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Keywords

Digital Money, Monetary Policy

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Abstract

The term digital money refers to various proposed electronic payment mechanisms designed to use by consumers to make retail payments. These mechanisms are based either on *smart cards* or on *network money*. Smart cards could potentially replace currency as the predominant means to pay for retail purchases. Software-based digital money products (network money) bring cheap electronic funds transfers to individuals and small firms. This paper examines how digital money affects the demand for money and how this process, in turn, affects the demand for reserves, monetary control, and the monetary transmission mechanism.

Introduction

The potential of digital money to replace currency in the payment for retail goods and its ability to flow freely across international borders has alarmed central bankers, the media, and scholars. There are rumors that central banks will lose control over the monetary aggregates, and, even worse, that digital money will alter foreign exchange rates, disturb money supplies, and encourage an overall financial crisis (Tanaka 1996). Opinions on this issue could not be more diverse. Ely (1996), for example, suggests that, fundamentally, digital money is no different from all other forms of money that exist today; consequently, the monetary policy implications of digital money are nil.

The proposed electronic payment mechanisms are based either on the *smart card* or on *network money*. The smart card, also known as the electronic purse, is a plastic card that has embedded a microprocessor, which can be loaded with a monetary value. With each purchase the card's value is reduced. The smart card is reloadable, can be used for multiple purposes, and needs no online authorization for value transfer. The first two characteristics distinguish the smart card from the single-purpose, prepaid card widely used in Europe. The third characteristic distinguishes it from the debit card.[1] Network money refers to software that allows the transfer of value on computer networks, particularly on the Internet.

Like a travelers check, a digital money balance is a floating claim on a private bank or other financial institution that is not linked to any particular account (White 1996). A digital

[1] Note that unlike all other existing electronic payment instruments (e.g. debit cards and credit cards) digital money is a medium of exchange, i.e., it is a truly (private) money. A debit card is not a medium of exchange. It is an electronic payment instrument that initiates a transfer of value between two transaction accounts. Literature on digital money has created many other expressions such as e-money, electronic money, network money, digital currency, electronic currency, digital cash, electronic cash, e-cash, etc. We prefer the term digital money to distinguish it from other electronic payment instruments such as debit and credit cards. For an extended definition and characterization of digital money see BIS (1996a, 1996b), Stuber (1996), or CBO (1996).

money balance on a smart card or computer hard drive is a form of credit because the balance is the liability of its issuer. An institution's incentive to issue digital money is the interest-free or low interest debt financing that the outstanding digital money balance provides.

Widespread use of digital money could affect central banks in such areas as monetary policy, banking supervision, supervision of the payment system, and the stability of the financial system. The main concern of central bankers today is security.[2] A security breach -- counterfeiting -- of a digital money product widely used could severely disturb the financial system.

For banking supervisors, the main issues are whether institutions, other than banks, should be allowed to issue digital money,[3] and whether traditional regulations, such as reserve requirements and capital regulations, should be extended to issuers of digital money products. In addition, there is concern that digital money could facilitate money laundering, fraud, and tax evasion. Widespread use of digital money could facilitate illegal activities because, in contrast to debit card and credit card transactions, some forms of digital money allow users to remain anonymous.

This paper examines how a widespread use of digital money would affect monetary policy. In section 1 we analyze how digital money affects the use of various payment instruments. Particularly, we study its effect on the demand for central bank currency and transaction deposits. We find that smart cards, designed as a substitute for central bank currency, could eventually replace the entire stock of central bank currency and, to a lesser extent, reduce the demand for transaction deposits.

Currency, as the predominant liability of central banks, plays an important role in the *implementation* of monetary policy. Section 2 discusses the implications of an extensive substitution of central bank currency for monetary control, particularly, the ability of central banks to control the market for bank reserves. Replacement of central bank currency and lower demand for transaction deposits would also affect monetary aggregates and the functioning of the *monetary policy transmission mechanism*. These effects are studied in Section 3.

