DIGITAL DOLLARS AND THE GOLDEN AGE OF CREDIT CARD REWARDS: WELFARE IMPLICATIONS OF A CENTRAL BANK DIGITAL CURRENCY ON THE PAYMENTS INDUSTRY

by

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I. Introduction

Central Bank Digital Currencies (CBDCs), a type of digital asset issued by a country's monetary authority, have very recently garnered academic attention, with a growing literature focused on their economic implications. However, much of this research has ignored the impact these currencies could have on the efficiency of payment systems. I attempt to fill this gap, seeking to understand how a CBDC-based digital payment system would impact the current payments landscape. To do so, I build out a simple one period model of a two-sided market based on the work of Rochet and Tirole (2003), Guthrie and Wright (2003), and Chakravorti and Roson (2006).

In my model, a continuum of buyers wish to purchase a consumption good from two merchants in standard hotelling competition. Buyers decide which payment instrument to use and merchants decide which payment instrument to accept. My model abstracts away buyer and merchant banks and assumes a single proprietary monopoly payment network competes with a government-provided CBDC-based payment network for both sides of the market. Both networks are funded exclusively by merchant fees. My model takes into account the strategic effects of merchant comptetition, causing merchants to internalize buyer network benefits. My model also allows for network differentiation along both axes of the market — buyer network benefits and merchant network benefits.

I find that in most cases, the presence of a CBDC-based payment network reduces merchant fees and increases welfare relative to the case when only the private monopoly network is available. Interestingly, I find that welfare is often increased even when the CBDC network is technologically inferior to the private network (i.e. the CBDC network possesses lower average per transaction buyer and merchant benefits). Intuitively, since buyer benefits are modeled as a continuum, and merchants internalize these benefits, even when the private network offers superior *average* per transaction benefits, the CBDC network can still attract a fraction of the market if the private network does not lower its fee. This competitive pressure is the mechanism through which welfare is increased.

However, although these results are robust to many different parameter specifications, there are instances in which the presence of the CBDC network can actually decrease welfare relative to the unchallenged monopoly case — even in cases when the CBDC network is technologically superior. Because merchants can be induced to accept merchant fees that exceed their individual per transaction benefit, when merchants accept payments on both networks, the private network can charge fees that exceed the total average per transaction benefit their network offers and still attract a fraction of the market. This can result in decreased welfare relative to the unchallenged monopoly case. Thus, although my model demonstrates that a CBDC payment network generally increases welfare, I find that a CBDC payment network can decrease welfare depending on the nature of network differentiation.

II. Background

A. Digital Currencies

Bitcoin and other cryptocurrencies have seen an extraordinary rise in popularity over the last decade. CoinMarketCap estimates the total global market capitalization of all cryptocurrency projects to be worth $2.27 trillion dollars — a figure that would position the aggregate as the 8th largest economy in the world.[11] The transformative potential of Distributed Ledger Technology (DLT), the underlying technology for Bitcoin and other cryptocurrencies, can not be ignored — DLT allows for a public ledger of transactions to be recorded, maintained, and protected against manipulation without the need for a centralized intermediary. Nevertheless, questions still remain as to the feasibility of decentralized cryptocurrencies as an effective replacement for traditional money. One such concern is the volatility of cryptocurrencies — frequent market crashes and ample uncertainty render cryptocurrencies like Bitcoin impractical for payments. Instead, many of the most notable cryptocurrencies function as speculative investment vehicles rather than true mediums of exchange.[24]

Stablecoins offer a solution to Bitcoin's volatility problem; according to an interagency report from the FDIC and OCC, stablecoins are "designed to maintain a stable [1:1] value relative to a national currency or other reference assets." Primarily used today to facilitate the trading, lending, and borrowing of other cryptocurrencies, stablecoins are increasingly getting attention from established financial institutions for their potential to facilitate digital payments. J.P. Morgan, in 2019, unveiled their own stablecoin, JPM Coin, as a service to facilitate overnight business-to-business money movement. Notably, Meta is working on its own stablecoin project called Diem, part of their vision for a digital economy controlled by Big Tech.[26] Despite not yet reaching mass adoption, stablecoins have already managed to disrupt the global financial system, leading to many new, transformative ideas and raising many unanswered questions.

One such idea is that of Central Bank Digital Currencies, or CBDCs. CBDCs are akin to stablecoins in the sense that they represent one unit of a national currency, but are issued by a country's central bank rather than by a private company. The International Monetary Fund defines a CBDC as "a digital representation of sovereign currency that is issued by a jurisdiction's monetary authority and appears on the liability side of the monetary authority's balance sheet."[20] This definition is two-pronged — CBDCs differ from cash and deposits in their digital nature and differ from existing electronic payment systems by representing a direct claim on the central bank rather than simply being a liability of a private financial institution. At first glance, the idea that the Federal Reserve might open its balance sheet to the general public seems far-fetched and improbable. However, there is actually ample historical precedent — the First and Second Banks of the United States both actively participated in credit and deposit markets, and from 1911 to 1967 government-backed deposit accounts were offered to citizens through the US post office system.[25]

Moreover, CBDCs have already garnered significant attention from the world's central banks — with declining cash usage and the technological potential of DLT, 86% of the world's central banks are now actively exploring the potential implications of their own CBDC, according to a 2020 survey by the Bank for International Settlements.[7] In fact, 2020 saw the launch of the world's first CBDC, with the Central Bank of the Bahamas releasing their "Sand Dollar" to the island nation's residents back in October. Notably, China has already begun tests of their own digital yuan, which would offer the Chinese government full surveillance power over payments and give the country a leg up over the dollar in their fight for global currency supremacy.[3] Currently, the most advanced stage projects for CBDCs reside in developing countries where the primary objectives include greater financial inclusion and increasing the central bank's authority in the underdeveloped economy. According to the International Monetary Fund, for developed economies such as the US, there are a number of possible motivations for a CBDC — improved monetary policy implementation, increased payment system efficiency, resolving privacy concerns of current payment systems, addressing concerns that current payment systems are anti-competitive, and, in light of COVID-19, the potential for expedited stimulus payments.[20]

The current body of academic literature on CBDCs is in its nascent stages and is primarily theoretical, relying on models in which CBDCs are treated as an imperfect substitute to commercial bank deposits in order to disentangle any effects on financial intermediation. However, as highlighted above, considering several of the policy motivators in the US for CBDC implementation revolve around improving payment systems, the current body of literature has, for the most part, neglected this aspect of the CBDC puzzle. In fact, to my knowledge, no research has specifically studied the potential welfare gains a CBDC could offer as an alternative to current payment systems. Thus, my research aims to start filling this gap, incorporating CBDCs into the theoretical literature on two-sided markets and payment systems. This strain of literature, as well as the existing research on CBDCs, will be highlighted in the literature review section of this paper.

B. Interchange and The Current Payments System

The use of cash as a payment instrument has been steadily declining in recent years as new electronic-based payment systems have taken a strong hold over the US economy. According to 2018 SCPC and DCPC data, only about 18% of all US transactions are now conducted in cash, a fraction that continues to shrink.[12] The electronic-based systems that have largely taken the place of cash, credit and debit card payment networks, are complex and involve multiple parties. The market for these payment networks is highly concentrated, with only four primary general purpose card networks operating in the US, the two largest being the non-proprietary networks Visa and Mastercard. These two networks coordinate transactions across four parties: the cardholder's bank (the issuer), the cardholder, the merchant's bank (the acquirer), and the merchant. This can be summarized in the simple diagram below:

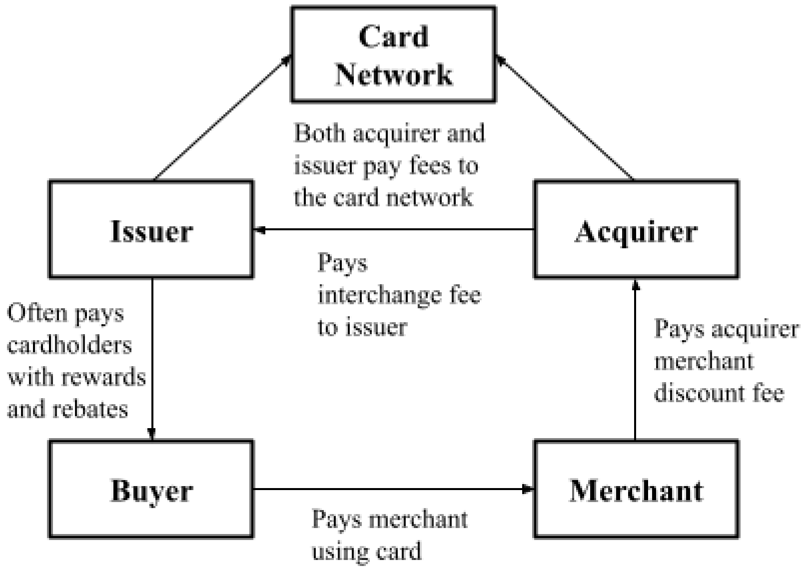

Figure 1: Diagram of payment flows in four-party payment systems.

