations in Section 6.2 of the paper. Each person I interviewed was either unaware or declined to comment on whether the Federal Reserve was exploring any variation of these four kinds of monetary policy levers.⁷⁰

Regardless of which experimental approach to monetary policy is chosen, the potential for tracking and understanding monetary stimulus with big data is an exciting challenge. To begin to put into perspective how easy it is to track the velocity of money and analyze monetary spending, I used Venmo data as a proxy for CBDCs, since they are a prevalent form of digital payment that occurs in the status quo.⁷¹ Because Venmo data is collected in a unified ledger, Venmo payment volume and information can be analyzed, and we can reveal trends about how money flows through digital payments. Since only Venmo holds proprietary information about the quantity of money being moved through each transaction, the information is confidential and cannot be accessed by third-party companies, govern-

⁶⁷Nelson, "The Benefits and Costs of a Central Bank Digital Currency for Monetary Policy"

⁶⁸ibid

⁶⁹ibid

⁷⁰Member of the collective of 400 Ph.D. economists employed by the Federal Reserve Board who produce working papers and conduct cutting edge research. Interview by the author.

⁷¹Thanks to Kanit Kuevilvanich from the UChicago Dept of Economics for the inspiration & assistance.

ments, or researchers. However, you can imagine the amount of specific information that can be analyzed if the database was able to reveal transaction or identity information (even if pseudonymized to avoid revealing personal information). From Venmo’s financial statements, we can get aggregated data about usage, indicating that smartphone digital payment mechanisms are picking up steam. This points to a well-researched trend that making mobile payments easier and more convenient (from both peer-to-peer and business-to-consumer) results in efficient financial transactions.⁷²

Year	Total Payment Volume	Users
<i>2015</i>	\$7.5 billion	3 million
<i>2016</i>	\$20 billion	5 million
<i>2017</i>	\$34 billion	10 million
<i>2018</i>	\$62 billion	23 million
<i>2019</i>	\$101 billion	40 million
<i>2020</i>	\$159 billion	52 million
<i>2021</i>	\$230 billion	70 million

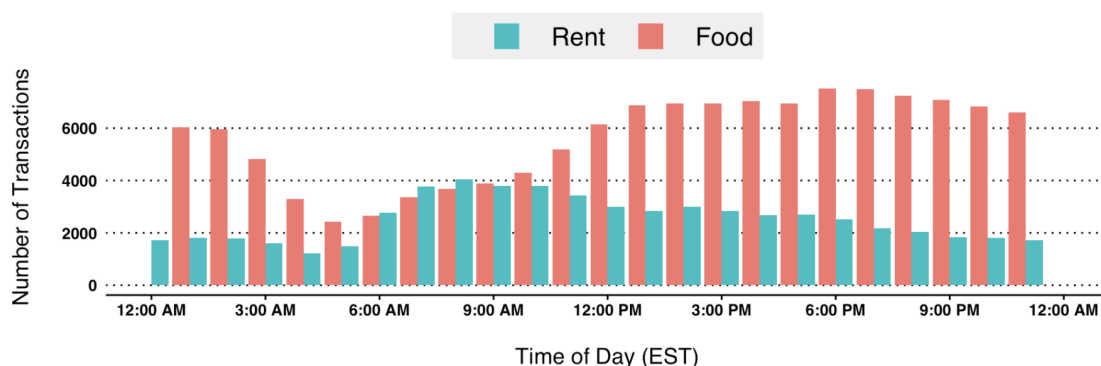
Since Venmo has an option to make transactions public, a simple Python scraping tool can parse through captions, frequency of usage, and the number of transactions despite not being able to see who is making the transactions or the monetary amounts. After using this tool, a dataset of 7 million transactions from just August to October of 2019 was generated after scraping public Venmo records.⁷³ The information found here can identify the time of day where transactions happen most often for server capacity purposes, what the most common use case for digital payments is, and the trends of Venmo usage. First, the most common keywords:

⁷²Curry, "Venmo Revenue and Usage Statistics (2022)"

⁷³Salmon, "Venmo Transaction Dataset"

Word	Total Uses
<i>Food</i>	135 thousand
<i>UBER</i>	92 thousand
<i>Bills/Bill</i>	74 thousand
<i>Rent</i>	60 thousand
<i>Love</i>	44 thousand
<i>Gas</i>	42 thousand
<i>Dinner</i>	31 thousand

By parsing through time stamps on the data, we can see how the usage of financial transactions changes over time, an ability that is hampered by non-digital types of currency.⁷⁴



This sort of data collection is only the tip of the iceberg and is mostly analyzing some fun permutations and combinations. An entity or organization that has access to financial transaction amounts can track how each individual dollar moves through the various parts of the United States. This is useful for a variety of purposes, including calculating the money multiplier as it moves through the economy, the exponential effect of monetary stimulus, and where stimulus should be targeted to create the largest expansionary potential. For example, something as simple as this Venmo data can help the US government understand server capacity needs around different times of day and year.⁷⁵

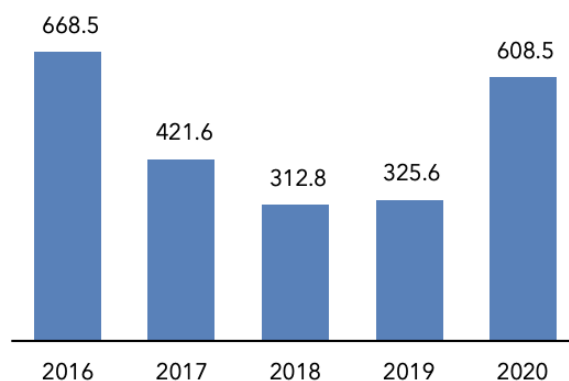
⁷⁴Oehmler, "Venmo Transaction Analysis"

⁷⁵ibid

4.4 Pros: Cost-Minimization & Seigniorage

Printing money and dealing with local central banks is costly - each year, the U.S. Mint realizes millions of dollars of seigniorage. Seigniorage is costs associated with the issuing of physical cash currency, noted as the difference between the face value of coins/bills versus their production costs.⁷⁶ In FY2020, the U.S. Mint had a seigniorage cost of 605 million dollars, and nearly 400 million in 2021 (mainly due to a decrease in quarter and penny production causing a massive coin shortage in the U.S. financial system).⁷⁷ Digitization saves money in the long run and lets us more efficiently disperse money across the economy during periods of quantitative easing and cash circulation.

Seigniorage and Net Income (dollars in millions, before protection cost)



Where do these costs come from? A simple breakdown of the cost of printing, distribution, minting, metal/material costs, and quality-checking reveals a shocking pattern of inefficiency. Some coins like the nickel and penny cost more to make than they are worth on the market, and a dollar bill, for example, loses nearly 5% of its value in the minting and printing process.⁷⁸ Given that, in fiscal year 2021, the U.S. Mint printed 7.0 billion notes, these costs compound themselves and foster disequilibrium. FY 2022 projections for print

⁷⁶Kuevibulvanich, "Economic Policy Analysis - Lecture Notes"

⁷⁷United States Mint, "2021 Annual Report"

⁷⁸ibid

amounts range from 6.9 billion notes to 9.7 billion notes, indicating that cash printing as the U.S. moves through a period of financial turbulence is only predicting to increase.⁷⁹ Given inflationary concerns, employment shifts, the move away from the pandemic-era economy, geopolitical tensions like the war in Ukraine, and more, instability looks to be incredibly high, eliciting an aggressive approach from the Federal Reserve.

Note	Cost Per Note (cents)	% of Face Value
<i>Penny</i>	2.1	210%
<i>Nickel</i>	8.52	170.4%
<i>Dime</i>	4.39	43.9%
<i>Quarter</i>	9.63	38.5%
<i>\$1, \$2</i>	4.9	4.9%
<i>\$5</i>	10.9	2.18%
<i>\$10</i>	10.3	1.03%
<i>\$20, \$50</i>	10.5	0.53%
<i>\$100</i>	12.3	0.12%

While digitization incurs a high fixed cost, like most business software and technological solutions, variable costs become negligible. As implementation stretches over a longer time horizon, theoretically, fixed costs are distributed over many years, reducing average fixed costs and average total costs in the long run. Research from Payment Canada estimates that CBDC has the potential to reduce the costs of Seigniorage by as much as 90%, since production cost approaches zero, the life expectancy of currency is infinite, and there are no circulation costs.⁸⁰

⁷⁹ibid

⁸⁰Borysowich, "Central Bank issued digital currencies: a global trend"

4.5 Cons: International Financial Inequity

CBDC implementation, by nature, requires access to technological infrastructure, and the unequal implementation of CBDCs could leave certain countries behind while more advanced nations propel themselves forward. Given that the currency market is inherently global, international economists and policymakers are wary of letting smaller countries fall behind in technological implementation, which could materially impact their ability to trade, engage in foreign currency markets, have stable inflation-protected currencies, and keep pace with a potentially cash-less world.⁸¹ And, since this paper analyzes the digital dollar, international concerns should be embedded with the calculus for domestic implementation. A network of global CBDCs could make cross-border payments and international transactions significantly easier since infrastructural networks of e-wallets could easily be coordinated between nations. Without exorbitant fees and regulatory loopholes, a global rollout of CBDCs can allow exchange rates to flourish and make international finance significantly more efficient than the status quo.⁸²

To quantify the difference between countries that invest in CBDCs and those that don't, we can simply look at the difference between developed and developing nations with respect to their implementation levels. This can help quantify the actual economic differential between countries that are considering CBDCs and those that will be theoretically left behind in the digitization era. International datasets can be compiled with information about a country's level of digitization and economic prosperity, as well as data points about mobile cellular subscriptions, capacity for innovation as measured by the World Intellectual Property Organization (WIPO) innovation output score, the scale of the informal economy, and level of financial development.⁸³⁸⁴⁸⁵ This information can be combined with the international

⁸¹Foster et al, "Digital currencies and CBDC impacts on least developed countries (LDCs)"

⁸²BIS, "Central bank digital currencies for cross-border payments"

⁸³WIPO, *Data for Researchers*

⁸⁴Elgin et al, "Informal Economy Database"

⁸⁵World Bank, *Global Financial Development Report*

database collected annually that benchmarks the level of CBDC research and implementation across the globe. In the CBDC Progress Index, I labeled the regimes as such: no CBDC work (0), preliminary research stage (1), proof of concept or advanced research stage (2), established pilot program launched (3), or a live implementation of retail, wholesale, or government-controlled CBDCs (4).⁸⁶ The regression being run is as follows:

$$Prob(CBDC_i = 0, 1, 2, 3, 4|x_i) = F(\beta_0 + \beta_1 Cell_t + \beta_2 Innov_t + \beta_3 FDI_t + \beta_4 Trade_t + \epsilon_t)$$

The table below summarizes the results from multivariate probit regressions performed on CBDC project indices regressed on various development variables, with a sample size of 195 countries:

Dependent Variable - Probit Regression	CBDC Project Index	Retail CBDC Index
<i>Phone Subscription (Cellular)</i>	0.014**	0.021***
<i>SE_{Cell}</i>	(0.001)	(0.002)
<i>Innovation Output Score</i>	0.045***	0.067***
<i>SE_{WIPO}</i>	(0.019)	(0.009)
<i>Financial Development Index</i>	3.9***	2.791***
<i>SE_{FinDev}</i>	(0.867)	(0.07)
$\frac{Imports+Exports}{GDP}$	-0.001	-0.02*
<i>SE_{Trade}</i>	(0.004)	(0.007)

***/**/* indicates significance at 1/5/10% level

Most generally, it can be confidently said that **CBDC projects are more advanced in more digitized economies**, as defined by cellular subscriptions, high levels of innovation output, and high levels of financial development; this information indicates that those

⁸⁶CBDC Tracker

countries who are further along in CBDC implementation not only have the capacity for technological infrastructure but also have more need for efficiency and settlement services for their plethora of economic transactions. While it seems like an intuitive result, there are real material consequences for emerging market economies.

The Impact of "Dollarization": The idea of "dollarization" or "euro-ization" is the recent phenomenon where many households and businesses in smaller countries simply use a foreign currency in daily financial transactions and contracts.⁸⁷ All domestic business is conducted in a foreign currency, throwing off money supply and central bank policymaking, as well as often leading to rapid local currency devaluation. Moreover, more countries are beginning to peg their currencies explicitly to perceived stable currencies, like the U.S. Dollar.⁸⁸ When countries peg their exchange rates on the global market, they lose the ability to have financial sovereignty over deciding to increase the interest rate in response to hyperinflation, a problem coined in an economic theory called the "Mundell-Fleming Trilemma Model".⁸⁹ The Mundell-Fleming model suggests that if countries set a fixed currency exchange rate and allow capital to flow freely with no fixed currency exchange rate agreement, then they lose the ability to craft autonomous monetary policy. Take a simple example, like the Hong Kong dollar (HKD), which is pegged 1:1 to the U.S. dollar. If inflation gets out of control in Hong Kong, the Hong Kong Monetary Authority (HKMA) would want to increase interest rates, which would subsequently cause the demand for HKD to increase. However, this increase in the demand would cause the HKD to appreciate, which cannot logically happen since HKD is pegged to the U.S. dollar! This lack of monetary flexibility is only one of the many consequences of dollarization, which creates fiscal and monetary power imbalances internationally.⁹⁰ For emerging markets that are attempting to grow internationally while also ensuring stability in their local currencies, CBDCs could hamper natural growth

⁸⁷Kuevibulvanich, "Economic Policy Analysis - Lecture Notes"

⁸⁸Berg and Borensztein, "The Pros and Cons of Full Dollarization"

⁸⁹Kuevibulvanich, "Economic Policy Analysis - Lecture Notes"

⁹⁰ibid

and increase vulnerability to foreign influence. And, while it is true that dollarization is inevitable in certain places, the ease and convenience of digital currencies enable substitution at a faster pace and could result in higher local inflation and exchange rate volatility. Non-uniform implementation of digital currencies defeats much of the purpose of CBDCs in international trade optimization.⁹¹

Given that cross-border payment efficiency is listed by countries as one of the top reasons CBDC enactment, these issues need to be grappled with if we want to truly create an equitable model of international financial inclusion.