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[2] In November 1995, central bank governors of the Group of Ten (G-10) countries commissioned studies on the security of digital money products. They published their results in BIS (1996a).

[3] The European Union, for example, plans to limit the issuance of multipurpose smart cards to registered banks only. See EMI (1994).

1 The Demand for Money

The section examines digital money's potential to replace central bank currency and other media of exchange. We begin with a description of the characteristics of digital money products. We then present a model that studies how a representative agent would choose among various payment instruments. The section ends with a complementary model that investigates the strategic interaction between firms and households that determines whether a new medium of exchange can be successfully introduced.

Characteristics of digital money products

Digital money products based on smart cards are designed to facilitate small-value payments in face-to-face retail transactions. The average transaction is expected to be less than $20, a sum for which use of credit and debit cards is inconvenient and too costly (CBO 1996). It is, therefore, expected that digital money products based on smart cards will reduce use of central bank notes and coins and, to a much lesser extent, use of debit and credit cards for face-to-face payments. Software-based digital money products are more likely to reduce use of checks, debit cards, and credit cards for non-face-to-face payments, i.e., for online payments.

In development are many different types of digital money products with varying characteristics. However, in principal at least, digital money can be designed to share all characteristics of central bank currency, and it could, therefore, be a very close substitute for bank notes and coins. The main differences are that digital money is not legal tender, which would reduce its acceptance initially, and that, unlike currency and all other media of exchange today, digital money does not require the physical presence of payer and payee for *payment finality* because digital money balances can be transferred across telecommunication networks in real time. Table 1 lists the main characteristics of currency, digital money, checks, and debit cards.

Replacement of currency could benefit issuers, consumers, and merchants. Issuers would benefit from the interest-free debt financing provided by digital money balances.[4] Consumers would benefit from the convenience. For merchants, accepting digital money would reduce costs if bits and bytes replaced physical coins and notes. The estimated annual costs of handling central bank currency by U.S. retailers and banks are $60 billion, which includes costs of processing and accounting of money, storage, transport, and security (Hayes et al. 1996).[5] Hayes et al. (1996) also suggests that the cost of an electronic payment ranges between

[4] Today, almost all proposed digital money schemes are developed by private institutions. The issuer, however, could also be a central bank.

[5] Beside cost savings, Hayes et al. (1996) suggest additional advantages of using digital money including an expected reduction in some forms of fraud, greater safety and security, and a potential for value-added services.

one-third and one-half of a paper check or paper giro payment. An indication of the low cost per transaction are the several money schemes under development that will allow (online) payment of transaction for as little as one cent (micropayments).

Table 1: Characteristics of currency, digital money*, checks, and debit cards

Characteristics	*Digital money*	*Currency*	*Check*	*Debit card*
Legal tender	No	Yes	No	No
Acceptability	?	Widespread	Restricted	Restricted
Marginal cost per transaction	Low	Medium	High	Medium
Payment finality face-to-face transaction	Yes	Yes	No	No
Payment finality non-face-to-face transaction	Yes	No	No	No
User-anonymity	Yes	Yes	No	No

* Many digital money schemes are being developed. Here, we consider a form of digital money that is as similar as possible to currency. E-cash, for example, the digital money scheme developed by Digicash, satisfies all the above characteristics.

While digital money products based on smart cards would mainly reduce the demand for currency, software-based digital money products could also affect the demand for transaction deposits due to *reduced transaction cost* and *learning spillovers*. Software-based digital money products could facilitate and reduce the cost of transferring value among different types of accounts, banks, and countries. White (1996) has pointed out the implications of reducing the cost of wiring money across borders:

> What strikes me as the most exciting potential development to come from the new payment technologies is that, as they lower the cost of wiring money from $20 to 2 cents or less per transaction, they give ordinary small savers affordable access to offshore banking. With direct deposit of paychecks, and with analog currency available at ATMs whenever we want it, many of us no longer need to visit our bank in person. Why not keep your account with a reputable bank (perhaps a branch of a major Swiss bank) in the Bahamas or Cayman Islands?