In this system, merchants contract with their acquiring institution to join the Visa or Mastercard network to receive card acceptance services, paying a merchant discount fee, which is purported to cover transaction processing costs, to the acquirer. The acquiring institution then sends an interchange fee, set by the card network, to the issuing institution, a fraction of which often ends up in the hands of cardholders as rewards and rebates.[27] Put simply, credit card (and to a lesser extent debit card) transactions are funded by merchant fees, the revenues from which are divided amongst the acquiring and issuing banks, the card association, and the cardholder. The primary mechanism that facilitates this division of revenues is the interchange fee. Before highlighting arguments for and against four-party payment systems and interchange fees, it is useful to understand the historical context of this system.

America's first four-party payment system, paper checks, emerged after the passage of the National Banking Act in 1864, which drove the disjointed state banking system into obsolescence during a period of rapid technological change and dramatically increased interstate commerce. From its inception, largely due to arbitrary customs, banks extracted revenues from this payment system by having merchant banks (acquirers) pay purchaser banks (issuers) an "exchange charge." This exchange charge was ultimately paid by the merchants themselves, directly paralleling modern day interchange fees.

The next evolution of the four-party payment system was the development of regional clearing houses, centralized institutions for processing the requisite debiting and crediting of accounts at issuer and acquirer banks, analogous to the modern day payment card networks of Visa and Mastercard. Many of these clearinghouses set exchange charges at zero as it seemed reasonable and equitable at the time. With the passage of the Federal Reserve Act of 1913, these clearing houses were organized at a national level, with the Federal Reserve establishing a zero exchange charge national check clearance system funded by returns on government securities.

The credit card made its first appearance in the 1950s when American Express introduced Travel and Entertainment (T&E) cards, a proprietary three-party system in which both merchant and purchaser banked with the same financial institution. Bank of America responded shortly thereafter, creating their own proprietary three-party credit card system, BankAmericard. The inception of the four-party bank credit card came in 1966, when Bank of America began licensing their BankAmericard service mark to issuers at a nationwide scale. In response, a number of issuing banks around the country began forming regional joint ventures to provide interchange services for their own credit cards. By 1969, these regional card associations had all merged into the InterBank Card Association, a nonprofit membership organization owned collectively by the card-issuing banks. In 1970, Bank of America relinquished control of BankAmericard to a consortium of issuers, establishing its governance structure as a for-profit corporation — InterBank would quickly follow suit. These two corporations, BankAmericard and InterBank, which had begun as joint ventures among issuing banks, would respectively become the dominant payment processors Visa and Mastercard.[5]

This brief historical synopsis highlights two important facts about credit card networks and interchange fees: there is ample historical precedent for the government to set interchange fees at zero and the modern payment card companies, Visa and Mastercard, began as collectives of issuers. These historical facts are by no means economic justifications to eliminate interchange fees or claim that current payment systems are anti-competitive or inefficient. Determining the efficiency of privately set interchange fees is a theoretical exercise and relies on models of two-sided markets, which are highly dependent on many simplifying assumptions. However, independent of any assessment of economic efficiency, these historical facts, in conjunction with the many observable inequities inherent to the current payment card system, calls for further scrutiny of privately set interchange fees.

One of the most glaring inequities associated with interchange fees is the burden placed on cash users, who tend to be lower income when compared to credit card transactors. Since merchants indirectly fund interchange fees and surcharging is either rare or prohibited at the state level, many economists claim that merchants must raise prices across the board to compensate for their acquirer fees.[36] According to economists from the Federal Reserve Bank of Boston, "Credit card transactions are cross-subsidized by lower-cost debit and cash payments…[and] disproportionately benefit higher-income consumers, who are more likely to hold rewards cards, tend to hold cards with higher reward levels, and tend to spend more on those cards."[12] In fact, a group of researchers were able to quantify the extent of this cross-subsidization, finding that credit card-using households indirectly receive $1,133 from cash-using households every year.[34]

The current four-party payment system also creates inequities on the merchant side. Not only do merchants nearly bear the full burden of funding interchange fees through merchant discount fees, collectively paying $53.6 billion in 2018 to Visa and Mastercard alone, small merchants actually face higher fees in comparison to large corporations with bargaining power. Amazon, Costco, and Walmart have all leveraged their market power in recent years to negotiate down the fees they pay card associations. To exacerbate the issue, Visa and Mastercard currently have plans to raise small merchant fees and further lower the fees they charge to large merchants.[2] In summary, small, local merchants and poorer, cash-reliant households bear the greatest burden in our current payment system. To reiterate, this is not an indictment against payment card companies as being inefficient from a welfare standpoint, but instead serves to provide an initial motivation for further scrutiny of the system — a system that, interestingly, is no stranger to antitrust litigation.

Visa and Mastercard both have a long history of antitrust lawsuits. One of the first antitrust lawsuits against Visa in 1986, *National Bancard Corp. (NaBanco) v. Visa*, ended with the court siding in Visa's favor. The court found that Visa's relevant market was not restricted to credit card interchange, but instead included cash and checks, concluding that Visa, therefore, could not possess market power.[8] Despite this ruling, the antitrust lawsuits continued — a 1998 Department of Justice suit against both Visa and Mastercard over exclusionary conduct forced the two companies to lift restrictions they had placed on their member banks from using other card networks such as Discover.[14] A similar lawsuit against Visa, Mastercard, and American Express initiated in 2010 over restrictive merchant surcharging rules went all the way to the Supreme Court.[19] More recently, the US District Court for the Northern District of California brought an antitrust lawsuit against Visa seeking to block its acquisition of the fintech company

Plaid. Many antitrust legal experts have claimed Visa and Mastercard exhibit anti-competitive behavior, with one such expert characterizing their actions as including, "threats, coercion to prevent innovation,…exclusive deals, and a high market share in an industry with high barriers to entry." Department of Justice officials have even been cited saying that threats and exclusive deals have allowed Visa to prevent "cheaper, more efficient online debt options from gaining traction."[14]

These antitrust allegations are largely fueled by the pricing behavior of Visa and Mastercard, which extends back to the late 1990s, when Visa and Mastercard began successively raising their interchange fees despite transaction processing costs steadily declining.[4] Recently, interchange fees have continued to increase year after year, spurred by a proliferation of specialized rewards cards referred to by many as the "golden age of credit card rewards." In fact, the aggregate amount of inflation-adjusted fees paid to credit card associations in 2018 was up 108% from 2012.[2] This new era of credit card rewards and higher interchange fees reflects a change in strategy on the issuing side — issuer profits are now largely based on the interchange revenue generated by high income customers rather than on the interest payments on the revolving balances of lower income customers.[19] Moreover, the rise in interchange fees can also be attributed to decreased competition in the issuing market — a recent report from the Government Accountability Office asserts that, "over the past decade, the majority of [credit card] accounts have become concentrated among a small number of large issuers."[26] In summary, an increasingly concentrated issuing market luring consumers with an array of differentiated rewards cards has allowed the two primary payment card companies to extract as much profit as possible from their networks by slowly raising fees on mostly powerless and price inelastic merchants. This has led to a payments system characterized by inequities and limited innovation.

The case for government intervention is therefore strong, especially if the current system is indicative of a market failure in which interchange fees are set above a competitive level. Many policy ideas for government intervention exist including interchange fee caps, less restrictive merchant surcharging rules, and cost-based regulations. However, with the advent of Distributed Ledger Technology, another potential solution presents itself — a Central Bank Digital Currency.

Many of the primary motivators that central banks have specifically pointed to with regards to a CBDC center around payments. A CBDC could function as an alternative payment option to the private market Visa and Mastercard debit and credit card options. Current existing CBDC projects could offer a blueprint for how a US CBDC could change the payments landscape. Although still only in its pilot stage, China's digital yuan is already transforming the country's payments systems. Policy experts have taken note of this sharp change, explaining how, "China's system largely disintermediates banks from payment transactions … [and] creates an alternative payment ecosystem with different incentives between merchants, consumers, and payment system providers."[20] Moreover, arguably the most significant changes the Bahamas' economy has seen as a result of the world's first full fledged CBDC revolve around payments and merchant fees. Merchants accepting the Sand Dollar have had their discount fees reduced by over 30%. In addition, the innovative technology behind the Sand Dollar has resulted in significant efficiency gains for merchants with most experiencing nearly immediate settlement and consequent improvements to cash flow and liquidity positions.[6] Could a US CBDC-based alternative payments system have similar results? This is the essential question my thesis poses. Given the current state of the US payments landscape and the technological possibilities unlocked by DLT, is now the time for transforming the way money moves in our economy? Is there even a theoretical welfare-based justification for pursuing such a system? If so, how would a US CBDC alter the payments platform market? What would the impact be on commercial bank revenue models? How would merchants respond to a lower-fee CBDC option?

These are only a handful of the questions I seek to address in my thesis, many of which will remain unresolved. This area of research is still in its early stages, so there are many exciting opportunities for future studies. The rest of this paper will be divided into four sections: literature review, model setup, model analysis, and conclusion. I will outline a simplified model based on the body of research that has been conducted on payment systems and two-side markets in which a CBDC payment platform will compete with a profit-maximizing monopolist payment platform. In doing so, I hope to determine the impact that the introduction of a CBDC payment platform would have on equilibrium merchant fees and total welfare.

III. Literature Review

Before outlining the work that has been done by academics with regards to interchange fees and payment platforms, it is worthwhile to briefly outline the literature that exists on CBDCs. There are two primary literature strains relating to CBDCs — the effect of CBDCs on financial stability and the risk of bank runs and the effect of CBDCs on financial intermediation and the economy's deposit base.