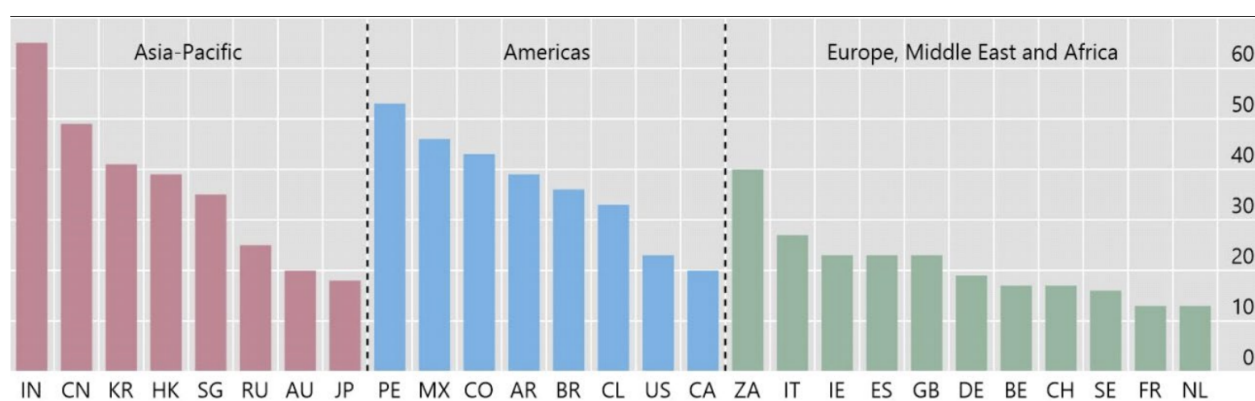
4.6 Cons: Privacy Concerns

Governments are, understandably, very wary about making sure that CBDC implementation is coupled with stringent regulations about data accessibility, with a strong emphasis on ensuring privacy for users.⁹² Though difficult to quantify, it is important to study what degree of access the Central Bank would want to balance security and privacy, especially since the BIS survey cites privacy as a leading cause of concern for banks across the world.⁹³

Preferences regarding privacy vary across countries

In per cent

Graph 8



⁹¹Auer et al, "CBDCs: Motives, Economic Implications and the Research Frontier"

⁹²WEF, "Privacy and Confidentiality Options for Central Bank Digital Currency"

⁹³Boar, Codruta, and Wehrli, "Ready, Steady, Go?"

Account-based CBDCs are efficient because central banks will honor the claims of users and store them within a centralized digital ledger controlled by the Federal Reserve. The value would be encrypted by a secret key in which the storage of the data is either managed by a trusted third-party private company contracted by the federal government or non-custodial, meaning it is stored physically on the device of the user that receives the payment. In practice, a balance could be struck between the two - while non-custodial designs help provide universal access, less financially literate consumers could lose access to their funds if they forget their private encryption key or accidentally leak it. Data controlled by third parties or directly on the e-wallet app helps to create centralized ledgers of transactions and all user credentials, which can lower risks associated with being locked out of accounts and creates network effects for data collection purposes.⁹⁴ These are challenges to data privacy that need to be legitimately considered, especially when the data is all personal financial transactions, and is regulated heavily by a variety of federal, state, local, and private entities that have rules of storage of confidential information in databases. Optimal policy design for data access is described in detail in Section 6.5 of the paper.

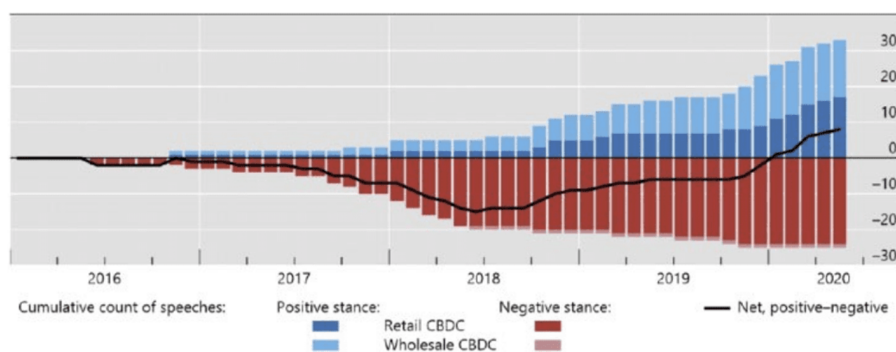
Many of the aforementioned benefits of digital currencies hinge on being able to track or analyze data with some level of granularity; this includes cracking down on financial crime, stopping tax evasion, analyzing how money moves through the economy, and more. Thus, a balance needs to be found between the interests of privacy/anonymity and enforcement/data analysis, a debate that was prominent during the post-9/11 period of mass U.S. surveillance. While authors like Bech & Garratt have argued for completely anonymous ledgers with a token-based cryptocurrency-like design, I believe that this is unrealistic, especially from a regulatory standpoint.⁹⁵ Regulatory laws demand that central banks design CBDCs that conform to disclosure requirements, even though combating terror funding and money laundering is not a core central bank objective. Striking a balance between data privacy and

⁹⁴Darbha and Arora, "Privacy in CBDC Technology"

⁹⁵Bech and Garratt, "Central Bank Cryptocurrencies"

protection and reducing illegal activity will require coordination with domestic government agencies like tax authorities and local money laundering task forces and operations, which can be a legitimate challenge.⁹⁶

In a recent international study, “46% of respondents stated they would NOT trust a digital currency issued by their government or central bank.” While this is higher than trust in Privately-Issued Crypto Assets, it reveals a trend of mistrust in institutional checks and balances.⁹⁷ This is an issue that needs to be alleviated, but one that may be difficult to work around - for example, in countries like the People’s Republic of China (PRC) where the digital yuan is in a full pilot stage, distrust of the currency is high simply because of the lack of anonymity of transactions. Citizens are understandably wary of how their transactions on the digital yuan are being tracked by government officials, and whether this information can be weaponized against them.⁹⁸ As digital currency moves towards more authoritarian and less benevolent countries, privacy concerns become exponentially more important, and the US needs to ensure that it is careful about data collection and storage. In general, however, it seems the tide of public opinion, at least in the United States, is shifting. Doing natural language processing (NLP) from notable central bank speeches, sentiment is turning more positive, which can signal better trust with data from the general public.⁹⁹



⁹⁶Pocher and Veneris, “Privacy and Transparency in CBDCs”

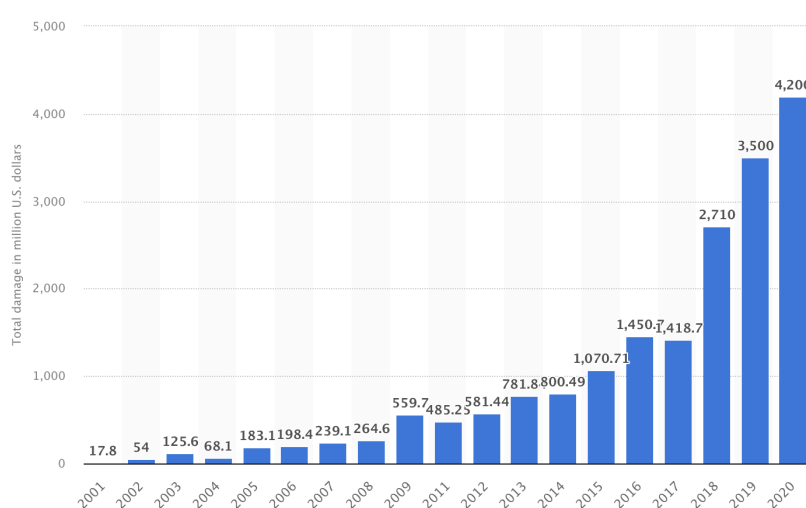
⁹⁷Haig, “Survey: Consumers Trust CBDCs Over Privately-Issued Crypto Assets”

⁹⁸Kshetri, “China’s Digital Yuan: Motivations of the Chinese Government and Potential Global Effects”

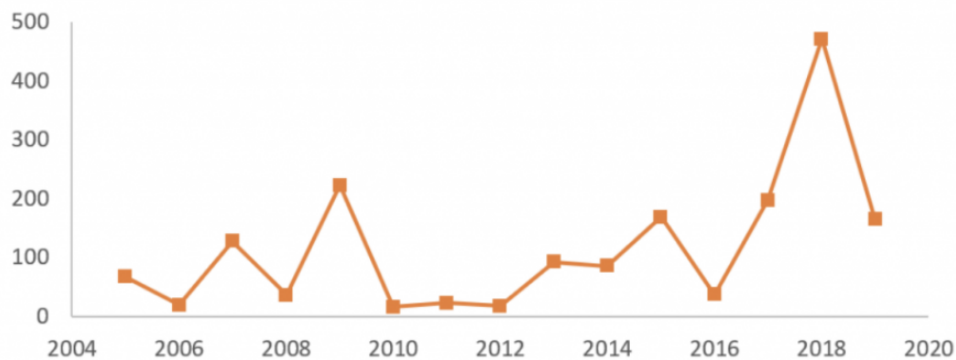
⁹⁹Shin, “Central banks and the new world of payments”

4.7 Cons: Data Security & Cybercrime

Cybercrime is on the rise now and data security for the centralized ledger should be a top priority for digital dollar design. Using data from IC3 under the Federal Bureau of Investigation, we have evidence that as malware and hacking become more sophisticated and technologically advanced, cyber attacks continue to rise. This has effects that spill over to cause identity theft, loss of private personal information, and unauthorized access to funds. The graph below shows the amount of monetary damage caused by reported cybercrime.¹⁰⁰



Additionally, the amount of identity theft cases continues to rise. On the Y-axis is, in the millions, the number of records stolen¹⁰¹:



¹⁰⁰IC3, "Internet Crime Report"

¹⁰¹ibid

This naturally raises the question of how to circumvent these problems through optimal wallet design. Given the ways that attackers have become more sophisticated, malware and side-channel attacks could be used to get login and key credentials from an individual's device.¹⁰² Any system needs to also have built-in credential recovery mechanisms which could be exploited if the data was not stored securely. One common workaround that is proposed in the literature is using blockchain technology, which would encrypt all transactions such that two other trusted parties would need to hold credentials to the same wallet. These are called "multi-sig" wallets, where the Fed itself or family/friends of the user hold credentials to the same wallet; however, they are significantly less user-friendly, since it would require each transaction to need the approval of another party.¹⁰³ 2-Factor Authentication using the Federal Reserve as the "multi-sig" repository is the most logical solution - every time you conduct a transaction, you would need a one-time passcode (OTP) from the Federal Reserve to ensure security within your transaction.¹⁰⁴

Another concern is that the government needs to have the ability to freeze or withdraw funds in certain cases, which is completely in line with other digital payment mechanisms and only used in last-resort cases. Because this role is an integral part of the requirement for a CBDC, it also opens the door for vulnerabilities if malicious actors can get inside of the system. Thus, strong regulation needs to be in place to ensure strong information technology (IT) solutions and a cybersecurity risk-management plan that designates when these protocols should be used. Multi-sig wallets make these attacks significantly more difficult as well.¹⁰⁵ As for the general master ledger, by partnering with private bank institutions and third-parties that already have robust security mechanisms to ensure that their financial data is not hacked, we can ensure some level of baseline security. End-to-end encryption of data that must be accessed with a secure and stable key also makes it extremely difficult to hack

¹⁰²Hansen and Delak, "Security Considerations for a Central Bank Digital Currency"

¹⁰³Allen et al, "Design Choices for Central Bank Digital Currency - Policy and Technical Considerations"

¹⁰⁴Lee, "CBDC Wallets and the Security Requirements"

¹⁰⁵Allen et al, "Design Choices for CBDC"

into the entire database, since each transaction is secured with its own unique marker.¹⁰⁶ The recommendation for how to structure digital wallet security is discussed at length in Sections 6.2 - 6.4.