The second reason -- *learning spillovers* -- refers to the notion that using software-based digital money products will improve the skills and knowledge of their users regarding the use of personal finance software and telecommunication technologies to optimize their finance. Personal finance software products keep track of account information and monetary transactions and help in creating budgets, managing investments, and filling out tax forms. They also provide access to electronic banking and electronic bill payment services.

See also the CBO (1996) study for the various incentives for issuers, consumers, and merchants to use digital money.

With these software products, small businesses and households will be able to optimize their money holdings more frequently and to automate basic tasks. One day, for example, software agents could automatically invest short-term excess liquidity overnight for ordinary households.[6] It is difficult to predict the quantitative effects of these developments on the demand for transaction deposits. However, lower transaction costs and more frequent adjustments of money holdings suggests a lower demand for demand deposits.

Competition among several media of exchange

The preceding analysis considered the characteristics of digital money products to obtain a first impression of their potential to substitute for more traditional media of exchange. Next, we study the demand for various media in a Baumol-Tobin type model of optimal money holdings. Baumol-Tobin type models are based on an inventory theoretic approach to explain the transaction demand for money.[7] The following discussion is based on a model by Santomero-Seater (1996).

Santomero-Seater study the behavior of a representative agent who can choose to pay for purchases among different *generally* accepted payment instruments. Attention is focused on how the characteristics of these monies affect the representative agent's choice of transaction vehicle, transaction frequency, and average balance in various media. We present a simplified version of their model, focusing on the demand for digital money.

Santomero-Seater's model is based on the standard Baumol-Tobin assumptions except that they allow consumers to hold inventories of commodities and they consider the use of several, generally accepted media simultaneously. The representative agent receives his income Y at the beginning of a period of fixed length. During this period, he spends the entire income by buying and consuming G different commodities g, $g = 1, \ldots, G$.

There are L media of exchange, M_i, $i = 1, \ldots, L$. The agent can use any or all of these media to buy each type of good; however, a separate shopping trip is required for each. During the period, he makes Z_{gi} shopping trips to buy commodity g with money M_i. Each shopping trip is associated with shopping cost b_{gi}. The household spends only a fraction of his income during one shopping trip. Unspent income is hold in a single savings asset, S, and in money balances. The savings asset earns the rate of return r_s, and the various kinds of money earn r_{Mi}. The return on the savings assets is larger than the return on any of the monetary assets.

There are T_i conversion trips to obtain money M_i and each conversion costs a_i. Conversion and shopping trips, which occur between conversion trips, are evenly spaced throughout the period. The household seeks to maximize the profit from managing its assets

[6] Software agents are intelligent programs that can simplify the processing, monitoring, and control of digital transactions by automating many activities.
[7] Baumol (1952) and Tobin (1956).

over a given time period. Because all conversion and shopping trips are evenly spaced and consumption proceeds at a constant rate, the profit function of the representative agent can be written in terms of average values of the respective assets.

$$(1) \qquad \pi = r_s \overline{S} + \sum_{i=1}^{L} r_{Mi} \overline{M_i} - \sum_{i=1}^{L} T_i a_i - \sum_{i=1}^{L} \sum_{g=1}^{G} Z_{gi} b_{gi}$$

The household chooses the optimal values for T_i , Z_{gi}, and X_{gi}. X_{gi} is the amount of commodity g that is bought during a shopping trip with money M_i.