Literature on the former relies on the canonical Diamond and Dybvig (1983) model of bank runs. Fernandez-Villaverde et al. (2021) extend this classic model to include a government-controlled central bank that can issue a CBDC. Their model includes an important distinction between commercial and investment banks, which allows the central bank to accomplish not only liquidity issuance, but also maturity transformation. The authors conclude that the presence of a CBDC would disintermediate commercial banks while simultaneously preventing bank runs and leading to greater financial stability, arguing that the lack of flexibility and non-callable nature of CBDC deposit contracts renders them run-proof.[13] Using the same underlying model, Keister and Monnet (2020) argue that a CBDC wouldn't necessarily reduce the likelihood of bank runs but would increase financial stability by decreasing the information asymmetry of policymakers during flights-to-safety. The underlying logic stems from an intertwinement of fiscal and monetary authority, wherein fiscal policymakers can see, in real time, the flow of central bank digital currency to and from specific banks, allowing policymakers to rapidly inject liquidity when needed.[17]

One of the first studies that seeks to understand the potential impact of a CBDC option on financial intermediation is Andolfotto's theoretical 2020 paper. Using the Diamond (1965) model of government debt with the Klein (1971) and Monti (1972) model of a monopolistic banking sector, Andolfotto concludes that a properly designed CBDC can avoid financial disintermediation and lead to a crowding in effect for aggregate investment. This conclusion hinges on three key assumptions — there is a real cost to opening a bank account, private bank deposits and a CBDC are technologically identical, and the policy reserve rate exceeds the policy CBDC rate. By assuming that the reserve-CBDC spread remains positive, a monopoly bank is incentivized to exactly match their deposit rate to the CBDC rate, placing a floor on the deposit rate. This leads to an increase in the equilibrium depository base, creating a crowding in effect for aggregate investment.[1]

The other relevant literature in this strain relies on dynamic general equilibrium models of the economy that are based on the monetary framework developed by Lagos and Wright (2004). Both Chiu et al. (2020) and Keister and Sanchez (2021) use this framework to computationally explore the possible macroeconomic implications of a CBDC and address the question of financial disintermediation. Using the Lagos and Wright framework, Chiu et al.

(2020) develop a model that expands the definition of money to include physical currency, private bank deposits, and a CBDC option, considers heterogenous sellers, and incorporates an imperfectly competitive deposit market characterized by Cournot competition and a perfectly competitive lending market. Paralleling Andolfotto's work, the authors conclude that as long as the CBDC interest rate is not set prohibitively high and as long as households have some inherent preference for private bank deposits, a CBDC option could enhance competition in the deposits market leading to increased financial intermediation and a crowding in effect.[10] Keister and Sanchez (2021) build on Chiu et al's work by considering a richer set of CBDC specifications, comparing the implications of a "targeted" CBDC that competes with only one existing form of payment and a "universal" CBDC that competes with both physical currency and deposits. Focusing on the deposit-like targeted CBDC specification, the authors' model predicts moderate financial disintermediation and crowding out, the degree of which is directly related to the CBDC deposit rate. Simultaneously, the authors find that this deposit-like targeted CBDC increases the aggregate stock of liquid assets in the economy leading to more efficient levels of exchange.

These conclusions contradict those drawn by Chiu et al., highlighting the richness and complexity of this topic, especially considering the fact that Keister and Sanchez adapt the same underlying model of Chiu et al.[18] What is also apparent from this brief overview of the CBDC literature is the gap in the literature on payments efficiency. Although Keister and Sanchez offer an initial exploration of exchange efficiency in their search theory-based model of the economy, the broad nature of the paper neglects the complex idiosyncrasies of the US payments industry. Instead, the complexities of the US payments industry have been thoroughly explored in a rich body of theoretical literature that has, until now, been completely divorced from the CBDC literature.

This research on payments began in 1983 when William Baxter published his seminal paper that introduced the unique problem of interchange into the economic literature, presenting the first model of a four-party payment system in which homogeneous purchasers and merchants demand transactional services from perfectly competitive issuers and acquirers. In Baxter's simplistic model, the two-sided nature of the market for transactional services implies that in order to maximize total surplus, merchants and purchasers must coordinate so that the proportion of the total transactional cost paid by either party reflects the heights of their demand curves. This coordination can be achieved through an interchange fee — the issuer receives less from the purchaser than their cost burden while the acquirer receives more than enough from the merchant to cover their costs, implying that the optimal interchange fee is exactly equal to the issuer's deficiency and the acquirer's surplus. Baxter then argues in favor of the collective setting of interchange fees, claiming that individual determination creates a free-rider problem in which monopsonist issuers can demand interchange fees above the competitive equilibrium.[5] Carlton and Frankel (1995) present the first challenge to Baxter's defense of interchange fees as a necessary coordination mechanism, arguing that if merchants had the ability to price discriminate according to payment instrument, the exact same equilibrium that Baxter derives could be achieved without an interchange fee. The authors acknowledge that interchange fees can be thought of as a subsidy to card-issuers to promote socially beneficial card usage, but highlight that this subsidy also functions as an unnecessary tax on cash and debit card users.[8]

Nearly two decades after Baxter's seminal paper was published, Rochet and Tirole (2002) put forward the first attempt at expanding and improving upon Baxter's simple model. The authors develop a more complete framework that endogenizes merchant and cardholder behavior, allows for imperfect competition among issuers, introduces an asymmetry between homogenous merchants and heterogeneous cardholders, and considers how merchant card acceptance strategy impacts equilibrium. Their analysis presents conditions, which heavily depend on the degree of merchant resistance to card acceptance, wherein privately set interchange fees depart from social optimality.[27] In doing so, Rochet and Tirole establish a new strain in the literature on four-party payment systems — one characterized by the asymmetry between merchants and cardholders. Using the model developed by Rochet and Tirole, Wright (2003a) considers two different extremes of merchant pricing, monopolistic pricing and Bertrand pricing, and by including cardholder membership fees, introduces a distinction between membership and usage decisions. Specifically, Wright compares outcomes when merchant surcharging is and is not allowed, finding that when merchants possess significant market power, the interchange fee can effectively balance costs between merchants and cardholders, but only under the no-surcharge rule.[36]

Schmalensee's 2002 work represents a departure from the asymmetric modeling of merchant and cardholder behavior indicative of Rochet and Tirole's original paper; instead, his model allows for merchant heterogeneity creating a new, symmetric strain of the literature. The author's model still bears many similarities to that of Rochet and Tirole, namely perfectly competitive acquirers and imperfectly competitive issuers. Schmalensee shows that the socially optimal interchange fee is a complex balancing act depending on merchant and consumer demand elasticities and the level of competition in the acquiring and issuing markets, among other factors. Importantly, Schmalensee finds that his analysis "reveals no straightforward policy toward the interchange fee that can be reliably expected to improve system performance."[32]

In the same vein of Schmalensee (2002), Wright (2003b) not only relaxes Baxter's assumption of merchant homogeneity but also Baxter's assumption that merchants do not accept cards to attract customers from rivals. Wright's model also deviates from Schamlensee's in that both issuers and acquirers are assumed to be perfectly competitive. In doing so, Wright is able to derive a formula for the socially optimal interchange fee that alters Baxter's original finding, equating the optimal merchant fee with the average transactional benefit of card-accepting merchants.[37] In a follow up paper, Wright (2004) builds out a tractable model of interchange fees that fully elicits the factors that cause deviation between the private and social optimums. Wright's model includes heterogeneous merchants and consumers defined by exogenous continuums of card-using convenience benefits, the effects of merchant competition, and varying degrees of competition in acquiring and issuing markets. Wright's analysis concludes that there are two key sources of deviation between the privately and socially optimal interchange fee — an asymmetry in the pass-through rates of acquiring and issuing costs and an asymmetry in the inframarginal effects of merchants and cardholders.[38] In an extension of both of their earlier work, Rochet and Wright (2010) work together to build a model of credit card pricing under a monopoly card network with symmetric merchants and cardholders, imperfectly competitive issuers, and perfectly competitive acquirers. Since it is assumed that the issuing side is imperfectly competitive while the acquiring side is perfectly competitive, the privately determined interchange fee only serves to transfer revenues to the profit-extracting side of the market. Thus, the authors are able to conclude that an interchange fee cap would unambiguously increase total welfare.[31]

Rochet and Tirole (2003) contribute to the symmetric strain of the literature and build on their 2002 analysis by considering the effects of platform competition on socially optimal interchange fees. Using a new framework with merchant heterogeneity, Rochet and Tirole compare the privately-determined interchange fees under platform competition to those set by a Ramsey planner. As a part of their analysis, the authors introduce the idea of multihoming to the literature — multihoming is when merchants accept cards (or purchasers hold cards) from two different payment platforms. This concept has significant impacts on equilibrium derivations as multihoming on one side of the market leads to pricing strategies on the opposite side of the market that "steer" users to single home.[28]

In another attempt to model payment platform competition, Guthrie and Wright (2003) model two competing payment platforms under the one-price assumption, extending Rochet and Tirole's 2003 analysis by allowing for strategic interaction among merchants. Importantly, the authors identify a key asymmetry between cardholders and merchants that impacts the equilibrium interchange fee — merchants gain utility by attracting new business when choosing to accept cards rather than only gaining utility from the card-usage convenience benefit enjoyed by both merchants and cardholders. This asymmetry implies that platform competition over-represents the interests of cardholders leading to higher interchange fees under platform competition assuming merchant heterogeneity.[15] Extending the literature on platform competition, Chakravorti and Roson (2006) model competing three-party payment systems that are differentiated in terms of the benefits they offer cardholders and merchants. In contrast to both Guthrie and Wright (2003) and Rochet and Tirole (2003b), the authors conclude that payment platform competition unambiguously increases cardholder and merchant welfare while decreasing network profits.[9]