¹⁰⁶Lee, "CBDC Wallets and the Security Requirements"

5 Theoretical Results - A Macroeconomic Model

A robust macroeconomic model is necessary to consider theoretical implementation and optimization frameworks for Central Bank Digital Currencies, since data availability is sparse and it's difficult to move outside the realm of theory because of the amount of confounding variables. The model is based off the findings of Massimo Minesso Ferrari, Arnaud Mehl, and Livio Stracca in their paper "Central bank digital currency in an open economy," and the process is replicated with interesting findings:¹⁰⁷

5.1 The Digital-Cash Hybrid Model - Optimization Framework

The first essential equation is a representation of the theoretical relationship between cash and CBDCs in the economy. Since CBDCs are meant to coexist with cash in the short-term, we need a model to consider how a person decides between their amount of cash holdings and amount of CBDC holdings when presented with both options in a vacuum.

$$\mu^{CBDC} = \frac{\Theta * \rho * r}{\chi} * \mu^{Cash}$$

$$\sigma^{CBDC} = (1 - \Theta - \rho + \chi) \sigma^{Cash}$$

There are three crucial parameters here. First is Θ , which is a person's preference for liquidity, or immediate access to funds, with a value of 1 meaning that CBDCs are exactly equivalent to cash. Θ cannot be 0, since that would mean that digital currency is as illiquid as a certificate of deposit (CD) or a bond that cannot be touched for a certain number of years, which is an illogical conclusion. Instead, it is most likely that Θ is greater than 1 because it provides liquidity services that are better than cash or other alternative forms of payment. There's evidence to suggest this is true: it's more secure and accessible on your

¹⁰⁷Ferrari, Mehl, and Stracca, "Central bank digital currency in an open economy"

phone, it is a more appealing form of payment to people because of its ease of usage, and it doesn't have large storage costs, especially if you have a lot of wealth. Second is χ , which is the switching costs or inconvenience costs of moving to the digital currency platform. Regardless of how the program is implemented, there is a time and labor cost associated with switching over to a new payment system, hence defining χ as the "convenience cost of CBDCs," which could include a number of things. Since people tend to be resistant to change with status quo bias, this force may be quite large. Third is r , which is simply the nominal interest rate that you would earn on CBDC holdings, which will (the majority of the times) be positive, since cash earns little to no interest. Fourth and finally is ρ , which is the miscellaneous benefits of CBDCs, including its ability to be used for cross-border payments, network effects, its potential for more efficiency, or the hypothetical increase in economic productivity as a result of the policy.

Next, we can write an equation for household utility to maximize, where C_t is current consumption level, C_{t-1} is yesterday's consumption level, β is the discount factor, $L(i)$ is the labor hours worked, M_t is cash holdings, P_t is the price level, DC_t is digital currency holdings, all the σ values are relative elasticities of substitution, and all the μ s are scaling parameters.¹⁰⁸ All other variables can be substituted from the relationships established above between cash and digital currency:

$$U(HH) = \frac{(C_t - \beta C_{t-1})^{1-\sigma}}{1-\sigma} - \int_0^1 L(i) di + \mu^{Cash} \frac{M_t^{1-\sigma^{Cash}}}{1-\sigma^{Cash}} + \mu^{CBDC} \frac{DC_t^{1-\sigma^{CBDC}}}{1-\sigma^{CBDC}}$$

We assume that households have traditional Constant Relative Risk Aversion (CRRA) utility preferences for wealth, meaning they have diminishing marginal utility of wealth. Next, the household budget constraint, where e_t is the exchange rate, B_t^H is domestic bonds and B_t^F is foreign bonds, D_t are deposits, w_t is the wage rate, r_t is return on bonds, δ is the storage cost of cash, and all other parameters are the same:

¹⁰⁸Ferrari, Mehl, and Stracca, "Central bank digital currency in an open economy"

$$P_t C_t + B_t^H + e_t B_t^F + D_t + M_t + DC_t \leq w_t L_t + r_t B_{t-1}^H + r_t^* e_t B_{t-1}^F + \delta^{Cash} M_{t-1} + r_t^D P_t D_{t-1} + r_t^{DC} DC_{t-1} + \pi_t$$

How can we interpret this equation? It's relatively simple past all of the math - your current level of consumption plus whatever bonds you buy, along with anything you hold (deposits, cash, or digital currency) must be less than or equal to whatever you earn. Your earnings in the model includes your labor income, the return on your domestic and foreign bonds that you bought in the previous time period, as well as your return on deposits, return on digital currency (nominal interest rate), less the storage cost of cash. The storage cost of cash includes two components: 1) holding costs of physical cash, and 2) the inflation rate, since cash depreciates when it lies outside of an interest-bearing account.

The last agent is the government, which sets the federal funds rate (FFR) based on a simple Taylor Rule, controlling inflation and GDP growth¹⁰⁹:

$$\ln(FFR_t) = (1 - \alpha)\ln(FFR_{t-1}) + \theta\ln(\pi_t) + \theta\ln(Y_t - Y_{t-1}) + R_{ss} + \epsilon_t$$

When a central bank makes a decision to issue CBDCs, it can do it either through balancing and analyzing the Taylor Rule above or through another mechanism. A couple of other options include simply targeting a long-term equilibrium interest rate and setting policy accordingly or issuing a fixed quantity of yearly GDP that grows at a certain rate ($DC_t = \gamma * Y_t$, where then $DC_t = P_t * (DC_t - DC_t^{Optimal})$). Once we have all the baseline players in the economy set up, the next step in Lagrangian optimization is taking first-order conditions (FOCs). The first two FOCs are not that interesting, and simply identify the bond-holding conditions, but they're useful to have as reference for future steps and to show the steps involved in the math:

$$e_t \left(\beta \frac{\lambda_{t+1}}{\lambda_t} \frac{r_t}{\pi_{t+1}} \right) = 1$$

¹⁰⁹Kuevibulvanich, "Economic Policy Analysis - Lecture Notes"

$$\exp(e_t)(C_t - hC_{t-1})^{-\sigma} - e_t[\beta h \exp(\epsilon_{t+1})(C_{t+1} - hC_t)^{-\sigma}] = \lambda_t$$

The next two FOCs are interesting. The first one is:

$$u^{Cash} m^{-\sigma^{Cash}} = \lambda_t - e_t \delta^{Cash} \left(\beta \frac{\lambda_{t+1}}{\pi_{t+1}} \right)$$

This equation is the Lagrangian optimization framework for cash, with m_t being the amount of physical currency that you choose to hold when presented with a CBDC option. Before we analyze the equation, we can plug in the values from the first baseline equation that derives CBDC utility in terms of its relationship to cash to analyze the other costs.

$$\frac{\chi}{\Theta * \rho * \tau} \mu^{CBDC} * m^{\frac{\sigma^{CBDC}}{(1-\Theta-\rho+\chi)}} = \lambda_t - e_t \delta^{Cash} \left(\beta \frac{\lambda_{t+1}}{\pi_{t+1}} \right)$$

There are a few interesting conclusions to be gained from this equation. First, a household's demand for non-digital currency increases if and only if the marginal utility of cash is positive AND marginal utility is non-negative. More interestingly, the demand for cash is decreasing with respect to the inflation rate and holding costs associated with physical currency. This is a logical conclusion - we tend to think of the inflation rate as being a "shadow cost" of holding cash (i.e. that since cash grows at no interest rate, inflation decreases cash's real value and thus is continually devaluating as the inflation rate goes up.) Once we plug in the baseline relationship, we can also see that as the interest rate on CBDCs goes up, it increases the incentive to hold digital currency. CBDC holding is also proportional to your level of liquidity preference, decreasing with respect to the switching/inconvenience cost of switching, and increasing with respect to the addition of other miscellaneous benefit.¹¹⁰ The second FOC is:

$$u^{DC} dc^{-\sigma^{DC}} = \lambda_t - e_t \delta^{Cash} \left(\beta r_t^{DC} \frac{\lambda_{t+1}}{\pi_{t+1}} \right)$$

¹¹⁰Ferrari, Mehl, and Stracca, "Central bank digital currency in an open economy"

While the first equation was demand for cash, this equation is the demand for CBDCs, with DC_t denoting the holdings of CBDCs minus the prevailing inflation rate, indicating your real holding quantity level of digital dollars. The key differences here are the dynamics of a potentially negative interest rate for CBDC e-wallets as well as the elimination of the δ holding costs associated with holding cash. Demand for CBDCs increases as long as the marginal utility of cash is positive and marginal utility is non-negative as well as when the interest rate increases (a feature not present with cash), and demand decreases in the inflation rate. We can combine these two equations to derive an equation in terms of marginal utility to remove the lambda factor:¹¹¹

$$m_t = \left[\frac{1}{u_{Cash}} \left((U'(dc_t) + \beta e_t \frac{\lambda_{t+1}}{\pi_{t+1}} (r_t^{DC} - \delta_{Cash})) \right) \right]^{-1}$$

This final equation allows us to express the demand for cash as related to the demand for CBDCs. Demand for cash is inversely correlated with the marginal utility gained from the holding of CBDCs. It is also positively correlated with the liquidity benefits provided by cash. Households also balance this with the physical costs of holding cash, captured by $\delta^{Cash} < 1$ and balance it against the interest gaining benefits from CBDCs, which are represented by $r^{DC} > 1$. Whichever of these factors is larger dictates the tradeoff between physical and digital modes of payment, and theoretically, the CBDC factor would be larger given that it grows at some nominal rate of inflation. Ferrari's paper delves into complicating the model with an understanding of how the foreign and international CBDC models would interact with each other with an understanding of exchange rate fluctuations, which is extraneous to a model for the blueprint for the digital dollar, but an interesting topic for future exploration.

¹¹¹ibid

5.2 Policy Lessons & Conclusions

What are the lessons from the cash-CBDC model that can be used to supplement policy recommendations and weigh the general equilibrium effects of CBDC implementation?

1) Policymakers should find ways to decrease switching costs from cash to CBDCs. If status quo bias overwhelms the benefits of digital currencies, people will feel no need to change the way they transact money. Offering incentives to deposit/transfer or increasing the ease of switching through physical and digital infrastructure investments can help make it easier for people to slowly move. China actually created a lottery-system and gave away free money (the equivalent of around \$32) to a random 200,000 people who signed up for the digital yuan pilot program.¹¹² Once a critical mass of people and businesses switch to digital dollars, network effects will push towards exponential growth.

2) Strong implementation should aim to increase the perceived and actual convenience of digital money to change the household's liquidity preference parameter. This includes a variety of things, including making the wallet user-friendly and easy to navigate, offering accessibility opportunities for those in low-Internet areas, and enabling quick seamless transactions.

3) A high nominal interest rate exponentially increases digital money holdings. This is self-explanatory: given that cash earns zero interest and grows slowly in bank accounts, a high nominal interest rate creates incentives to move money to the digital wallet.

4) High inflation regimes benefit digital money usage. Since inflation is a shadow cost of holding cash, high levels of inflation drive people away from cash. Additionally, as inflation rises, nominal interest rates increase in digital wallets.

5) The Federal Reserve should minimize any holding costs associated with having digital

¹¹²Reuters, "Chinese central bank's digital yuan given trial by lottery"

currency, including the elimination of minimum balances or excessive fee structures. Holding costs for cash are a large deterrent to storing all wealth physically, including storage costs and bank fees/minimum balance requirements. Elimination of this differentiates digital currency from cash and offers benefits for low-income underbanked communities who are skeptical of commercial banking systems, thus promoting more financial inclusion.

6) Digital currency demand will increase if there are other benefits to be gained, including cross-border efficiency, perception of economic security/privacy, and economic prosperity. This highlights the necessity of complementary tools for implementation, including proper management of data, integration with international systems for interoperability, and effective experimental monetary policy tools.

6 Part 2: Policy Recommendations

Since we have theoretically and qualitatively proven the potential of CBDCs to succeed in the United States, the natural next step is to think about how to coordinate the moving parts. Sub-par and hasty implementation of digital currencies has the potential to destroy exchange rate stability, reduce the flexibility of the Federal Reserve in responding to crises, exacerbate financial inequality, destroy the financial technology and services industry, and move the economy out of general equilibrium. While these seem like exaggerations, the consequences of currency policy are extreme in magnitude and ripple through all facets of the economy. The purpose of the rest of this paper will be to quantitatively and qualitatively recommend best practices for digital dollar implementation to establish a feasible blueprint. The following section is a fleshed-out list of 7 key recommendations that are crucial for implementation of central bank digital currencies in the United States.