Our main interest is to study the demand for digital money. If $A := \sum_{g=1}^{G} X_{gEM}$ denotes total digital money spending, the demand for digital money, $\overline{M_{EM}}$ is given by the following expression:

$$(2) \qquad \overline{M_{EM}} = \left(\frac{a_{EM} A}{2(r_s - r_{M_{EM}})} \right)^{\frac{1}{2}} - \sum_{g=1}^{G} \left(\frac{b_{gEM} X_{gEM}}{2 r_{M_{EM}}} \right)^{\frac{1}{2}}$$

According to (2), the demand for digital money depends on the cost of transferring digital money on a smart card or a computer hard drive, a_{EM}, the cost per shopping trip b_{gEM}, total digital money spending, A, and the interest differential between the savings asset and electronic money balances, $r_s - r_{M_{EM}}$.

Note, to evaluate the dependence of the demand for digital money on these parameters one cannot simply take derivatives and evaluate them. To see this, consider a marginal increase of transaction cost, a_{EM}. This could have two opposing effects. For a given volume of purchases with digital money, A, the representative agent would hold larger digital money balances. The increase, however, could trigger a reduction in the use of digital money by reducing the number of commodities bought with digital money.

The cost of using digital money to buy commodity g, i.e., the cost per shopping trip b_{gEM}, consists mainly of potential fees per purchase charged by the shop owner or issuer of the smart card.[8] It is likely that the use of digital money will be free for consumers because competition between digital money issuers and the competition between digital money and costless paper money will prevent issuers to raise fees on digital money transactions. If the cost per shopping trip is zero, i.e., $b_{gEM} = 0$, the equation for the demand for digital money, M_{EM}, is reduced to the standard Baumol-Tobin square-root formula:

[8] It also includes the expected cost of lose and theft, and the expected cost of a card becoming unreadable. Expected costs of lose and theft are similar to paper currency. The risk of loosing money due to a technical failure is apparently larger with smart cards.

$$(3) \quad \overline{M_{EM}} = \left(\frac{a_{EM} A}{2(r_s - r_{M_{EM}})} \right)^{\frac{1}{2}}$$

Equation (3) suggests that demand for digital money will likely be small due to the magnitude of the transaction cost, a_{EM} , and due to the total amount of digital money spent, *A*. The cost of conversion, a_{EM}, is likely to be small and will decrease further as technology improves and smart card readers are more widely distributed. The cost of conversion includes opportunity cost of time spent for this activity (for example, walking to a smart card reader) and per transaction fees charged by the issuer of digital money and/or by the provider of the telecommunication service. With the proliferation of telephones, personal computers, ATMs, and point-of-sale equipment to read smart cards, consumers will be able to load their smart cards almost everywhere, reducing the opportunity cost to minimal amounts. Competition among issuers of digital money makes it likely that consumers will pay no per transaction fees and negligible telecommunication cost.

Low cost of conversion suggests a *low demand for digital money*, i.e., a low balance of digital money on smart cards and computer hard drives. As pointed out by Grigg (1996), the demand for digital money designed specifically for value transfer on the Internet (Internet money) could approach zero for the same reason. A consumer who wants to make an on-line payment could with the same push of the button download the desired amount from his interest-bearing account and then transfer the amount to the payee instead of storing digital money on his hard drive and making payments out of it.

Demand for digital money also depends on the total amount of digital money, *A*, spent in each period. *A* is likely to remain small for a long time, but it could eventually grow as digital money substantially replaces currency. What remains to be considered is the effect on the interest differential $r_s - r_{M_{EM}}$. Competitive pressure could force the digital money issuer to pay interest on digital money balances. The smaller this differential, the larger the demand for digital money.

What remains to discuss is the model's prediction of digital money's potential to replace existing payment instruments, particularly, central bank currency. Santomero-Seater (1996, p. 959) suggest that smart cards represent a credible threat for central bank currency:

> The stored value card represents a credible threat for cash transactions. Rates of return are both zero, […]. Given their new ease of use, smart cards could also be competitive from a transfer fee perspective. In fact, given the lower cost of transferring value into the card, it may dominate cash in the near future.