There are several other authors who have contributed to the literature on payment systems. Hunt (2003) offers a non-technical overview of the underlying economic principles that characterize the payment cards industry, highlighting the tradeoffs associated with interchange fees, honor-all-cards rules, and surcharges.[16] Schwartz and Vincent (2006) specifically study the effect of the no surcharge rule (NSR) on welfare, making two important assumptions — payment mode is treated as exogenous with two separate consumer groups exclusively using either cash or payment card and merchants are modeled as local monopolists, thus eliminating the impact of merchant competition. The authors find that the NSR generally raises private profits while lowering the welfare of cash users and merchants; total welfare only increases under the NSR if the ratio of cash to card users is sufficiently large.[34] In two 2008 papers, Rochet and Tirole expand their work on payments by taking a closer look at two specific payment card features — honor-all-cards (HAC) rules and the must-take cards argument. Honor-all-cards (HAC) rules require merchants to accept all cards from a given platform. Using an adaptation of their prior models, Rochet and Tirole argue that HAC rules increase social welfare through a rebalancing effect between debit and credit card prices.[29] The must-take cards argument, which is commonly used against the private setting of interchange fees, states that merchants accept discount fees well above their convenience benefit for strategic reasons. In addition to theoretically validating this argument, Rochet and Tirole also synthesize the famous 'tourist test' benchmark for excessive interchange fees, which is passed if and only if the associated merchant discount is set so that merchants are indifferent between accepting cash or cards.[30]

The literature on payments is abundant, with many different strategies for modeling the two-sided nature of the market. Despite this, no papers have considered a public, welfare-maximizing competitor to private payment platforms, largely because it has been technologically infeasible. Now, with the emergence of distributed ledger technology, a government-run payments platform is possible — one that would take the form of a central bank digital currency. In their recent report on central bank digital currencies the Federal Reserve highlighted "faster and cheaper payments" as being one of the most important potential benefits of a CBDC.[22] In that context, being able to understand how a CBDC would interact with, and hopefully complement, the current payments system is especially pertinent. In the next section of this paper, I will present a model, relying heavily on the work of authors such as Rochet and Tirole and Wright, in which a public three-party payment platform competes with a private, monopolist four-party payment platform. In doing so, I will try to understand how the current card networks can coexist with a CBDC option and whether a CBDC option can exert competitive pressure on card networks to lower interchange fees and raise welfare.

IV. Model Setup

Drawing from Rochet and Tirole (2003), Guthrie and Wright (2003), and Chakravorti and Roson (2006), I will construct a one-period model in which a profit-maximizing proprietary monopoly payment network must respond to a government-provided CBDC payment network. In the fashion of Chakravorti and Roson (2006), I will not explicitly model the interchange fee, as the CBDC network and the monopoly network will both serve as issuer and acquirer. This assumption is motivated by the hypothetical structure of a retail CBDC, in which the Federal Reserve acts as a commercial bank for consumers and merchants alike. Additionally, I will assume that payment networks charge no buyer fees and rely entirely on funds from merchant fees. This assumption is meant to highlight the fact that in the US, issuer fees are increasingly rare while merchant discount fees have steadily gone up to fund the golden age of credit card rewards. Merchant competition will be modeled in the standard Hotelling fashion, reminiscent of Rochet and Tirole (2003) and Guthrie and Wright (2003). This will allow for the consideration of business-stealing effects, which makes merchants internalize consumer transactional benefits from card or CBDC usage. Importantly, in the fashion of Chakravorti and Roson (2006), the monopoly network and the CBDC network will be differentiated in terms of the transactional benefits they offer to consumers and merchants, allowing for price structure to have an impact on usage decisions. This assumption is motivated by the fact that there would be large technological differences and feature differences between a CBDC network and the current networks run by Visa, Mastercard, American Express, and Discover. After presenting the components of the model, in the model analysis section of the paper, I will first consider the merchant fees set by the monopoly card network in the absence of a CBDC option. Then, I will consider what happens to merchant fees when a not-for-profit, government-provided CBDC is made available to consumers.

In my model, there is a measure of one of potential consumers (referred to as buyers) who wish to buy one good from two competing merchants in a standard hotelling setup. Buyer valuations, v, of the consumption good are assumed to be sufficiently high so that all buyers transact (i.e. the market is covered). The key buyer decision is the choice of payment instrument. Cash is the default payment instrument that has no cost but also no transactional benefits. The private payment network gives each buyer a per-transaction benefit b_p^b drawn independently from a uniform distribution with support $[0, \tau_p]$, defined by the random variable $B_p^b \sim \mathcal{U}_{[0, \tau_p]}$, with a cumulative distribution function $F_{B_p^b}(x)$ and density function $f_{B_p^b}(x)$. Similarly, the CBDC network gives buyers a per-transaction benefit b_c^b drawn from a uniform distribution with support $[0, \tau_c]$, defined by the random variable $B_c^b \sim \mathcal{U}_{[0, \tau_c]}$, with a cumulative distribution function $F_{B_c^b}(x)$ and density function $f_{B_c^b}(x)$. By assuming that both the private network and the CBDC network charge consumers no fees, there is no marginal cost to card usage. Thus, all buyers will multihome. This assumption greatly simplifies the equilibrium analyses.

There are two merchants, indexed by $i \in \{1, 2\}$, in standard hotelling competition selling differentiated products that both cost *d* to produce. Both merchants receive per-transactional benefit b_p^s from accepting the private network card and pay a per-transaction fee f_p. Both merchants also receive per-transaction benefit b_c^s from accepting payments on the CBDC network and pay a per-transaction fee f_c. Due to hotelling competition, business-stealing effects are pertinent to each merchant's decision to join either payment network. Merchants, after observing private and CBDC fees, decide simultaneously whether or not to accept cards and what prices to charge (p_1 and p_2). Merchants are not allowed to price discriminate based on payment instrument.

As outlined above, the monopoly payment network receives revenue exclusively from per-transaction merchant fees. The monopoly payment network also faces per-transaction costs of c_p. Thus, the profit formula for the monopoly payment network can be written as follows where $T_p \in [0, 1]$ is transaction volume on the monopoly network:

$$\Pi_p = (f_p - c_p)T_p$$

From this equation, we can see that monopoly profits are a function of the marginal revenue received per transaction over the marginal cost per transaction and a function of the total volume of transactions the platform is able to attract. The CBDC network faces per transaction costs of c_c. I will assume that the CBDC network will make no profit and set their merchant fee to exactly cover the per-transaction cost: $f_c = c_c$.

I will also assume that the per transaction costs for each network are equal, or that $c_p = c_c = c$. Furthermore, I will assume that the expected total transactional benefit for each network exceeds this per transaction cost: $\frac{\tau_p}{2} + b_p^s > c$ and $\frac{\tau_c}{2} + b_c^s > c$. This assumption is useful because it implies that transactions on either network generate more total welfare than transactions mediated through cash. Moreover, this assumption implies that welfare is maximized when all transactions occur on the network with the highest expected total transactional benefit at a merchant fee of $f = c$, ensuring that the network is fully funded. These assumptions will be useful in characterizing equilibria that maximize welfare or unambiguously increase welfare relative to welfare when there is no CBDC option. The key assumptions are summarized as follows:

(A1) *Merchants are not allowed to price discriminate based on payment instrument.*

(A2) *Cardholders cannot be charged fees on either network.*

(A3) *The per transaction cost for each network is* $c_p = c_c = c$.

(A4) *The CBDC network makes no profit with per transaction merchant fee* $f_c = c$.

(A5) *The expected total per transaction benefit for each network exceeds the per transaction cost:* $\frac{\tau_p}{2} + b_p^s > c$ *and* $\frac{\tau_c}{2} + b_c^s > c$.

V. Model Analysis

A. Monopoly Payment Network

First, I will consider the case when only the monopoly payment network is available to buyers and merchants. In the standard hotelling setup, the two merchants are exogenously located at either end of the "linear city" — the unit interval [0,1]. To reflect product differentiation, buyers are uniformly distributed along the interval so that a buyer located at x

faces transportation costs tx from purchasing from seller 1 and $t(1 - x)$ from purchasing from seller 2. First, the private card network sets its merchant fee so as to maximize profits. Then, the two competing merchants, based on the level of the fee, simultaneously decide whether to accept cards and set their respective prices, p_1 and p_2. Based on their independent realizations of x, buyers decide which merchant to purchase from, opting to use their card if the merchant accepts it, using cash otherwise.

Proposition 1: Given A1-A5, in the absence of the CBDC network, the private monopoly payment network will set their merchant fee to be $f_p^m = \frac{\tau_p}{2} + b_p^s$. Under this fee, the total expected per transaction surplus is 0.