6.1 Recc. 1 - Account-Based Retail CBDC

Account-based retail CBDCs are the most practical and comprehensive form of FIAT currency that should serve as a blueprint for the digital dollar. There are two fundamental types of CBDCs, wholesale and retail. Wholesale CBDCs, which have been implemented in a few countries, are a digital currency that is only available to institutions including, but not limited to, local and chartered financial institutions, third-party banks, government organizations, and publicly-held companies. Retail CBDC, on the other hand, which has been analyzed for this paper in the macroeconomic model and the pros/cons, is available to all businesses and citizens of the US, making it truly public.¹¹³ The currency would be accepted in regular business transactions and could pass from peer-to-peer, business-to-business, or consumer-to-business. Within retail CBDCs, there are two major

¹¹³DiPippo, "Options for a Digital Dollar: Central Bank Digital Currency and Stablecoins"

types: account and token. Token-based digital currency would be like paper dollars and cents, allowing for anonymity in transactions and creating an end-to-end process that goes through without Federal Reserve or US Treasury interference. In contrast, account-based CDBC's are held in the form of a digital wallet, and all balances are held directly in a ledger controlled by the central bank. Money cannot anonymously circulate, but instead moves similar to bank transactions, where you need to transfer money out and deposit money in, with all transactions recorded in a digitized ledger.¹¹⁴ Senator Sherrod Brown unsuccessfully proposed the Banking for All Act during the passing of the CARES Act during the onset of the coronavirus pandemic, advocating for an account-based digital dollar wallet that is controlled by the Federal Reserve. The funds would be available through an app called FedAccounts, which would help all Americans receive their stimulus payments directly rather than through the Treasury mechanism used. It promotes many of the financial inclusion benefits described earlier, having no minimum balance requirement and no fees for over-drafting, with protection of all of their data and anonymity during transactions.¹¹⁵ While the proposal seemed to be a bit too early given the level of infrastructural commitment, it points to a broader trend of a commitment in DC towards account-based retail central bank digital currencies. **Cash should not immediately be removed from circulation in the economy.** Rather, a gradual phase-out after a comprehensive evaluation of usage metrics and success is necessary to ensure a smooth transition from physical to digital financial transactions.¹¹⁶

An alternative suggestion within economic literature is a wider adoption of stablecoins. Stablecoins are a new class of cryptocurrencies that offer volatility-shielding benefits by being linked to a reserve asset. These coins peg their value to an external reference like the price of a commodity or, more commonly, a specific currency like the US Dollar. They claim to offer the "best of both worlds" by allowing for decentralization and instant processing of

¹¹⁴Keister and Monnet, "Central Bank Digital Currency: Stability and Information"

¹¹⁵U.S. Senate, *Banking for All Act*

¹¹⁶Labonte and Nelson, "Central Bank Digital Currencies: Policy Issues"

payments along with offering protection against large amounts of investment volatility.¹¹⁷ While stablecoins were once thought of as purely a store of value, they have slowly evolved into a legitimate means for financial exchange, with monetary institutions and private actors using stable cryptocurrencies as payment vehicles for various types of business and consumer transactions.¹¹⁸

While a model of CBDC and stablecoin co-existence is feasible, in the face of choosing one or the other, centrally-owned digital currencies are favorable to privately-controlled stablecoins for four reasons. First, from a regulatory standpoint, since CBDCs are centrally controlled by governments, they are only surveilled under the purview of government authorities. However, stablecoins can be subject to "regulatory oversight from multiple agencies, depending on their classification as assets, securities, or even money-market funds."¹¹⁹ Second, stablecoins have no exchange value with any other international currency. By being publicly controlled, CBDCs facilitate interoperability and cross-border efficiency, since collaboration amongst established country governments is favorable to fragmented private authorities. Additionally, since international transactions would fall under the scrutiny of the Financial Action Task Force, stablecoins regulations would be extended across borders to other countries as well, greatly decreasing the potential for global collaboration.¹²⁰ Third, the decentralized nature of stablecoins reduces their potential to be used for specific monetary policy interventions, financial crime tracing, and robust data collection. To understand trends in spending patterns and the velocity of money, an authority would require private permissioned access to the central ledger. Granting private access to the stablecoin ledger is the antithesis of decentralized cryptocurrencies, which attempt to democratize finance by making all ledger information public and anonymous on the blockchain. Finally, CBDCs would be guarded by reserve assets of a country as compared to stablecoins, which solely

¹¹⁷Investopedia, "Stablecoin"

¹¹⁸Bode, Higginson, and Niederkorn, "CBDC and stablecoins: Early coexistence on an uncertain road"

¹¹⁹ibid

¹²⁰Ask Any Difference, "Difference Between Stablecoin and CBDC"

use private money and are not controlled or managed by any private or public entity. This makes CBDC accounts relatively safer and better insured in case of liquidity problems or financial panic.¹²¹

6.2 Recc. 2 - An Interest-Growing CBDC Wallet

How should money grow in digital wallets? There are three main options presented here, in order of least to most desirable:

Inflation-Growing CBDC: Under this option, CBDCs would grow at the rate of inflation so they have constant real value. This is probably the worst solution. As long as monetary policy keeps inflation relatively stable (which is almost always true except for the "not-so-transitory" period of inflation we are currently experiencing), the rationale for price indexing is not very clear.¹²² It also largely limits the ability of the central bank to step in when aggregate demand is low and real interest rates are negative. If real rates are negative, then a CBDC account would need to have a zero real interest rate, which creates a *zero lower bound on REAL interest rates*.¹²³ This is much worse than a zero lower bound on NOMINAL interest rates, which is what currently exists, and it would destroy any ability of central banks to shift the federal funds rate by more than a few basis points. Therefore, quantitative easing (QE) would become pretty much the only solution for boosting the economy, and it is illogical to reduce the number of instruments available to the central bank.

Zero-Interest Cash-Adjacent CBDC: The second option is that CBDC deposits are exactly like cash, which means they do not multiply and just maintain their value. This is the most neutral option because it likely would not change the landscape of fiscal policy, but its flaw is in its neutrality. It represents very little change from the status quo, which

¹²¹ibid

¹²²Agur, Ari, and Dell'Ariccia, "Designing central bank digital currencies"

¹²³BIS, Central bank digital currencies. Technical report,"

means we would likely incur a heavy loss in fixed costs if this were implemented nationwide. This could hurt aggregate demand since when interest rates are positive (which is pretty much always), households would just decide to move all of their funds out of zero-interest CBDC accounts. Here, there would be essentially no monetary policy benefit, since it has very few distinguishing factors from cash.¹²⁴ And, since there is status quo bias, usage of digital currency would suffer as people would be reluctant to switch.

Interest-Growing CBDC - The Best Option: Central banks have continued to struggle with the zero-lower bound (ZLB) problem during times of economic crisis. Since the central bank cannot make interest rates negative (or everyone would take all their money out of the bank), the Federal Reserve runs into problems when interest rates are already historically low and cannot be dropped further. This means the Fed has to pursue other unconventional methods of monetary stimulus like forward stimulus and huge balance sheet purchases, which are significantly less effective. And, since the Fed moves the real interest rate (nominal interest rate minus rate of inflation), the steady decline of the real interest rate is of large concern for policymakers. This can cause a worst-case scenario: a deflationary spiral. As inflation plummets, real interest rates will rise (since it's defined as the nominal interest rate minus the inflation rate). However, since the Fed cannot move nominal rates lower than zero, it will inadvertently tighten the economy because it cannot offset the change in real rates. This causes inflation to fall more, real interest rates to rise, monetary policy getting less effective, and a deflationary spiral.¹²⁵ This is the problem with the zero-lower bound and historically low interest rates. Economists agree that being able to set short-term nominal interest rates slightly negative would solve this issue and create economic stimulus.

Fundamentally, CBDCs remove the ZLB problem by allowing the interest rates on wallets to be slightly negative, with money essentially being made as a payment to the Fed from the digital wallets. Negative interest rates are so effective because they encourage households

¹²⁴ibid

¹²⁵Kuevibulvanich, "Economic Policy Analysis - Lecture Notes"

to spend their money immediately, since saving money results in a negative expected value within the CBDC wallet. And, since rates move together, interest on reserve balances and the federal funds rates would follow to low (albeit non-negative) levels, making other alternatives unprofitable.¹²⁶ While this sounds like an unfair implicit tax, keep in mind that this is a policy tool that is used sparingly and for extremely short periods. How negative would rates be? After the 2008 financial crisis, the Federal Reserve released a statement indicating that being able to reduce the rate to -8% would've mitigated the risks to the economy and boosted aggregate demand to a sustainable pre-crisis level. If this were implemented in a world with CBDCs, that means that over the entire course of the crisis (which is relatively short), you would lose 8% of the value and it would be paid to the U.S. Treasury.¹²⁷ While this seems drastic, consider this as being one of the absolute worst-case scenarios for negative interest rate usage during a historically bad recessionary period.

The important fact is that during times of prosperity and productivity, which is the majority of economic cycles in the US, CBDCs will grow at some nominal interest rate like a savings account. Milton Friedman, in 1960, argued for this approach (albeit without all the blockchain and digital currency references), when he argued that government money should earn you the same return as any other risk-free asset in the economy to be an efficient system.¹²⁸ This option also offers the most flexible central bank policy by allowing the Fed to reduce interest rates when necessary to stabilize prices and encourage economic growth.¹²⁹ However, since cash accrues zero interest, people are incentivized to store money in cash when nominal interest rates are negative, which did happen during the bank panics of the early 1930s. Ideally, cash would be phased out so it is not an option for currency holders. However, given that this is unrealistic, I propose two things. First, implementing fees on large and continual transfers from CBDCs to cash to make it unprofitable for investors to

¹²⁶Nelson, "The Benefits and Costs of a Central Bank Digital Currency for Monetary Policy"

¹²⁷FOMC, "Monetary Policy Alternatives"

¹²⁸Hall, Swamy, and Tavlas, "Milton Friedman, the Demand for Money, and the ECB's Monetary Policy Strategy"

¹²⁹Nelson, "The Benefits and Costs of a Central Bank Digital Currency for Monetary Policy"

immediately rush to cash when nominal interest rates are negative, so the policy is not constrained by the ZLB. Second, allowing account holders to have a reserve balance of a few thousand dollars that was guaranteed to not lose value even when interest rates dropped below zero, an amount that would certainly not affect the monetary policy decisions of the Federal Reserve. If implemented correctly, there would be no need to maintain any inflation buffer, and the CBDC interest rate (along with other aforementioned monetary policy levers in Section 4.3) could become a very important tool.¹³⁰

6.3 Recc. 3 - Semi-Centralized Blockchain-Built Ledgers

To store and manage a ledger of millions of transactions, it is necessary to envision what kind of technological infrastructure is necessary. For some background, a ledger is a simple record book with information about financial transactions, including detailed information about the sender, recipient, transaction amount, time, date, and more.¹³¹ While decentralized blockchain technology exists and is used for a wide variety of cryptocurrency payment processing, any existing ledger will be unable to handle the amount of data flow that would move through a Retail CBDC system. In addition, in contrast to cryptocurrency ledgers, which are decentralized and public, a CBDC ledger would need to not only be private, but also be structured in a way such that the Federal Reserve and relevant government authorities can make changes (altering, reversing, or deleting transactions). This naturally rules out the option for a fully decentralized blockchain ledger (despite its success with Bitcoin for over a decade) since there is no way a central authority like the Fed could ever reverse transactions, change transactions, or intervene in any way.¹³²

While a fully-centralized blockchain-based CBDC ledger is the first natural conclusion,

¹³⁰Allen et al, "Design Choices for Central Bank Digital Currency - Policy and Technical Considerations"

¹³¹Lubin, "Blockchain Solutions for Central Bank Digital Currency (CBDC)"

¹³²World Economic Forum "Central Banks and Distributed Ledger Technology: How are Central Banks Exploring Blockchain Today?"

it has a few structural problems. While the information would be distributed amongst multiple locations and data centers, a fully centralized ledger that is controlled only by the Fed means concentration around a small number of servers. While smaller infrastructure is easier to coordinate and manage, it remains the most vulnerable to third-party attacks and malicious data breaches.¹³³ Deleting transactions from the ledger, rolling back or delaying software processes, or stealing identity information is facilitated when the server storage is controlled by one entity managing one ledger. As such, a more complicated hybrid approach is necessary.¹³⁴

Therefore, a semi-centralized hybrid blockchain-built ledger is optimal for CBDC implementation. This entails two important differences from the fully-centralized model. First, the CBDC is managed by a set of independent parties picked by the Federal Reserve - this would likely include a variety of commercial banks, payment infrastructure companies, and financial institutions.¹³⁵ Of course, this requires relinquishment of complete control by the Federal Reserve, but given the logistical necessity for the processing of millions of transactions, delegating implementation and regulation responsibilities to third parties is a logical solution. Having hundreds of independent operators requires strict codes and regulations that would bar these entities from making changes to the ledger at will and an agreement as a government contractor that would include strict punishment for backsliding. This process reduces the logistical burden on the central bank while also allowing for more data safety from malware and hackers since the ledger is now spread amongst various groups.¹³⁶ The second key difference is that the master ledger is split into multiple parallel ledgers, and each ledger is linked to each other while operating on completely different servers, meaning the potential to add an infinite number of parallel chains as server capacity is expanded. Yin et al 19 in "Hotstuff: BFT consensus with linearity and responsiveness" and Baudet et al 19 in

¹³³ibid

¹³⁴Lagos and Wright, "A Unified Framework for Monetary Theory and Policy Analysis"

¹³⁵ibid

¹³⁶Allen et al, "Design Choices for Central Bank Digital Currency - Policy and Technical Considerations"

”State machine replication in the Libra blockchain” have studied ”state machine replication solutions” to resolve the problem of difficult communication across various nodes and greatly optimized this process.¹³⁷¹³⁸Meta’s (formerly Facebook) Libra, a blockchain-based payment system, operates algorithms similar to these two findings.