Proof:

Since we assume that the monopoly card network charges no per-transaction fees to cardholders, and since the support of the distribution of benefits for cardholders is $[0, \tau_p]$, all buyers will hold the monopoly card and opt to use it whenever it is accepted by merchants. Thus, the monopoly network maximizes profits by setting the highest possible merchant fee that both merchants are willing to accept, ensuring all transactions occur on their network. In order to identify this fee, we first need to derive the demand function for each seller. This involves identifying the marginal buyer who is indifferent between either seller, which is the market share, m_i, of each seller. The marginal buyer, or market share, is defined as the location along the unit interval where the expected utility of purchasing from seller 1, $U_1(x, p_1)$, equals the expected utility of purchasing from seller 2, $U_2(x, p_2)$. Let I_1^p and I_2^p be indicator functions for whether sellers 1 and 2 accept the monopoly card, respectively (when we consider the case when there is a CBDC option, these indicators will refer to whether the seller exclusively accepts the private card, or when the seller singlehomes). Then, these two expected utility functions are defined as follows:

$$U_1(x, p_1) = v + I_1^p E[B_p^b] - p_1 - tx = v + \frac{I_1^p \tau_p}{2} - p_1 - tx$$

$$U_2(x, p_2) = v + I_2^p E[B_p^b] - p_2 - t(1 - x) = v + \frac{I_2^p \tau_p}{2} - p_2 - t(1 - x)$$

Solving for x, the marginal buyer, gives us the market shares of merchants 1 and 2 ($m_1 = x$ and $m_2 = 1 - x$):

$$m_1 = \frac{1}{2} + \frac{1}{2t}[p_2 - p_1 + \frac{\tau_p}{2}(I_1^p - I_2^p)]$$

$$m_2 = \frac{1}{2} + \frac{1}{2t}[p_1 - p_2 + \frac{\tau_p}{2}(I_2^p - I_1^p)]$$

Next, assuming that both sellers face equal marginal costs for their goods, d, we can write seller 1 and 2's profit formulas as:

$$\pi_1 = m_1[p_1 - d + (b_p^s - f_p)I_1^p]$$

$$\pi_2 = m_2[p_2 - d + (b_p^s - f_p)I_2^p]$$

Solving for the equilibrium prices charged by merchants 1 and 2 involves solving the first order conditions $\frac{\partial \pi_1}{\partial p_1} = 0$ and $\frac{\partial \pi_2}{\partial p_2} = 0$ and substituting into each other the resulting profit-maximizing prices, which yields:

$$p_1 = t + d - (b_p^s - f_p)I_1^p + \frac{1}{3}(\frac{\tau_p}{2} + (b_p^s - f_p))(I_1^p - I_2^p)$$

$$p_2 = t + d - (b_p^s - f_p)I_2^p + \frac{1}{3}(\frac{\tau_p}{2} + (b_p^s - f_p))(I_2^p - I_1^p)$$

If we substitute the equilibrium price back into the profit and market share equations above, we get the following results:

$$m_1 = \frac{1}{2} + \frac{1}{6t}(\frac{\tau_p}{2} + (b_p^s - f_p))(I_1^p - I_2^p)$$

$$m_2 = \frac{1}{2} + \frac{1}{6t}(\frac{\tau_p}{2} + (b_p^s - f_p))(I_2^p - I_1^p)$$

$$\pi_1 = 2tm_1^2$$

$$\pi_2 = 2tm_2^2$$

Thus, because we have shown that merchant profit is a function of market share only, in Nash equilibrium, regardless of what the other merchant chooses, each merchant will accept the private monopoly network's card if doing so increases their market share. In other words, if the term $\frac{\tau_p}{2} + (b_p^s - f_p)$ is greater than zero, both merchants will accept cards, as doing so increases their Nash equilibrium market share. This implies that the maximum fee sellers are willing to pay is $f_p^m = \frac{\tau_p}{2} + b_p^s$. Thus, a profit-maximizing monopoly card network would set this as their fee since it is the highest possible fee that ensures all transactions occur on their network. Under this fee, each transactions total expected surplus (i.e. the expected per transaction benefits of merchants and buyers minus the per transaction fee) is equal to $\frac{\tau_p}{2} + b_p^s - f_p^m = \frac{\tau_p}{2} + b_p^s - \frac{\tau_p}{2} - b_p^s = 0.$

B. CBDC Network vs. Private Network

When a CBDC option is available, the set-up of the game is virtually identical to when the CBDC option is unavailable. When the government provides a CBDC payment network with

$f_c = c_c = c$, first, the private network observes this fee and responds by setting f_p to maximize their profits. Then, the two competing merchants, based on the levels of the fees, simultaneously decide whether to accept cards on each network and set their respective prices, p_1 and p_2. Based on their independent realizations of x, B_c^b, and B_p^b, buyers observe the payment types each merchant accepts and their prices and decide which merchant to purchase from, and, if that merchant multihomes, which payment type to use.

First, let us redefine some variables and define several new variables that will be useful in understanding the competitive effects a CBDC network would have on the equilibrium merchant fee. Let Let I_1^p and I_2^p be indicator functions for whether sellers 1 and 2 exclusively accept the monopoly card; let I_1^c and I_2^c be indicator functions for whether sellers 1 and 2 exclusively accept the CBDC card; and let M_1 and M_2 be indicator functions for whether sellers 1 and 2 multihome and accept both payment options. Next, define $\mu^b = max\{E[B_c^b],\ E[B_p^b]\} = max\{\frac{\tau_c}{2}, \frac{\tau_p}{2}\}$ to be the expected transactional benefit multihoming buyers get from using their payment options. For merchants, define $\mu^s = \lambda_c(b_c^s - f_c) + \lambda_p(b_p^s - f_p)$ to be the expected transactional surplus multihoming merchants get from accepting both payment options. λ_c is the proportion of buyers who would use the CBDC option when purchasing from a multihoming merchant and is equal to $P(B_c^b - B_p^b \geq 0)$. λ_p is the proportion of buyers who would use the private option when purchasing from a multihoming merchant and is equal to $P(B_p^b - B_c^b \geq 0)$.

Solving for the fee, f_p, that the monopoly network would set given $f_c = c$ is analogous to the proof above. First, we need to find the marginal buyer, or market share, m_i, of each seller.

To do this we need to define the expected utility of a given buyer from purchasing from seller 1, $U_1(x, p_1)$, and the expected utility of a given buyer from purchasing from seller 2, $U_2(x, p_2)$, and set them to be equal to each other. These two expected utility functions can be written as follows:

$$U_1(x, p_1) = v + I_1^p E[B_p^b] + I_1^c E[B_c^b] + \mu^b M_1 - p_1 - tx$$
$$= v + \frac{I_1^p \tau_p}{2} + \frac{I_1^c \tau_c}{2} + \mu^b M_1 - p_1 - tx$$
$$U_2(x, p_2) = v + I_2^p E[B_p^b] + I_2^c E[B_c^b] + \mu^b M_2 - p_2 - t(1 - x)$$
$$= v + \frac{I_2^p \tau_p}{2} + \frac{I_2^c \tau_c}{2} + \mu^b M_2 - p_2 - t(1 - x)$$

Equating these two utility functions and solving for x, the marginal buyer, gives us the market shares of merchants 1 and 2 ($m_1 = x$ and $m_2 = 1 - x$):

$$m_1 = \frac{1}{2} + \frac{1}{2t}[p_2 - p_1 + \frac{\tau_p}{2}(I_1^p - I_2^p) + \frac{\tau_c}{2}(I_1^c - I_2^c) + \mu^b(M_1 - M_2)]$$

$$m_2 = \frac{1}{2} + \frac{1}{2t}[p_1 - p_2 + \frac{\tau_p}{2}(I_2^p - I_1^p) + \frac{\tau_c}{2}(I_2^c - I_1^c) + \mu^b(M_2 - M_1)]$$

Identifying the profit formulae for merchant's 1 and 2 is more complex than before, as we have to evaluate μ^s, which involves finding the proportion of buyers who are expected to use either the CBDC option or the private network option when purchasing from a multihoming merchant. The procedure for determining λ_c and λ_p involves applying the convolution formula to the two random variables B_c^b and B_p^b. It can be shown that λ_c and λ_p are defined by the following:

$$\lambda_c = \begin{Bmatrix} \frac{\tau_c - {}^{\tau_p}/_2}{\tau_c} & ; \tau_c > \tau_p \\ {}^1/_2 & ; \tau_c = \tau_p \\ \frac{{}^{\tau_c}/_2}{\tau_p} & ; \tau_c < \tau_p \end{Bmatrix} \quad \lambda_p = \begin{Bmatrix} \frac{{}^{\tau_p}/_2}{\tau_c} & ; \tau_c > \tau_p \\ {}^1/_2 & ; \tau_c = \tau_p \\ \frac{\tau_p - {}^{\tau_c}/_2}{\tau_p} & ; \tau_c < \tau_p \end{Bmatrix}$$

For notational simplicity we will prefer to write the profit formulae for merchants 1 and 2 as:

$$\pi_1 = m_1[p_1 - d + (b_p^s - f_p)I_1^p + (b_c^s - f_c)I_1^c + (\lambda_p(b_p^s - f_p) + \lambda_c(b_c^s - f_c))M_1]$$

$$\pi_2 = m_2[p_2 - d + (b_p^s - f_p)I_2^p + (b_c^s - f_c)I_2^c + (\lambda_p(b_p^s - f_p) + \lambda_c(b_c^s - f_c))M_2]$$