This option allows for the ledger to be built upon blockchain technology by creating a shared ledger that is private and permission-contingent, capturing all the benefits and flexibility of decentralized technology while simultaneously allowing control from the central bank and authorized third-party coordinators. MIT has begun working with the United States Federal Reserve to create a pilot architecture to test semi-decentralized payment processing in their experiment titled Project Hamilton. Their Phase 1 studies show remarkable results, with a processing power of over 1.7 million transactions per second. Amongst those transactions, 99% of transactions were completed in less than one second, and more than half of all transactions were fully processed end-to-end within 500 milliseconds. The infrastructure is emergency-resilient; the processing power does not decrease and no data is lost even if two whole data centers are completely offline (due to server network issues or natural disasters), and the process scales as more servers are added in case more computing power is necessary during peak hours.¹³⁹ This kind of technology has been proven to be, in studies by XRP Ledger and Ripple platformers, 61,000 times more efficient than public blockchains.¹⁴⁰ Phase 2 studies will attempt to re-optimize and add considerations for data privacy and storage as research on CBDCs continues at MIT.¹⁴¹ Other researchers are delving into the specifics of blockchain implementation, conducting surveys from central banks, gaining insight from how central banks have created use cases for blockchain, and summarizing literature from

¹³⁷Yin et al, ”HotStuff: BFT Consensus with Linearity and Responsiveness”

¹³⁸Baudet et al, ”State Machine Replication in the Libra Blockchain”

¹³⁹Federal Reserve Bank of Boston. ”Project Hamilton Phase 1 Executive Summary”

¹⁴⁰Frost, ”Ripple Makes Private Blockchain for Building Central Bank Digital Currencies”

¹⁴¹Federal Reserve Bank of Boston. ”Project Hamilton Phase 1 Executive Summary”

proof-of-concept prototypes.¹⁴²¹⁴³¹⁴⁴

6.4 Recc. 4 - The Private Sector - Account Creation, Authentication, & Transactions

Given the lobbying size and sheer force of the private commercial banking industry and financial services companies, cutting out the private sector is infeasible. Creating collaboration and capitalizing on existing financial infrastructure can help promote private-public collaboration through the account creation, authentication, and transaction period. The first key issue to reconcile is account creation and management. Each account would need to be created on the smartphone app (it was called FedAccounts in the hypothetical bill proposed by Senator Sherrod Brown) and each person has an account on the app linked to their personal ID. Delegating account management is a key feature of the People's Republic of China's rollout of the digital yuan as well as in various pilot projects like the Bank of England's digital pound. Working with commercial banks, the Federal Reserve could delegate the responsibility of account management and creation so it doesn't have to create its own infrastructure; this also has the added benefit of letting citizens feel less of a change during the transition period, since they could still continue interaction with their local banking institution.¹⁴⁵ The Bank of England refers to these groups as "Payment Interface Providers (PIPs)," and they can compete with one another to acquire customers and integrate members onto their systems. I propose **delegating account creation and management responsibilities to commercial banks and other authorized Payment Interface Providers (PIPs)**. This allows for the central bank to tap into the robust network of commercial banks

¹⁴²Boar, Codruta, and Wehrli, "Ready, steady, go?"

¹⁴³Dashkevich, Counsell, and Destefanis, "Blockchain Application for Central Banks: A Systematic Mapping Study"

¹⁴⁴Opore and Kim, "A Compendium of Practices for Central Bank Digital Currencies for Multinational Financial Infrastructures"

¹⁴⁵Andolfatto, "Assessing the impact of central bank digital currency on private banks"

and their customers while giving these groups incentives and responsibilities for managing parallel parts of the ledger. From a political and lobbying standpoint, it would make CBDCs significantly more favorable for commercial banks and the financial sector. Companies like VISA have already begun conducting their own research about how to scale their existing platforms to account-based retail CBDC projects.¹⁴⁶

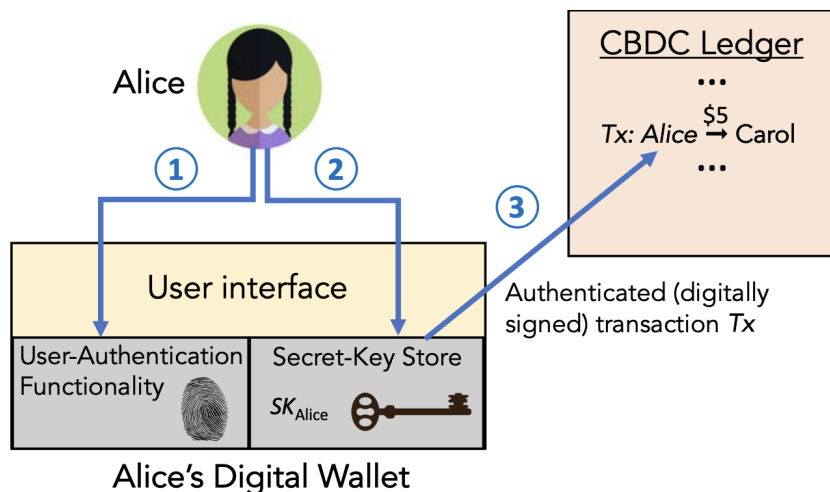
There are various approaches to ID verification; having naive identity verification tools will not suffice for account creation, and are generally not used in the industry for the management of financial data. Email accounts are easy to fake and create, phone numbers (while mostly foolproof) are also subject to anonymous prepaid plans, and CAPTCHAs can easily be cracked using machine learning. While other options remain possible, **the most logical first step is to use existing bank infrastructure of in-person identity verification**, where the account holder brings a driver's license, birth certificate, social security card, or passport to an in-person office along with something to prove residence in an address to create an account.¹⁴⁷ Other digital mechanisms exist but require more sophistication before a full-scale roll-out. For example, video identity management has gained popularity, with a requirement for a recorded live video to prove your identity to a machine learning camera algorithm. However, these have been subject to attacks from advanced deepfake technology and algorithm manipulation that are difficult to remedy. A person's identity on a CBDC digital wallet would include all relevant personal information about them similar to any other bank account. The figure below from the Brookings Institute paper by Allen et al shows a typical transaction and the three crucial steps.¹⁴⁸

Once an account is created, how does a transaction take place from one user to another on the private-public CBDC network? There are three major steps as labeled in the figure. First is the simple process of getting into your account, which should include some form of

¹⁴⁶Carney, "Central Bank Digital Currency - Opportunities, Challenges and Design."

¹⁴⁷Allen et al, "Design Choices for Central Bank Digital Currency - Policy and Technical Considerations"

¹⁴⁸ibid



a simple pin/password, or, increasingly, some sort of biometric proof of identity like Apple's Face ID or Touch ID. The second step is the authentication of the actual transaction (i.e. making sure that it was the sender who authorized the payment or transfer) which is the most complicated part of the process. While the most simple solution is to greenlight all intermediary transactions that go through authenticated users, this makes it very easy for hackers to compromise a single intermediary infrastructure and create fake transactions once they're into the system; additional security mechanisms are necessary to ensure multiple barriers to entry.¹⁴⁹ Cryptocurrency exchanges work around this using a private-public key system and digital signatures; when a transaction happens, a public key that is associated with the specific account is verified using a private key that only the individual has access to. This means that even if a Payment Interface Provider is compromised, they cannot forge transactions from another account because a private key is inaccessible to anyone but the account holder.¹⁵⁰ The reason for this is the concept of pure decentralization, but in a system where the Central Bank has sole control over accounts, it can store private keys for users; thus, digital-signature CBDC authenticates users by creating digital signatures through centrally-stored private keys for each transaction.¹⁵¹ A digital wallet would store

¹⁴⁹ibid

¹⁵⁰ibid

¹⁵¹ibid

a user's private keys inside of the app itself and makes it available through hardware for them when they need to access the software-side transaction power of CBDCs - however, what happens if a user loses access to their physical phone or wants to use another device for CBDC transfer? Because of the centralized nature of the program, the Central Bank and all PIPs can "revoke the public key and corresponding private key associated with an account, and authorize new keys," with regulations established for when to authorize such transactions.¹⁵² The third and final step of the transaction happens the quickest, which is the transmission of information to the central CBDC ledger; this data byte would include all relevant details about the digitally-signed process.

6.5 Recc. 5 - Privacy Concerns and Access to Data

A core issue with a model of currency exchange where the Central Bank controls information is the level of non-private data collection. Cash transactions that would've otherwise gone unnoticed or card payments for which records only exist between banks and clients are now stored in a centralized ledger. There is a crucial balance that must be struck between security (flagging illegal transactions and money laundering) and privacy (accessing information about citizens in intrusive ways). Without trust in government and faith in fair use, users could become wary of using CBDCs and volunteering information over to the public record. Survey results from Goldfarb and Tucker show that consumers are becoming more concerned with consumer and financial privacy, especially in the wake of Snowden leaks about NSA overreach.¹⁵³

There are two extremes: 1) a CBDC where you have complete real-world identities and all information is fully visible and accessible by the central bank. Oversight of how the data is used would be controlled by regulatory and policy rules set by government. 2) a CBDC

¹⁵²ibid

¹⁵³Goldfarb and Tucker, "Shifts in Privacy Concerns"

that is essentially "digital cash," which is fully anonymized like cryptocurrency but would enable illegal transactions. There is a middle ground that should be established, but this is an area where the Central Bank will need to decide how much authority it requires.¹⁵⁴ Because the ledger is non-public and requires permission to access, anonymizing transactions using anything beyond pseudonyms is unnecessary. A problem with public ledgers is that hackers can understand transaction patterns and deanonymize Bitcoin addresses to link to them to people; in a world in which the ledger is completely inaccessible, this ceases to be an issue. For transaction and identity anonymity, algorithms are able to check and process data to see anomalies and potential security breaches. However, while the transaction is stored in the ledger and accessed by humans, they are unable to see the transaction amount, reason for payment, the parties involved, or other information about the process. This ensures that human intervention is involved only after an artificial intelligence algorithm flags a transaction as suspicious.¹⁵⁵

There is work being done on how to envision privacy rules and regulations about data access for CBDC ledgers from a policy perspective, creating scenarios and thresholds that warrant intervention. This includes algorithmic numeraire for transaction frequency, account creation limits, transaction amounts (a suspicious amount or establishing strict limits), newness of accounts, and more. These computer-generated thresholds preserve privacy since they require little human intervention, and can work within proactive compliance and retroactive compliance. This is a machine learning supervised task that require collaboration amongst various organizations to understand trends in financial transactions and use a computer to find patterns where humans cannot. Other authors consider the warrant-generating process necessary to flag an account, and how judicial systems would be lightly involved for disclosure of confidential information from third parties in the ledger.¹⁵⁶¹⁵⁷¹⁵⁸ Other authors have

¹⁵⁴Keister and Sanches, "Should central banks issue digital currency?"

¹⁵⁵Allen et al, "Design Choices for Central Bank Digital Currency - Policy and Technical Considerations"

¹⁵⁶Hinge, "Anti-money laundering and countering the financing of terrorism"

¹⁵⁷Segal, "Central Bank Digital Currency, Design Choices, and Impacts on Currency Internationalization"

¹⁵⁸Feigenbaum, "Multiple Objectives of Lawful-Surveillance Protocols"

been analyzing how models from privacy-forward cryptocurrencies like Zcash can be applied to a blueprint for a CBDC, finding that these payment systems can anonymize transactions and flag suspicious behavior with little human intervention.¹⁵⁹

However, it is worth grappling with an uncomfortable truth: No matter how it's implemented, **any reasonable model for CBDCs will "reveal significantly more information about individuals' transactions to [government] than existing systems do."**¹⁶⁰ The question gears around creating strictly-written laws and codes about how the data can be accessed and to make sure that the government is not tracking payment information to any level of granularity or precision unless warranted. As long as the intentions are benevolent, and we can trust various constitutional and legal provisions that explicitly make this kind of surveillance illegal, this should not be a hindrance. The US Federal Reserve is nowhere close to as authoritarian as the Chinese government for example, and there are various legal and regulatory checks to make sure data is used and stored aptly, only accessed under extreme scenarios. However, if a vision for the eventual global implementation of digital currencies is on the horizon, trustworthiness and data privacy is a crucial component.¹⁶¹ From a policy perspective, authoritarian governments that have the ability to gain so much data about each individual person can result in huge human rights violations and infringements of civil liberties. In the People's Republic of China, the launch of the digital yuan is causing huge strife amongst the population. On one hand, while many appreciate the convenience and access provided by CBDCs, a population that doesn't trust its government will never be able to transition fully away from physical currency. As international and domestic law continues to be written and technology for data collection and management expands, the world should be cautious of governmental overreach, and international organizations like the World Bank should consider setting international data regulations for member nations.¹⁶²

¹⁵⁹Wüst, Kostiainen, and Capkun, "Platypus: A Central Bank Digital Currency with Unlinkable Transactions and Privacy Preserving Regulation."

¹⁶⁰Allen et al, "Design Choices for Central Bank Digital Currency - Policy and Technical Considerations"

¹⁶¹ibid

¹⁶²Kshetri, "China's Digital Yuan: Motivations of the Chinese Government and Potential Global Effects"

6.6 Recc. 6 - Expanding Internet Access & Financial Education

While financial inclusion is an issue that can be tackled by CBDCs, digital currencies are not a silver bullet for resolving the digital divide in the United States. In fact, subpar implementation can exacerbate status quo problems and increase financial inequality. In the United States, Third Way estimates that broadband availability is significantly lower in counties and localities that have majority Black/Native-American populations. Compared to majority-white counties, majority-black counties have broadband access which is 16 percentage points lower and Native-American counties have access which is 45 percentage points lower.¹⁶³ Since CBDC access is reliant on smartphone ownership, reliable Internet connection, and broadband data access, a simple rollout of a FedAccounts app will reach a population of people who already are benefiting from private banking and digital payment systems.¹⁶⁴ Another large issue with CBDC rollout is financial literacy, which is also much lower in majority-minority counties. There are also studies that prove that those with lower income (and thus lower levels of education) have higher mistrust of authorities and digital currencies. They will tend to use these services at a lower rate and are, thus, losing out on the benefits of high-interest rates and network effects. A digital wallet needs to be accessible and user-friendly to all.¹⁶⁵

To tackle the two important problems for financial inclusion, **a rollout of a digital dollar should be complemented by financial education programs in low-income counties and expansion of Internet infrastructure.** The FCC did a large-scale study of Internet access and approximated that the cost of delivering broadband infrastructure and access to all US citizens would be around \$80 billion. The federal and state government has worked towards increasing momentum towards broadband expansion - the two pandemic-

¹⁶³Berkowitz and Horowitz, "Broadband for All: Connecting Everyone, Everywhere to the Digital Economy"

¹⁶⁴Pantuliano and Tyson, "Can Central Banks Digital Currencies deliver for people in poverty?"

¹⁶⁵Macmillan, "Digital Financial Services: Regulating for Financial Inclusion"

era CARES and Consolidated Appropriations Act allocated a combined \$7.6 billion to the expansion of broadband infrastructure. On the local level, 47 states have offices and task forces dedicated to Internet, and state governments have begun providing "grants and loans to Internet service providers and local governments." In the FCC proposal, which has been brought up to Congress and other US lawmakers, \$40 billion brings physical infrastructure like cables and wiring to the hardest 2% of unserved locations. \$42 billion in block grants administered by the Commerce Department are given to state governments as long as they follow ARPA guidelines and a specific set of broadband investment regulations. The emphasis is not only on creating the infrastructure but also on making sure that there are low-cost options available to all users - it includes a \$30 a month assistance to low-income families to afford their Internet service programs through third parties. The program also includes \$2 billion for tribal broadband expansion, \$2 billion for the Department of Agriculture's rural development ReConnect Program, \$1 billion in grants for investing in "middle mile" connections from central to local broadband networks, and \$600 million for private activity bonds to finance broadband projects." This proposal was in Biden's American Jobs Plan (more commonly referred to as his infrastructure bill), and it remains unclear whether this level of investment is sufficient.¹⁶⁶ However, it is a necessary first step to ensuring data access and equity in technological spaces. In addition, partnerships with local community centers, banks, and other trusted neighborhood locations are necessary to increase financial literacy. These could take the form of advertising budgets and seminars/workshops to help set up digital wallets, as well as classes about financial literacy and managing money in a CBDC platform. In the United Kingdom, for example, the government partnered with the University of Oxford and the University of Cambridge to provide financial technology courses to all 43 Commonwealth countries and help community members learn about digital money management. To date, 120 officials from these 43 countries from all 5 regions registered for the training program, which is helping build trust with local low-income communities.¹⁶⁷

¹⁶⁶President Biden's Bipartisan Infrastructure Law

¹⁶⁷The Commonwealth, "Commonwealth Small States Prioritise Financial Inclusion and Lead the World

In addition, a comprehensive CBDC plan should include physical payment infrastructure and offline technology capabilities. As mentioned in the first part of the paper, DCEP's "touch and touch" functionality can be easily built into existing mobile devices and allow people to make peer-to-peer transfers by physically touching their smartphones even when they're offline. Therefore, in places with low internet access or data penetration, servers can still be reached locally. However, importantly, this offline technology is only valuable if you're able to get access to the Internet relatively frequently - in places where there is zero Internet access, the technology would fail to work, since the app would need to be online to settle balances and send information to the ledger.¹⁶⁸ Additionally, to convert their existing money into CBDCs or deposit/transfer funds, they would need reliable Internet access to get into their FedAccounts app. This highlights the need for expanded Internet and data infrastructure for inexpensive, reliable options for lower-income communities. For the unbanked and underbanked to truly reap the benefits of a CBDC, local institutions like town halls and post offices need to have physical infrastructure or services to help access accounts and manage finances.¹⁶⁹ For example, the Industrial and Commercial Bank of China designed its digital yuan to allow offline technology for processing payments. In addition, all local post offices and community centers have infrastructure to access online accounts for those who do not own a smartphone but want to deposit money, transfer, or check their balances.¹⁷⁰ Their infrastructure allows for instant offline transactions between parties and is able to verify no malicious behavior and account identity validation. Additionally, you can tap on physical keypads set up at select retailers and shops to pay touch-to-touch from your mobile phone to the business, regardless of broadband quality. Once again, however, it requires access to the Internet to eventually settle balances and confirm transactions to the ledger, highlighting the importance of investment in broadband

on Central Bank Digital Currencies"

¹⁶⁸English, "Finding a secure solution for offline use of central bank digital currencies"

¹⁶⁹Allen et al, "Design Choices for Central Bank Digital Currency - Policy and Technical Considerations"

¹⁷⁰ibid

access.¹⁷¹

6.7 Recc. 7 - International Commitments and Aid

Finally, a slow domestic rollout of the digital dollar should help inform future international aid to create cross-border network effects and bring CBDCs to developing nations. The future of the international financial system relies on a gradual transition to digitization, as cross-border online servicing continues to increase each year. International tourism has doubled in the past 15 years, the global shipment of parcels has tripled, and remittances are a market worth \$720 billion. In particular, the market for international tourism and remittances has led to a variety of solutions for sending money internationally while meeting strict regulatory guidelines.¹⁷² These methods are, however, expensive, slow, and cumbersome to use. Cross-border interoperability needs to be at the core of any design for the digital dollar - this includes collaborating amongst nations that already have digital currencies as well as aiding in efforts to bring more nations into the network. Out of the 47 retail CBDC projects that exist now, just under 25% of them already have mechanisms for working with each other cross-border, proving the future of international finance to expand globally.¹⁷³ The latest is Project Dunbar, a cross-border partnership between South Africa, Singapore, Malaysia, and Australia.¹⁷⁴

Naturally, a large barrier to implementation for developing countries is the lack of electricity, Internet, and smartphone access. This proves the need for a slower approach to global CBDC networks to ensure that poorer developing countries are integrated within systems that can help propel their nations forward. Investing in lower-income countries is a sound economic strategy. The Lucas Paradox studies the surprising lack of investments

¹⁷¹English, "Finding a secure solution for offline use of central bank digital currencies"

¹⁷²World Investment Report, "INTERNATIONAL PRODUCTION BEYOND THE PANDEMIC"

¹⁷³Shin, "Central Bank Digital Currencies: an Opportunity for the Monetary System"

¹⁷⁴Atlantic Council CBDC Currency Tracker

into poorer countries from rich countries. In fact, given that there are diminishing marginal returns on capital, we would expect that smaller and poorer countries have the most growth opportunities to achieve economic prosperity. Therefore, the Lucas Paradox posits the question as to why, from a humanitarian and equity perspective, richer countries do not invest in poorer countries, given how little investment (as a fraction of gross domestic product) it would require, and the network-level benefits it would provide to international financial systems.¹⁷⁵ Pledging aid and integrating digital currency connection into World Bank and United Nations missions can help ensure against unequal access to digital solutions, even if it is a long-term process.

As for the aforementioned issue of dollarization, the phenomenon is not driven much by the format of the currency, it's driven mostly by public trust in local monetary institutions (i.e. will they be able to maintain a stable inflation value in the long term?). Second, there are a lot of policy tools, such as creating accounts based on ID, so both parties need to agree on cross-border use. Third, cooperation could mitigate risks of currency substitution, since you would have no incentive to want to destabilize other economies. Finally, headwinds need to be made first and foremost, and having thriving models in developed nations allows us to slowly better inform the implementation in developing nations. Unfortunately, all technological advancements are by nature slower to arrive in developing countries - for example, solar panels have yet to show up in a majority of developing countries in the world, but slowly renewable energy is making its way through. The inequities with solar panel distribution or renewable energy grants, however, are never used as justification for pausing climate change innovation efforts.

¹⁷⁵Lucas, "Why Doesn't Capital Flow from Rich to Poor Countries?"

7 Conclusion - A Gradual, Comprehensive, And Cautious Rollout

In summary, a cautious but determined approach should be taken to the implementation of central bank digital currencies in the United States. While there are many benefits of CBDCs including financial inclusion, data-driven monetary policy, tracking of the underground economy, convenience, and cost minimization, it is important to weigh the potential risks. A digital dollar could exacerbate global inequity and financial exclusion, infringe on core liberties of privacy and compromise confidential financial information. In general, there remain many unanswered questions about the feasibility and desirability of central bank digital currencies. However, given a careful analysis of the pros and cons of the digital dollar, it is worth exploring a path for implementation and using best practices to ensure maximum usage and convenient policy design. These design choices should factor in mitigation strategies for the key downsides of CBDCs while crafting an implementation plan that maximizes the positive potential of digital currencies.

As such, this paper lays out a 7-part implementation plan that should guide a timeline for eventual CBDC rollout, coupled with areas where more policy and technology research is necessary. A digital dollar should be an account-based retail CBDC held within a digital wallet on your smartphone, released with the eventual goal of phasing out cash but not requiring complete removal of physical currency for payments. The money stored in the wallet would grow at a nominal interest rate, with the potential to be slightly negative during times of extreme economic crisis. All information about transactions would be stored in a blockchain-built private ledger with multiple layers of protection. Involvement with Payment Interface Providers (PIPs) would enable collaboration between the central bank and local commercial banks to allow for more customer retention and network effects. Using in-person identity verification, a person's account would be setup and during a transaction,

all private keys would be stored within the user's profile with control given to the central bank authority. To prevent abuse of power, transaction and identity details would be anonymous unless flagged by an algorithm, and search would only be allowed in warranted situations. Finally, along with a domestic implementation of CBDCs, the United States should focus on providing broadband access to all, increasing financial literacy programs, and boosting international aid to create a global network of cross-border digital currencies.

A move towards digital currency should not be immediate and abrupt; in fact, many of these recommendations will likely take till 2030 to implement, and the infrastructure would need to go through stress testing and constant interactions to handle the financial load. Cash would not be immediately removed from economy, and the goal would be to slowly migrate people onto digital currency, making cash obsolete for its inconvenience and deflationary properties. Sub-par and hasty implementation could erode US trust in its financial and monetary institutions, exacerbate economic inequality, and ruin efforts to transition to a digital age. The Federal Reserve has begun doing important research into policy implementation, and the next step would be to locally pilot the program and see usage patterns and frequency. The general attitude is to be cautiously optimistic about the future and think about how the United States plans to keep up with the world and propel itself forward into a digital financial age. While the US is a country that loves tradition, the monetary system is losing steam and more nuanced technological solutions are outrunning the competition. A correctly-implemented central bank digital currency can increase financial inclusion, help create significantly better monetary policy, reduce financial crime, and make transactions in our economy more efficient domestically and abroad.

8 References

Adrian, Tobias, and Tommaso Mancini-Griffoli. *The Rise of Digital Money*. Washington, D.C.: International Monetary Fund, 2019.

Agur, Itai, Anil Ari, and Giovanni Dell'Ariccia. “Designing Central Bank Digital Currencies.” VOX, CEPR Policy Portal, May 19, 2020. <https://voxeu.org/article/designing-central-bank-digital-currencies>.

Allen, Michaella, Antonia Esser, and Barry Cooper. “Central Bank Digital Currency (CBDC) and Financial Inclusion.” *CENFRI*, June 10, 2019. <https://doi.org/https://cenfri.org/publications/central-bank-digital-currency-cbdc-and-financial-inclusion/>.

Allen, Sarah, Srdjan Capkun, Ittay Eyal, Giulia Fanti, Bryan Ford, James Grimmelmann, Fan Zhang, et al. “Design Choices for Central Bank Digital Currency - Policy and Technical Considerations.” *Brookings Institution*, July 23, 2020. https://doi.org/https://www.brookings.edu/wp-content/uploads/2020/07/Design-Choices-for-CBDC_Final-for-web.pdf.

In collaboration with Initiative for CryptoCurrencies and Contracts (IC3), Swiss Federal Institute of Technology in Zürich (ETH Zürich), Israel Institute of Technology (Technion), Carnegie Mellon University (CMU), Swiss Federal Institute of Technology in Lausanne (EPFL), Cornell Tech, Cornell Law School, University College London (UCL), University of Illinois at Urbana-Champaign (UIUC), and Cornell University

Andolfatto, David. “Assessing the Impact of Central Bank Digital Currency on Private Banks,” 2018. <https://doi.org/10.20955/wp.2018.026>.

Arndt, H. W. “The ‘Trickle-down’ Myth.” *Economic Development and Cultural Change* 32, no. 1 (1983): 1–10. https://doi.org/https://www.journals.uchicago.edu/doi/pdf/10.1086/451369?casa_token=0pIeS0-JzB8AAAAA:CUuybkG1MeiySawHTigSQ444cDUA2Vuh0DxglbClbo4Jc-f5PA9P8R1zW_V6RDGA56Q1yTURX50.