Solving for the equilibrium prices charged by merchants 1 and 2 involves solving the first order conditions $\frac{\partial \pi_1}{\partial p_1} = 0$ and $\frac{\partial \pi_2}{\partial p_2} = 0$ and substituting into each other the resulting profit-maximizing prices, which yields:

$$\begin{aligned} p_1 = t + d - (b_p^s - f_p)I_1^p - (b_c^s - f_c)I_1^c - (\lambda_p(b_p^s - f_p) + \lambda_c(b_c^s - f_c))M_1 \\ + \tfrac{1}{3}[(\tfrac{\tau_p}{2} + (b_p^s - f_p))(I_1^p - I_2^p) + (\tfrac{\tau_c}{2} + (b_c^s - f_c))(I_1^c - I_2^c) \\ + (\mu^b + \lambda_p(b_p^s - f_p) + \lambda_c(b_c^s - f_c))(M_1 - M_2)] \end{aligned}$$

$$\begin{aligned} p_2 = t + d - (b_p^s - f_p)I_2^p - (b_c^s - f_c)I_2^c - (\lambda_p(b_p^s - f_p) + \lambda_c(b_c^s - f_c))M_2 \\ + \tfrac{1}{3}[(\tfrac{\tau_p}{2} + (b_p^s - f_p))(I_2^p - I_1^p) + (\tfrac{\tau_c}{2} + (b_c^s - f_c))(I_2^c - I_1^c) \\ + (\mu^b + \lambda_p(b_p^s - f_p) + \lambda_c(b_c^s - f_c))(M_2 - M_1)] \end{aligned}$$

If we substitute the equilibrium price back into the profit and market share equations above, we get the following results:

$$\begin{aligned} m_1 = \tfrac{1}{2} + \tfrac{1}{6t}[(\tfrac{\tau_p}{2} + (b_p^s - f_p))(I_1^p - I_2^p) + (\tfrac{\tau_c}{2} + (b_c^s - f_c))(I_1^c - I_2^c) \\ + (\mu^b + \lambda_p(b_p^s - f_p) + \lambda_c(b_c^s - f_c))(M_1 - M_2)] \end{aligned}$$

$$\begin{aligned} m_2 = \tfrac{1}{2} + \tfrac{1}{6t}[(\tfrac{\tau_p}{2} + (b_p^s - f_p))(I_2^p - I_1^p) + (\tfrac{\tau_c}{2} + (b_c^s - f_c))(I_2^c - I_1^c) \\ + (\mu^b + \lambda_p(b_p^s - f_p) + \lambda_c(b_c^s - f_c))(M_2 - M_1)] \end{aligned}$$

$$\pi_1 = 2tm_1^2$$

$$\pi_2 = 2tm_2^2$$

Again, we have shown that each merchant's profit is only a function of each merchant's respective market share. Thus, in a Nash equilibrium, regardless of what the other merchant chooses, each merchant will choose to accept the CBDC card exclusively, the private monopoly card exclusively, or both if doing so increases their market share. We can therefore define each merchant's objective function as choosing the action that leads to the greatest additional market share relative to a merchant that accepts no cards. Because the problem is identical for both merchants, they are guaranteed to choose the same action. The additional market shares associated with each action are summarized in the table below:

Action	*Additional Market Share*
Exclusively accept private card	$\frac{1}{6t}(\frac{\tau_p}{2} + (b_p^s - f_p))$
Exclusively accept CBDC	$\frac{1}{6t}(\frac{\tau_c}{2} + (b_c^s - f_c))$
Accept both private card and CBDC	$\frac{1}{6t}(max\{\frac{\tau_c}{2}, \frac{\tau_p}{2}\} + \lambda_p(b_p^s - f_p) + \lambda_c(b_c^s - f_c))$

This setup gives rise to a number of potential equilibria which will be dependent the values of the following parameters: τ_c, τ_p, b_c^s, and b_p^s. These potential equilibria are summarized in the table below:

	$b_c^s > b_p^s$	$b_c^s = b_p^s$	$b_c^s < b_p^s$
$\tau_c > \tau_p$	**1** **Merchant behavior:** - CBDC singlehoming **Welfare implication:** - Welfare is maximized	**2** **Merchant behavior:** - Indifferent between CBDC singlehoming and multihoming **Welfare implication:** - Welfare is increased relative to monopoly case	**3** **Merchant behavior:** *CBDC superiority*: - Multihoming *Private network superiority:* - Private network singlehoming or multihoming (depends on private network decision based on specific parameter values) **Welfare implication:** - Ambiguous
$\tau_c = \tau_p$	**4** **Merchant behavior:** - CBDC singlehoming **Welfare implication:** - Welfare is maximized	**5** **Merchant behavior:** - Indifferent between CBDC singlehoming, private network singlehoming, and multihoming. **Welfare implication:** - Welfare is maximized	**6** **Merchant behavior:** - Private network singlehoming **Welfare implication:** - Welfare is increased relative to monopoly case
$\tau_c < \tau_p$	**7** **Merchant behavior:** *CBDC superiority*: - CBDC singlehoming or multihoming (depends on private network decision based on specific parameter values) *Private network superiority:* - Multihoming **Welfare implication:** *CBDC superiority*: - Ambiguous *Private network superiority:* - Welfare is increased relative to monopoly case	**8** **Merchant behavior:** - Multihoming **Welfare implication:** - Welfare is increased relative to monopoly case	**9** **Merchant behavior:** - Private network singlehoming or multihoming (depends on private network decision based on specific parameter values) **Welfare implication:** - Welfare is increased relative to monopoly case

*Table 1: S*ummary of merchant behavior and welfare implications for different parameter values

In the sub-sections that follow, we will derive the results summarized in this table. First, we will consider the case when both networks are identical in terms of their total expected per transaction benefits. Then we will consider the cases in which the CBDC network is superior, offering more total expected per transaction benefits than the private network. Finally, we will consider the cases in which the private network is superior, offering more total expected per transaction benefits than the CBDC network.

i. Identical Networks

Proposition 2: Given A1-A5, if networks are identical ($\tau_c = \tau_p = \tau$ and $b^s_c = b^s_p = b^s$), in the presence of a CBDC network, a single private network sets their merchant fee to be $f_p = f_c = c$ and welfare is maximized (this corresponds to cell 5 in Table 1).

Proof:

If we assume that both networks are identical in terms of the transactional benefits they create for buyers and merchants ($\tau_c = \tau_p = \tau$ and $b^s_c = b^s_p = b^s$), then the private network is forced to match the CBDC network fee. This is because if the private network sets their fee to be slightly higher than the CBDC network fee, then $\frac{1}{6t}(\frac{\tau}{2} + (b^s - f_c)) > \frac{1}{6t}(\frac{\tau}{2} + (b^s - f_p))$ and $\frac{1}{6t}(\frac{\tau}{2} + (b^s - f_c)) > \frac{1}{6t}(\frac{\tau}{2} + \frac{1}{2}(b^s - f_p) + \frac{1}{2}(b^s - f_c))$, meaning merchants will singlehome on the CBDC network and the private network's profit will be 0. The private network cannot set a merchant fee lower than the CBDC fee because they would not be able to cover their transactional costs. Thus, when we assume that networks are identical, the monopoly network makes zero profit, setting their merchant fee to exactly equal per-transaction costs resulting in three potential equilibria: merchants singlehome on the CBDC network, merchants singlehome on the private network, or merchants multihome and each network processes exactly half of all transactions. Regardless of the specific equilibrium realized, welfare is maximized as the total expected per transaction surplus is the same in each: $\frac{\tau}{2} + b^s - c$. ▮

ii. Superior CBDC Network

Next, we will consider the set of cases in which the CBDC network offers higher total expected per transaction benefits than the private network (i.e. the CBDC network is superior to the private network from a welfare standpoint). This would imply $\frac{\tau_c}{2} + b^s_c > \frac{\tau_p}{2} + b^s_p$. If this is the case, it is easy to show that singlehoming on the private network is dominated by singlehoming on the CBDC network in the merchant's objective function. In order for the private network to make singlehoming on their network more appealing to merchants than singlehoming on the CBDC network, the private fee would have to be set such that $\frac{1}{6t}(\frac{\tau_p}{2} + (b^s_p - f_p)) > \frac{1}{6t}(\frac{\tau_c}{2} + (b^s_c - f_c))$. This would imply $f_p < c$ which would render the private network unprofitable. However, there are possible equilibria in which the private network can set a fee that induces merchants to multihome, and, in some cases, do so profitably. Solving for this fee means finding the fee in which merchants are indifferent between multihoming and singlehoming on the CBDC network. We will break this analysis into three parts based on the parameters of the consumer benefit distributions, τ_c and τ_p.

A. *Identical expected buyer benefits* ($\tau_c = \tau_p = \tau$).

Since we have assumed CBDC network superiority, the distribution of buyer benefits being identical for the two networks implies that the CBDC network must offer merchants higher per-transaction benefits: $b^s_c > b^s_p$. Assuming $\tau_c = \tau_p = \tau$, it can easily be shown that the private fee that would make merchants indifferent between multihoming and singlehoming on the CBDC network is $f_p = (b_p^s - b_c^s) + c$. However, because $b_c^s > b_p^s$, the private network would have to charge merchants a fee that is lower than their marginal transaction cost to induce this indifference. Thus, when there is CBDC network superiority but identical expected buyer benefits for each network, the only possible equilibrium is that both merchants singlehome on the CBDC network. When this is the case, welfare is maximized — all transactions occur on the superior CBDC network at a merchant fee of $f = c$ (this corresponds to cell 4 in Table 1).

B. *Superior CBDC expected buyer benefits* ($\tau_c > \tau_p$).

It can easily be shown that the private fee that would make merchants indifferent between multihoming and singlehoming on the CBDC network when $\tau_c > \tau_p$ is $f_p = (b_p^s - b_c^s) + c$. Under the assumption of CBDC network superiority, it is possible for $b_c^s > b_p^s$, $b_c^s = b_p^s$, and $b_c^s < b_p^s$ (as long as $\frac{\tau_c}{2} - \frac{\tau_p}{2} > b_p^s - b_c^s$). If $b_c^s > b_p^s$, then the private network would have to charge a fee lower than their marginal transaction cost to induce indifference. In this scenario, the only equilibrium is that merchants single home on the CBDC network, leading to welfare maximization (this corresponds to cell 1 in Table 1). If $b_c^s = b_p^s$, then the private network would have to charge a fee exactly equal to their marginal transaction cost to induce indifference, making no profit. Two possible equilibria arise in this case: merchants single home on the CBDC network or merchants multihome and $\lambda_c = \frac{\tau_c - \frac{\tau_p}{2}}{\tau_c}$ of all transactions occur on the CBDC network and $\lambda_p = \frac{\frac{\tau_p}{2}}{\tau_c}$ of all transactions occur on the private network. Both equilibria are characterized by higher welfare when compared to the unchallenged monopoly case as merchant fees on either network equal c. Welfare, however, is not maximized, as the equilibrium in which merchants multihome involves a fraction of transactions occurring on the inferior private network (this corresponds to cell 2 in Table 1). The case in which $b_c^s < b_p^s$ is more complicated, as there is now a scenario in which the private network can induce merchants to multihome while turning a profit. The private network can charge a fee slightly lower than $(b_p^s - b_c^s) + c$ and induce both merchants to multihome, attracting $\lambda_p = \frac{\frac{\tau_p}{2}}{\tau_c}$ of the market to their platform. The per-transaction profit for the private network would be slightly less than $(b_p^s - b_c^s)$. Intuitively, the private network is able to extract per transaction revenue over their per transaction cost equal to the surplus utility they provide merchants over the CBDC network. The welfare implications of this equilibrium are ambiguous and depend on the specific values of the parameters — welfare is not guaranteed to be higher when compared to welfare under the unchallenged monopoly network (this corresponds to half of cell 3 in Table 1).

C. *Superior private network expected buyer benefits* $(\tau_p > \tau_c)$.

When we consider the case in which there is CBDC network superiority but the private network offers buyers higher expected per-transaction benefits than the CBDC network, the CBDC network must offer merchants higher per-transaction benefits than the private network. Together, this implies that $b_c^s - b_p^s > \frac{\tau_p}{2} - \frac{\tau_c}{2} > 0$. In order to make merchants indifferent between multihoming and singlehoming on the CBDC network, it can be shown that the private network fee must be set to:

$$f_p = c + (b_p^s - b_c^s) + \frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2}) = c + (b_p^s - b_c^s) + \frac{\tau_p}{\tau_p - \frac{\tau_c}{2}}(\frac{\tau_p}{2} - \frac{\tau_c}{2})$$

The term $(b_p^s - b_c^s)$ is guaranteed to be negative while the term $\frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2})$ is guaranteed to be positive. Thus, if $\left|b_p^s - b_c^s\right| > \frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2})$, then the private network would have to set a fee below its per-transaction cost to induce merchants to multihome, meaning merchants would singlehome on the CBDC network. If $\left|b_p^s - b_c^s\right| = \frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2})$, then the private network would have to set a fee exactly equal to its per-transaction cost, making no profit, in order to induce merchants to multihome. If $\left|b_p^s - b_c^s\right| < \frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2})$, then the private network could set a fee higher than its per-transaction cost and still induce merchants to multihome, making positive profits per transaction equal to $\frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2}) - (b_c^s - b_p^s)$. Thus, this represents another potential equilibrium where, despite the fact that the CBDC network is better for society, the private network can attract some of the transactions while still charging fees above the per transaction cost. This is also a case where the resulting equilibrium depends on the specific values of the parameters and not just how they are related to each other directionally. The welfare implications of this case are ambiguous. If $\left|b_p^s - b_c^s\right| > \frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2})$, merchants singlehome on the CBDC network and welfare is maximized. If $\left|b_p^s - b_c^s\right| = \frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2})$, welfare is unambiguously increased relative to the unchallenged monopoly case, but welfare is not maximized as some transactions still occur on the inferior private network. Finally, if

$\left|b_p^s - b_c^s\right| < \frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2})$, welfare is not unambiguously higher when compared to the unchallenged monopoly case (this corresponds to the first half of cell 7 of Table 1).

iii. Superior Private Network

Finally, we will consider the set of cases in which the private network offers higher total expected per transaction benefits than the CBDC network (i.e. $\frac{\tau_p}{2} + b_p^s > \frac{\tau_c}{2} + b_c^s$). First, before analyzing these cases, let us remind ourselves of the profit formula for the private payment network: $\Pi_p = (f_p - c_p)T_p = (f_p - c)T_p$. Here, $T_p = 1$ if merchants singlehome on the private network, $T_p = 0$ if merchants singlehome on the CBDC network, and $T_p = \lambda_p$ if merchants multihome. We will break this analysis into three parts based on the parameters of the consumer benefit distributions, τ_p and τ_c.

A. *Identical expected buyer benefits* $(\tau_p = \tau_c = \tau)$.

First, let us consider the simplest case, where the distribution of buyer benefits is identical for the two networks. Since we have assumed private network superiority, the private network must offer merchants higher per-transaction benefits: $b_p^s > b_s^s$. It can easily be shown that in order for merchants to be indifferent between multihoming, singlehoming on the CBDC network, and singlehoming on the private network, the private network would have to set a fee equal to $f_p = (b_p^s - b_c^s) + c$. This implies that any fee that satisfies $f_p < (b_p^s - b_c^s) + c$ would incentivize merchants to singlehome on the private network, as it would be preferable to both multihoming and singlehoming on the CBDC network. Thus, the private network would set a fee slightly lower than $(b_p^s - b_c^s) + c$, capture the entire market, and make profit that is slightly less than $b_p^s - b_c^s$, the surplus per-transaction benefit they offer merchants over the CBDC network. In this equilibrium, all transactions occur on the private network with, due to A5, an expected per transaction total surplus that is greater than 0 and equal to

$\frac{\tau}{2} + b_p^s - ((b_p^s - b_c^s) + c) = \frac{\tau}{2} + b_c^s - c > 0$. Thus, when compared to the case of the unchallenged monopoly, where the expected per transaction total surplus is 0, welfare is unambiguously increased (this corresponds to cell 6 in Table 1).

B. *Superior private network expected buyer benefits* $(\tau_p > \tau_c)$.

If we next consider the case in which the expected buyer benefits of the private network exceed the expected buyer benefits of the CBDC network while still assuming private network superiority, there are three possible specifications for seller benefits: $b_p^s = b_c^s$, $b_p^s > b_c^s$, and $b_p^s < b_c^s$ (as long as $\frac{\tau_p}{2} - \frac{\tau_c}{2} > b_c^s - b_p^s$). First, if we assume identical seller benefits, or $b_p^s = b_c^s$, it can be shown that in order for merchants to prefer singlehoming on the private network to singlehoming on the CBDC network, the merchant fee must satisfy $f_p < (\frac{\tau_p}{2} - \frac{\tau_c}{2}) + c$. However, in order for the private network to make singlehoming on their network more preferable than multihoming, they would have to set a fee that satisfies $f_p < c$. Thus, the private network can not incentivize merchants to singlehome on their network and still maintain profitability. This means the only possible equilibrium is that merchants multihome, with the private network charging a merchant fee that is slightly less than $(\frac{\tau_p}{2} - \frac{\tau_c}{2}) + c$, attracting

$\lambda_p = \frac{\tau_p - \frac{\tau_c}{2}}{\tau_p}$ of the market and making profit that is slightly less than $\Pi_p = \lambda_p(\frac{\tau_p}{2} - \frac{\tau_c}{2})$. Intuitively, this result implies that the private network is able to extract profits by charging merchants a fee that captures the expected buyer per transaction surplus merchants have internalized in their objective function. The per-transaction expected total surplus for this equilibrium has increased relative to the zero per-transaction expected total surplus under the unchallenged monopoly network. The per-transaction surplus for this equilibrium would be $\lambda_c(b_c^s + \frac{\tau_c}{2} - c) + \lambda_p(b_p^s + \frac{\tau_c}{2} - c) > 0$ because A5 implies $\frac{\tau_c}{2} + b_c^s > c$ and we've assumed $b_c^s = b_p^s$ (this corresponds to cell 8 in Table 1).