Atlantic Council Central Bank Digital Currency Tracker, <https://www.atlanticcouncil.org/cbdctracker/>

Auer, Raphael, and Rainer Boehme. “The Technology of Retail Central Bank Digital Currency.” *BIS Quarterly Review*, March 1, 2020. https://doi.org/https://www.bis.org/publ/qtrpdf/r_qt2003j.htm.

Auer, Raphael, Codruta Boar, Giulio Cornelli, Jon Frost, Henry Holden, and Andreas Wehrli. “CBDCs beyond Borders: Results from a Survey of Central Banks .” *Bank for International Settlements*, June 2021. <https://doi.org/https://www.bis.org/publ/bppdf/bispap116.pdf>.

- Auer, Raphael, Giulio Cornelli, and Jon Frost. “Rise of the Central Bank Digital Currencies: Drivers, Approaches and Technologies.” *SSRN Electronic Journal*, August 24, 2020. <https://doi.org/10.2139/ssrn.3724070>.
- Auer, Raphael, Jon Frost, Leonardo Gambacorta, Cyril Monnet, Tara Rice, and Hyun Song Shin. “Central Bank Digital Currencies: Motives, Economic Implications and the Research Frontier.” *BIS*, November 2021. <https://doi.org/10.2139/ssrn.3922836>.
- Barr, Michael S., Adrienne Harris, Lev Menand, and Karin Thrasher. “Should Central Banks Use Distributed Ledger Technology and Digital Currencies to Advance Financial Inclusion?” *SSRN Electronic Journal - Center on Finance, Law, & Policy - University of Michigan*, May 17, 2021. <https://doi.org/10.2139/ssrn.3849051>.
- Barrdear, John, and Michael Kumhof. “The Macroeconomics of Central Bank Issued Digital Currencies.” *SSRN Electronic Journal*, July 18, 2016. <https://doi.org/10.2139/ssrn.2811208>.
- Baudet, Mathieu, Avery Ching, Andrey Chursin, George Danezis, François Garillot, Zekun Li, Dahlia Malkhi, Oded Naor, Dmitri Perelman, and Alberto Sonnino. “State Machine Replication in the Libra Blockchain.” *Diem Developers*, n.d. <https://doi.org/https://developers.diem.com/papers/diem-consensus-state-machine-replication-in-the-diem-blockchain/2019-06-28.pdf>.
- Bech, Morten, and Rodney Garratt. “Central Bank Cryptocurrencies.” *Bank for International Settlements Quarterly Review*, September 2017, 55–70. <https://doi.org/10.2307/j.ctv1wgvcz.12>.
- Berg, Andrew, and Eduardo R. Borensztein. “The Pros and Cons of Full Dollarization.” *The Dollarization Debate*, December 2000, 73–101. <https://doi.org/10.1093/0195155351.003.0004>.
- Berkowitz, Kelsey, and Gabe Horwitz. “Broadband for All: Connecting Everyone, Everywhere to the Digital Economy – Third Way.” *Third Way*. Accessed January 2022. <https://www.thirdway.org/report/broadband-for-all-connecting-everyone-everywhere-to-the-digital-economy>.
- BIS. “Central Bank Digital Currencies for Cross-Border Payments.” *Committee on Payments and Market Infrastructures Report to the G20* (July 2021). <https://doi.org/https://www.bis.org/publ/othp38.pdf>.
- Boar, Codruta, and Andreas Wehrli. “Ready, Steady, Go? - Results of the Third BIS Survey on Central Bank Digital Currency.” *Monetary and Economic Department - BIS 114* (January 2021). <https://doi.org/https://www.bis.org/publ/bppdf/bispap114.pdf>.

- “Board of Governors of the Federal Reserve System.” The Federal Reserve - Meet the Economists. Accessed March 2, 2022.
<https://www.federalreserve.gov/econres/theeconomists.htm>.
- Bode, Ian De, Matt Higginson, and Marc Niederkorn. “CBDC and Stablecoins: Early Coexistence on an Uncertain Road.” McKinsey & Company. McKinsey & Company, October 12, 2021. <https://www.mckinsey.com/industries/financial-services/our-insights/cbdc-and-stablecoins-early-coexistence-on-an-uncertain-road>.
- Borysowich, Craig. “Central Bank Issued Digital Currencies: A Global Trend.” Payments Canada, March 12, 2020. <https://www.payments.ca/industry-info/our-research/payments-perspectives/central-bank-issued-digital-currencies-global-trend>.
- Brunnermeier, Markus Konrad, and Dirk Niepelt. “On the Equivalence of Private and Public Money.” *SSRN Electronic Journal*, no. 25877 (May 2019).
<https://doi.org/10.2139/ssrn.3424724>.
- Carney, Mark. “Central Bank Digital Currency - Opportunities, Challenges and Design.” *Bank of England*, March 2020. <https://doi.org/https://www.bankofengland.co.uk/-/media/boe/files/paper/2020/central-bank-digital-currency-opportunities-challenges-and-design.pdf?la=en&hash=A71920A2FFB6511E43F787019C549262049CC7A8#page=21>.
- CBDC Tracker, <https://cbdctracker.org/>
- Chiu, Jonathan, Mohammad Davoodalhosseini, Janet Jiang, and Yu Zhu. “Bank Market Power and Central Bank Digital Currency: Theory and Quantitative Assessment.” *Bank of Canada - Funds Management and Banking Department*, May 2019.
<https://doi.org/https://www.bankofcanada.ca/wp-content/uploads/2019/05/swp2019-20.pdf>.
- Committee on Financial Services., and House Hearing. Bill, Inclusive Banking during a pandemic: Using Fedaccounts and digital tools to improve delivery of stimulus payments: Hearing before the Task Force on Financial Technology of the Committee on Financial Services, U.S. House of Representatives, one hundred sixteenth congress, Second Session, June 11, 2020 §. <https://www.govinfo.gov/content/pkg/CHRG-116hhr42895/html/CHRG-116hhr42895.htm> (2020).
- The Commonwealth. “Commonwealth Small States Prioritise Financial Inclusion and Lead the World on Central Bank Digital Currencies.” Commonwealth, October 11, 2021.
<https://thecommonwealth.org/press-release/commonwealth-small-states-prioritise-financial-inclusion-and-lead-world-central-bank>.
- Curry, David. “Venmo Revenue and Usage Statistics (2022).” Business of Apps, March 17, 2022. <https://www.businessofapps.com/data/venmo-statistics/>.

- Cœuré, Benoît, and Jacqueline Loh. "Central Bank Digital Currencies." *Committee on Payments and Market Infrastructures*, March 2018.
<https://doi.org/https://www.bis.org/cpmi/publ/d174.pdf>.
- Dar, Neha, Ondrej Dusek, and Sid Tiwari. "Technology-Led Shifts and Opportunities in Card-Based Payments." McKinsey & Company, April 14, 2021.
<https://www.mckinsey.com/industries/financial-services/our-insights/banking-matters/technology-led-shifts-and-opportunities-in-card-based-payments>.
- Darbha, Sriram, and Rakesh Arora. "Privacy in CBDC Technology." *Bank of Canada*, June 2020. <https://doi.org/https://www.bankofcanada.ca/2020/06/staff-analytical-note-2020-9/>.
- Dashkevich, Natalia, Steve Counsell, and Giuseppe Destefanis. "Blockchain Application for Central Banks: A Systematic Mapping Study." *IEEE Access* 8 (2020): 139918–52.
<https://doi.org/10.1109/access.2020.3012295>.
- Deloitte. "Are CBDCs the Money of Tomorrow?," n.d.
<https://doi.org/https://www2.deloitte.com/content/dam/Deloitte/lu/Documents/financial-services/Banking/lu-are-central-bank-digital-currencies.pdf>.
- Demirgüç-Kunt, Asli, Leora Klapper, Dorothe Singer, Saniya Ansar, and Jake Hess. "The Global Findex Database - Measuring Financial Inclusion and the Fintech Revolution," 2019.
<https://globalfindex.worldbank.org/>.
- Diamond, Douglas W., and Philip H. Dybvig. "Bank Runs, Deposit Insurance, and Liquidity." *Quarterly Review* 24, no. 1 (June 1983). <https://doi.org/10.21034/qv.2412>.
- "Difference between Stablecoin and CBDC (with Table)." Ask Any Difference, January 31, 2022. <https://askanydifference.com/difference-between-stablecoin-and-cbdc/>.
- DiPippo, Gerard. "Options for a Digital Dollar: Central Bank Digital Currency and Stablecoins." Options for a Digital Dollar: Central Bank Digital Currency and Stablecoins | Center for Strategic and International Studies, February 24, 2022.
<https://www.csis.org/analysis/options-digital-dollar-central-bank-digital-currency-and-stablecoins>.
- EIA. "ELECTRICITY," 2022. <https://www.eia.gov/electricity/data.php>.
- Elgin, C, M A Rose, F Ohnsorge, and S Yu. "Understanding Informality." London, September 8, 2021. <https://www.worldbank.org/en/research/brief/informal-economy-database>.
- Engert, Walter, and Ben Fung. "Central Bank Digital Currency: Motivations and Implications." *Bank of Canada*, November 2017. <https://doi.org/https://doi.org/10.34989/sdp-2017-16>.
- English, Erin. "Finding a Secure Solution for Offline Use of Central Bank Digital Currencies." *VISA Economic Empowerment Institute*, March 2021.

<https://doi.org/https://usa.visa.com/dam/VCOM/global/sites/visa-economic-empowerment-institute/documents/veei-secure-offline-cbdc.pdf>.

European Commission. “Study and Reports on the VAT Gap in the EU-28 Member States - 2020 Final ReportEu,” September 2020.

https://ec.europa.eu/taxation_customs/system/files/2020-09/vat-gap-full-report-2020_en.pdf.

FDIC. “FDIC Survey of Household Use of Banking and Financial Services,” 2021.

<https://www.economicinclusion.gov/surveys/>.

FDIC. “How America Banks: Household Use of Banking and Financial Services.” *Federal Deposit Insurance Corporation (FDIC)*, December 17, 2021.

<https://doi.org/https://www.fdic.gov/analysis/household-survey/>.

Federal Reserve. “Money and Payments: The U.S. Dollar in the Age of Digital Transformation.” *Federal Reserve*, January 2022.

<https://doi.org/https://www.federalreserve.gov/publications/files/money-and-payments-20220120.pdf>.

Federal Reserve Bank of Boston. “Project Hamilton Phase 1 Executive Summary.” Federal Reserve Bank of Boston, February 3, 2022. <https://www.bostonfed.org/publications/one-time-pubs/project-hamilton-phase-1-executive-summary.aspx>.

Feigenbaum, Joan, and Bryan Ford. “Multiple Objectives of Lawful-Surveillance Protocols.” *Security Protocols XXV*, 2017, 1–8. https://doi.org/10.1007/978-3-319-71075-4_1.

Fernández-Villaverde, Jesús, Daniel Sanches, Linda Schilling, and Harald Uhlig. “Central Bank Digital Currency: Central Banking for All?” *National Bureau of Economic Research*, no. 26753 (2020). <https://doi.org/10.3386/w26753>.

Ferrari, Massimo Minesso, Arnaud Mehl, and Livio Stracca. “Central Bank Digital Currency in an Open Economy.” *SSRN Electronic Journal*, no. 2488 (November 2020).

<https://doi.org/10.2139/ssrn.3733463>.

Foster, Katherine, Sofie Blakstad, Sangita Gazi, and Martijn Bos. “Digital Currencies and CBDC Impacts on Least Developed Countries (Ldcs).” *SSRN Electronic Journal*, 2021.

<https://doi.org/https://www.undp.org/sites/g/files/zskgke326/files/2021-06/UNDP-UNCDF-TP-1-2-Digital-Currencies-and-CBDC-Impacts-on-Least-Developed-Countries-LDCs-EN.pdf>.

Frost, Liam. “Ripple Makes Private Blockchain for Building Central Bank Digital Currencies.”

Decrypt. Decrypt, March 4, 2021. <https://decrypt.co/60169/ripple-makes-private-blockchain-for-building-central-bank-digital-currencies>.