Next, we will assume that the private network also offers merchants higher per transaction benefits in comparison to the CBDC network (i.e. $b_p^s > b_c^s$). It can be shown that in order to incentivize merchants to prefer singlehoming on the private network to singlehoming on the CBDC network, the private merchant fee would have to satisfy $f_p < (\frac{\tau_p}{2} - \frac{\tau_c}{2}) + (b_p^s - b_c^s) + c$. It can also be shown that to make singlehoming on the private network preferable to multihoming, the private network would need to charge a merchant fee that satisfies $f_p < (b_p^s - b_c^s) + c$. This implies that in order to guarantee that merchants singlehome on their network, the private network would have to charge a fee that is slightly less than $f_p = (b_p^s - b_c^s) + c$. The private network could, however, choose to set a higher fee and guarantee that they capture $\lambda_p = \frac{\tau_p - \frac{\tau_c}{2}}{\tau_p}$ of the market, as long as that fee is slightly less than $f_p = (\frac{\tau_p}{2} - \frac{\tau_c}{2}) + (b_p^s - b_c^s) + c$. Thus, if the private network sets their fee to be

$f_p = (b_p^s - b_c^s) + c$ (i.e. merchants are indifferent between singlehoming on the private network and multihoming) and merchants singlehome on their network, private network profits would be $\Pi_p = b_p^s - b_c^s$. If the private network chooses to set a fee equal to $f_p = (\frac{\tau_p}{2} - \frac{\tau_c}{2}) + (b_p^s - b_c^s) + c,$ leading to merchant multihoming, then private network profits would be $\Pi_p = \lambda_p((\frac{\tau_p}{2} - \frac{\tau_c}{2}) + (b_p^s - b_c^s))$. Thus, the profit maximizing decision for the private network depends on the specific values of the parameters. The private network will set the higher fee and allow merchants to multihome if $\lambda_p(\frac{\tau_p}{2} - \frac{\tau_c}{2}) > (1 - \lambda_p)(b_p^s - b_c^s)$. Otherwise, the private network will lower their fee and incentivize both merchants to singlehome on their network. If we compare the total expected per transaction welfare of these two equilibria, we can see that welfare is higher when merchants singlehome on the private network than when merchants multihome: the per-transaction expected welfare under private network singlehoming would be $\frac{\tau_p}{2} + b_c^s - c$ versus $\frac{\tau_c}{2} + b_c^s - c$ under multihoming. Regardless, when compared to the case of the unchallenged monopoly, where the expected per transaction total surplus is 0, welfare is unambiguously increased under both equilibria, as A5 implies $\frac{\tau_c}{2} + b_c^s > c$ and we've assumed $\tau_p > \tau_c$ (this corresponds to cell 9 in Table 1).

Finally, consider the case of private network superiority where $b_p^s < b_c^s$, implying that $\frac{\tau_p}{2} - \frac{\tau_c}{2} > b_c^s - b_p^s$. It can be shown that the private fee that makes merchants prefer singlehoming on the private network to singlehoming on the CBDC network satisfies $f_p < (\frac{\tau_p}{2} - \frac{\tau_c}{2}) - (b_c^s - b_p^s) + c$. It can also be shown that the private fee that makes merchants prefer singlehoming on the private network to multihoming satisfies $f_p < (b_p^s - b_c^s) + c$. Since $b_p^s < b_c^s$, the private network can not set a fee that satisfies this condition and be profitable. Thus, the private network can not induce merchants to singlehome on their network. However, the private network can incentivize merchants to multihome instead of singlehoming on the CBDC network if the private fee they set satisfies $f_p < \frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2}) - (b_c^s - b_p^s) + c$. They can do this profitably, as $\frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2}) > b_c^s - b_p^s$. Thus, we have one resulting equilibrium, merchants multihome and the private network fee satisfies $f_p < \frac{1}{\lambda_p}(\frac{\tau_p}{2} - \frac{\tau_c}{2}) - (b_c^s - b_p^s) + c$. In this equilibrium, the total expected per transaction surplus is greater than the total expected per transaction surplus under the unchallenged monopoly network. Because of A5 and the assumption that $\tau_p > \tau_c$, the expected per transaction surplus is greater than 0 and is equal to $\lambda_c(\frac{\tau_c}{2} + b_c^s - c) + \lambda_p(\frac{\tau_p}{2} + b_c^s - c) + (\frac{\tau_p}{2} - \frac{\tau_c}{2}) > 0$. Thus, welfare is unambiguously increased relative to welfare under the unchallenged monopoly network (this corresponds to half of cell 7 in Table 1).

C. *Superior CBDC expected buyer benefits* ($\tau_c > \tau_p$).

When we consider the case in which there is private network superiority but the CBDC network offers buyers higher expected per-transaction benefits, the private network must offer merchants higher per-transaction benefits than the CBDC network. Together, this implies that $b_p^s - b_c^s > \frac{\tau_c}{2} - \frac{\tau_p}{2} > 0$. First, we can show that the private fee that would make merchants prefer singlehoming on the private network to singlehoming on the CBDC network satisfies

$f_p < (b_p^s - b_c^s) - (\frac{\tau_c}{2} - \frac{\tau_p}{2}) + c$. However, to make merchants prefer singlehoming on the private network to multihoming, the private fee would have to satisfy $f_p < (b_p^s - b_c^s) - \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2}) + c$. This is profitable for the private network if $(b_p^s - b_c^s) > \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2})$. If this profitability condition is satisfied, the private network can charge a fee slightly less than $f_p = (b_p^s - b_c^s) - \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2}) + c$, induce merchants to singlehome on their network, and make profit equal to $\Pi_p = (b_p^s - b_c^s) - \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2})$. If this condition is not satisfied, the private network can not profitably induce merchants to singlehome on their network, but can still profitably induce merchants to multihome if $f_p < (b_p^s - b_c^s) + c$. The private network would charge a fee slightly less than $f_p = (b_p^s - b_c^s) + c$, attract λ_p of the market, and make profit equal to $\Pi_p = \lambda_p(b_p^s - b_c^s)$. If $(1 - \lambda_p)(b_p^s - b_c^s) - \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2}) > 0$ then the private network would actually prefer to charge this higher fee, allow merchants to mulithome, and capture a fraction of the market instead of charging a lower fee to induce merchant singlehoming. Thus, we have two potential equilibria that depend on the values of the parameters. If $(1 - \lambda_p)(b_p^s - b_c^s) - \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2}) < 0$ and $(b_p^s - b_c^s) > \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2})$, then the private network would set a fee slightly less than $f_p = (b_p^s - b_c^s) - \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2}) + c$ and induce merchants to singlehome on their network. If $(1 - \lambda_p)(b_p^s - b_c^s) - \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2}) < 0$ or $(b_p^s - b_c^s) < \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2})$, then the private network would set a fee slightly less than

$f_p = (b_p^s - b_c^s) + c$ and induce merchants to mulithome. Importantly, only the merchant singlehoming equilibrium unambiguously increases welfare relative to the unchallenged monopoly network. For the merchant singlehoming equilibrium, the expected per transaction surplus is equal to $(\frac{\tau_p}{2} + b_p^s - c) + [\frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2}) - (b_p^s - b_c^s)]$. This expression is unambiguously greater than 0, the surplus under the unchallenged monopoly network, because of A5 and the fact that this equilibrium requires that $(b_p^s - b_c^s) < \frac{1}{\lambda_c}(\frac{\tau_c}{2} - \frac{\tau_p}{2})$. For the merchant multihoming equilibrium, the expected per transaction surplus is equal to $\lambda_c(\frac{\tau_c}{2} + b_c^s - c) + \lambda_p(\frac{\tau_p}{2} + b_c^s - c)$. The transactions occurring on the CBDC network unambiguously result in positive per transaction expected total surplus because of A5, but this is not the case for transactions occurring on the private network, meaning welfare is not unambiguously increased relative to the unchallenged monopoly case (this corresponds to half of cell 3 in Table 1).

VI. Conclusion

This paper provides a simple theoretical model for the analysis of the impact of a government-provided CBDC payment platform on the merchant fees set by a single private payment platform. It builds off the work of authors such as Rochet and Tirole (2003), Guthrie and Wright (2003), and Chakravorti and Roson (2006), who have all developed theoretical models of competing payment networks, by presenting a model where buyer per-transaction surplus is exogenous, networks are differentiated, and the strategic effects of merchant competition are incorporated. My paper also builds on the work of authors such as Chiu et al.

(2020) and Keister and Sanchez (2021), who have studied the theoretical impactions of CBDCs, by considering the impact a CBDC would have on payments.

My model demonstrates that the presence of CBDC-based payment network maximizes welfare if the CBDC network is identical to the private network. In most cases, when the CBDC network and the private network are differentiated, my model shows that the presence of the CBDC network increases welfare and lowers merchant fees relative to welfare and merchant fees under a monopoly payment platform. Importantly, the presence of the CBDC network can increase welfare even when the CBDC network is technologically inferior to the private network. However, increased welfare is not guaranteed and depends on the degree of network differentiation and along which axis networks are differentiated — the buyer side or the merchant side. Thus, the welfare effects that a CBDC-based payment system might have on the payments industry are complex. Moreover, my model makes many assumptions for the sake of simplifying the analysis that don't represent the actual state of the payments industry — I model the payment industry as a single monopoly network; I abstract away issuers and acquirers and don't explicitly model the interchange fee; I model the consumer side as exogenous, not allowing payment networks to charge fees or offer rewards to cardholders; and I assume that a CBDC network and private network would have the same marginal cost. Thus, more research needs to be done to fully understand the effects a CBDC would have on the payments industry and how these effects tie into the broader macroeconomic implications of a CBDC.

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