- Goldfarb, Avi, and Catherine Tucker. "Shifts in Privacy Concerns." *American Economic Association* 102, no. 3 (May 2012). <https://doi.org/10.2139/ssrn.1976321>.
- Gurley, John G., and Edward Stone Shaw. *Money in a Theory of Finance*. WASHINGTON: BROOKING INST, 1976.
- Haig, Samuel. "Survey: Consumers Trust CBDCs Over Privately-Issued Crypto Assets." *Cointelegraph*. The future of money, April 20, 2020. <https://cointelegraph.com/news/survey-consumers-trust-cbdcs-over-privately-issued-crypto-assets>.
- Hall, Stephen G., P.A.V.B. Swamy, and George S. Tavlas. "Milton Friedman, the Demand for Money, and the ECB's Monetary Policy Strategy." *St. Louis Fed* 94, no. 3 (2012). <https://doi.org/10.20955/r.94.153-186>.
- Hansen, Tarik, and Katya Delak. "Security Considerations for a Central Bank Digital Currency." *FEDS Notes* 2022, no. 2970 (February 3, 2022). <https://doi.org/10.17016/2380-7172.2970>.
- Hinge, Dan. "Anti-Money Laundering and Countering the Financing of Terrorism." *KROLL Central Banking Focus Report* (2022). <https://doi.org/https://www.kroll.com/-/media/kroll/pdfs/publications/anti-money-laundering-countering-financing-terrorism-focus-report-2022.pdf>.
- Hope, David, and Julian Limberg. "The Economic Consequences of Major Tax Cuts for the Rich." *The London School for Economics and Political Science*, December 2020. https://doi.org/https://eprints.lse.ac.uk/107919/1/Hope_economic_consequences_of_major_tax_cuts_published.pdf.
- Internet Crime Complaint Center (IC3). "Internet Crime Report," 2021. https://www.ic3.gov/Media/PDF/AnnualReport/2021_IC3Report.pdf.
- Investopedia. "Stablecoin Definition." Investopedia. April 13, 2022. <https://www.investopedia.com/terms/s/stablecoin.asp>.
- Investopedia. "What Does Underbanked Mean?". Investopedia, April 13, 2022. <https://www.investopedia.com/terms/u/underbanked.asp#:~:text=Many%20People%20Underbanked%3F-,What%20Does%20Underbanked%20Mean%3F,their%20finances%20and%20fund%20purchases.>
- Investopedia. "What's the Environmental Impact of Cryptocurrency?" Investopedia. <https://www.investopedia.com/tech/whats-environmental-impact-cryptocurrency/>
- Keister, Todd, and Cyril Monnet. "Central Bank Digital Currency: Stability and Information." *Search and Matching in Macro and Finance*, October 7, 2020.

https://doi.org/https://sammf.com/wp-content/uploads/2020/10/6_paper_Keister-Monnet.pdf.

Keister, Todd, and Daniel Sanches. “Should Central Banks Issue Digital Currency?” *Working paper (Federal Reserve Bank of Philadelphia)*, November 2021. <https://doi.org/10.21799/frbp.wp.2021.37>.

Klement, Joachim. “CBDC Part II: A New Form of Monetary Policy?: Portfolio for the Future.” CAIA Association, December 22, 2021. <https://caia.org/blog/2021/12/22/cbdc-part-ii-new-form-monetary-policy>.

Koulayev, Sergei, Marc Rysman, Scott Schuh, and Joanna Stavins. “Explaining Adoption and Use of Payment Instruments by US Consumers.” *The RAND Journal of Economics* 47, no. 2 (September 2016): 293–325. <https://doi.org/10.1111/1756-2171.12129>.

Kshetri, Nir. “China’s Digital Yuan: Motivations of the Chinese Government and Potential Global Effects.” *Journal of Contemporary China*, March 20, 2022, 1–19. <https://doi.org/10.1080/10670564.2022.2052441>.

Kuevibulvanich, Kanit. “Economic Policy Analysis – Lecture Notes” University of Chicago, available via canvas.uchicago.edu

Kumhof, Michael, and Clare Noone. “Central Bank Digital Currencies - Design Principles and Balance Sheet Implications.” *Bank of England*, May 2018. <https://doi.org/10.2139/ssrn.3180713>.

Labonte, Marc, and Rebecca M. Nelson. “Central Bank Digital Currencies: Policy Issues.” *Congressional Research Service*, February 7, 2022. <https://doi.org/https://sgp.fas.org/crs/misc/R46850.pdf>.

Lagos, Ricardo, and Randall Wright. “A Unified Framework for Monetary Theory and Policy Analysis.” *Journal of Political Economy* 113, no. 3 (September 2004): 463–84. <https://doi.org/10.1086/429804>.

Lee, Teddy Kyung. “CBDC Wallets and the Security Requirements.” Global Semiconductor Alliance, May 4, 2021. <https://www.gsaglobal.org/forums/cbdc-wallets-and-the-security-requirements/>.

Lubin, Joseph. “Blockchain Solutions for Central Bank Digital Currency.” ConsenSys. Accessed April 2022. <https://consensys.net/solutions/payments-and-money/cbdc/>.

Lucas, Robert E. “p?” *The American Economic Review* 80, no. 2 (May 1990). <https://doi.org/https://www.jstor.org/stable/2006549>.

Macmillan, Rory. “Digital Financial Services: Regulating for Financial Inclusion.” *Conference: ITU-WB Global Dialogue on Financial Inclusion*, June 2017.

https://doi.org/https://www.researchgate.net/publication/325746031_Digital_financial_services_regulating_for_financial_inclusion.

Matsui, Toshiko, and Daniel Perez. “Data-Driven Analysis of Central Bank Digital Currency (CBDC) Projects Drivers.” *arXiv*, no. 2102.11807 (February 2021).
<https://doi.org/https://doi.org/10.48550/arXiv.2102.11807>.

McDonald, Richard J. “The ‘Underground Economy’ and BLS Statistical Data.” *Bureau of Labor Statistics*, n.d. <https://doi.org/https://stats.bls.gov/opub/mlr/1984/01/art1full.pdf>.

Nelson, Bill. “The Benefits and Costs of a Central Bank Digital Currency for Monetary Policy.” *Bank Policy Institute*, April 15, 2021. <https://doi.org/https://bpi.com/the-benefits-and-costs-of-a-central-bank-digital-currency-for-monetary-policy/>.

Oehmler, Trey. “Venmo Transaction Analysis.” RPubS, 2019.
<https://www.rpubs.com/toehmler/559525>.

Opare, Edwin Ayisi, and Kwangjo Kim. “A Compendium of Practices for Central Bank Digital Currencies for Multinational Financial Infrastructures.” *IEEE Access* 8 (2020): 110810–47.
<https://doi.org/10.1109/access.2020.3001970>.

Ozili, Peterson K. “Central Bank Digital Currency Research around the World: A Review of Literature.” *Journal of Money Laundering Control*, January 2022.
<https://doi.org/10.1108/jmlc-11-2021-0126>.

Pantuliano, Sara, and Judith Tyson. “Can Central Banks Digital Currencies Deliver for People in Poverty?” ODI. Accessed March 2022. <https://odi.org/en/insights/can-central-banks-digital-currencies-deliver-for-people-in-poverty/>.

Person, Reuters. “Chinese Central Bank's Digital Yuan given Trial by Lottery.” Reuters. Thomson Reuters, June 2, 2021. <https://www.reuters.com/business/finance/chinese-central-banks-digital-yuan-given-trial-by-lottery-2021-06-02/>.

Pew Research Center. “Mobile Fact Sheet,” April 7, 2021.
<https://www.pewresearch.org/internet/fact-sheet/mobile/>.

Pocher, Nadia, and Andreas Veneris. “Privacy and Transparency in Cbdc: A Regulation-by-Design AML/CFT Scheme.” *2021 IEEE International Conference on Blockchain and Cryptocurrency (ICBC)*, March 2021. <https://doi.org/10.1109/icbc51069.2021.9461090>.

Prasad, Eswar S. *The Future of Money How the Digital Revolution Is Transforming Currencies and Finance*. Cambridge, MA: The Belknap Press of Harvard University Press, 2022.

PREPARED FOR THE FEDERAL OPEN MARKET COMMITTEE BY THE STAFF OF THE BOARD OF GOVERNORS OF THE FEDERAL RESERVE SYSTEM. “CLASS I FOMC - RESTRICTED CONTROLLED (FR).” *MONETARY POLICY ALTERNATIVES*, June 18,

2009.

<https://doi.org/https://www.federalreserve.gov/monetarypolicy/files/FOMC20090624bluebook20090618.pdf>.

President Biden's Bipartisan Infrastructure Law, <https://www.whitehouse.gov/bipartisan-infrastructure-law/> §. The White House (n.d.).

Raghuveera, Nikhil. “Central Bank Digital Currency Can Contribute to Financial Inclusion but Cannot Solve Its Root Causes.” Atlantic Council, April 20, 2021. <https://www.atlanticcouncil.org/blogs/geotech-cues/central-bank-digital-currency-can-contribute-to-financial-inclusion-but-cannot-solve-its-root-causes/>.

Ruiz, Àlex. “The Shadow Economy: Too Great a Burden.” *Caixa Bank Research*, August 30, 2013. <https://doi.org/https://www.caixabankresearch.com/en/economics-markets/recent-developments/shadow-economy-too-great-burden>.

Salmon, Dan. “Venmo Transaction Dataset,” June 2019. <https://github.com/sa7mon/venmo-data>.

Schilling, Linda, Jesús Fernández-Villaverde, and Harald Uhlig. “Central Bank Digital Currency: When Price and Bank Stability Collide.” *National Bureau of Economic Research*, December 2020. <https://doi.org/10.3386/w28237>.

Segal, Stephanie. “Central Bank Digital Currency, Design Choices, and Impacts on Currency Internationalization.” Central Bank Digital Currency, Design Choices, and Impacts on Currency Internationalization | Center for Strategic and International Studies. Center for Strategic and International Studies (CSIS), February 17, 2022. <https://www.csis.org/analysis/central-bank-digital-currency-design-choices-and-impacts-currency-internationalization>.

Senate - Banking, Housing, and Urban Affairs, and Sherrod Brown. Bill, <https://www.congress.gov/bill/116th-congress/senate-bill/3571> Banking for All Act §. Banking for All Act (116AD).

Shin, Hyun Song. “Central Bank Digital Currencies: an Opportunity for the Monetary System.” *Speech at the 91st BIS AGM*, June 29, 2021. <https://doi.org/https://www.bis.org/speeches/sp210629b.htm>.

Shin, Hyun Song. “Central Banks and the New World of Payments .” *BIS*, June 30, 2020. <https://doi.org/https://www.bis.org/speeches/sp200630b.pdf>.

Simon, C P, A D Witte, K Eakin, and A Ziegart. “Underground Economy - Estimate of Size, Trends and Structure Executive Summary.” *US Department of Justice - Office of Justice Programs* 86866 (n.d.). <https://doi.org/https://www.ojp.gov/ncjrs/virtual-library/abstracts/underground-economy-estimate-size-trends-and-structure-executive>.

- “The Structure and Functions of the Federal Reserve System.” *Federal Reserve Education*, n.d.
<https://doi.org/https://www.federalreserveeducation.org/about-the-fed/structure-and-functions>.
- Sun, He, Hongliang Mao, Xiaomin Bai, Zhidong Chen, Kai Hu, and Wei Yu. “Multi-Blockchain Model for Central Bank Digital Currency.” *2017 18th International Conference on Parallel and Distributed Computing, Applications and Technologies (PDCAT)*, 2017.
<https://doi.org/10.1109/pdcat.2017.00066>.
- Tobin, James. “Financial Innovation and Deregulation in Perspective.” *Bank of Japan - The Institute for Monetary and Economic Studies*, May 29, 1985.
<https://doi.org/https://www.imes.boj.or.jp/research/papers/english/me3-2-3.pdf>.
- United States Mint. “United States Mint 2021 Annual Report,” 2021.
<https://doi.org/https://www.usmint.gov/wordpress/wp-content/uploads/2021/12/2021-US-Mint-Annual-Report.pdf>.
- WEF. “Privacy and Confidentiality Options for Central Bank Digital Currency.” *World Economic Forum - Digital Currency Governance Consortium White Paper Series 6/8* (November 2021).
https://doi.org/https://www3.weforum.org/docs/WEF_Privacy_and_Confidentiality_Options_for_CBDCs_2021.pdf.
- Williamson, Stephen. “Central Bank Digital Currency: Welfare and Policy Implications.” *University of Western Ontario*, May 31, 2021.
<https://doi.org/http://econ.msu.edu/seminars/docs/digital10.pdf>.
- WIPO. “Data for Researchers,” n.d. https://www.wipo.int/econ_stat/en/economics/research/.
- World Bank. “Global Financial Development Report 2019 / 2020: Bank Regulation and Supervision a Decade after the Global Financial Crisis,” 2020.
<https://www.worldbank.org/en/publication/gfdr/data/global-financial-development-database>.
- World Economic Forum. “Central Banks and Distributed Ledger Technology: How Are Central Banks Exploring Blockchain Today?” *White Paper*, March 2019.
https://doi.org/https://www3.weforum.org/docs/WEF_Central_Bank_Activity_in_Blockchain_DLT.pdf.
- World Investment Report. “World Investment Report 2020 - UNCTAD.” UNCTAD, 2020.
https://unctad.org/system/files/official-document/wir2020_en.pdf.
- Wüst, Karl, Kari Kostianen, and Srdjan Capkun. “Platypus: A Central Bank Digital Currency with Unlinkable Transactions and Privacy Preserving Regulation.” *IACR*, n.d.
<https://doi.org/https://eprint.iacr.org/2021/1443.pdf>.

Yeung, Bernard. "Digital Currency, CBDC, e-CNY." *ABFER*, October 7, 2021.

Yin, Maofan, Dahlia Malkhi, Michael K. Reiter, Guy Golan Gueta, and Ittai Abraham.
"HotStuff: BFT Consensus with Linearity and Responsiveness." *Proceedings of the 2019 ACM Symposium on Principles of Distributed Computing*, 2019.
<https://doi.org/10.1145/3293611.3331591>.

Zhang, Shuonan, and Eun Young Oh. "Central Bank Digital Currency and Informal Economy."
University of Portsmouth, Portsmouth Business School, Economics and Finance Subject Group, November 2020. <https://doi.org/https://ideas.repec.org/p/pbs/ecofin/2020-11.html>.