In summary, the comparison of the characteristics of digital money and paper currency in Table 1 and Santomero-Seater's model suggest that digital money has the potential to replace central bank currency. Moreover, the Santomero-Seater's Baumol-Tobin approach to derive the transaction demand for digital money suggest that demand for digital money will be low due to small conversion cost. In particular, the demand for network money will be negligible.

Strategic interaction between firms and households

The Santomero-Seater model is an important step in studying multiple payment instruments and the pattern of their use. The model suggests that in equilibrium different media of exchange are in circulation and that agents with different income or consumption pattern might buy the same commodity with different media.[9] Thus, it neatly captures the variety of payment instruments we observe in reality.

The main shortcoming of the model, however, is that while consumers can optimize among different types of monies, shop owners don't have a choice. They must passively accept whatever payment instrument agents want to use. That is, in their model all media of exchange are generally accepted. This is in contrast to what we observe in reality where shop owners are rather choosy when it comes to accepting a payment instrument. The model does not take into account the strategic interaction between firms and consumers that determine whether a medium of exchange can be successfully introduced.

We end this section with a simple model that captures this strategic interaction. The starting point, i.e., the status quo, is the existence of a generally accepted medium of exchange used to pay for all purchases in the economy. At some point, a private entity launches a new type of money with favorable properties for shop owners and consumers. The use of the new money requires an initial investment for both firms and consumers. Each agent has to decide whether he wants to invest to use the new money in the future. The rate of return of the investment depends on the investment decisions of all other agents. Thus, comparable to a telephone network, the incentive to participate depends on the number of users. If only a few merchants accept digital money, why would a consumer acquire a smart card or network money? At the same time, if only a few consumers are using smart cards, why would a merchant invest in equipment to process digital money?

To keep the model simple, there is one representative agent and one representative shop and there is only one transaction between the two. Both parties have to decide whether they want to use the old or the new money to pay for the transaction. The status quo type of money is denoted *by* M_1 and is called cash. The use of cash costs a_1 for the consumer and also for the shop owner. The new medium of exchange, named digital cash, is denoted by M_2. The use of

[9] The following additional results emerge from the model. An agent uses always the same medium of exchange to buy a given commodity. The larger the share of total expenditure of a particular commodity, the more likely the medium of exchange used by the household will offer the highest rate of return. An increase in the rate of return of the savings asset tends to reduce the number of monies used. A change in the rate of return of a medium of exchange has ambiguous effects. It can increase or decrease its use. An increase of the conversion cost of one medium of exchange reduces its use. The number of money used increases when income increases.

digital cash requires from both parties an initial investment expenditure *f*.[10] The use of digital cash costs a_2 for the consumer and also for the shop owner. Digital cash has superior characteristics for both merchants and consumers. In particular, for both parties the total cost are smaller when they use digital cash, i.e., $a_1 > f + a_2$.

Of course, the profitability of the investment depends on whether the other party uses the new medium of exchange. Denote the probability that the shop owner invests in the new medium of exchange by θ_1 and the probability that the consumer invests by θ_2. Then when *P* denotes the revenue of the transaction, the profit function for the shop owner is:

$$(4) \quad \pi = (1-\theta_1)(P-a_1) + \theta_1[\theta_2(P-a_2) + (1-\theta_2)(P-a_1) - f].$$

The shop owner chooses θ_1 to maximize (4). The best response correspondence is given by the following rule:

If $f > \theta_2(a_1 - a_2)$, the shop owner does not invest;

If $f < \theta_2(a_1 - a_2)$, the shop owner invests in the new media; and

If $f = \theta_2(a_1 - a_2)$, the shop owner is indifferent.

Note that the larger the investment expenditure, *f*, and the larger the transaction cost of digital cash, a_2, the less likely the shop owner will invest in digital cash. Also, the larger the transaction cost of cash, a_1, and the larger the probability that the consumer will use the new medium, θ_2, the more likely the shop owner will invest in the new medium of exchange.

Next, consider the representative consumer who has to decide whether to make the investment. The expenditure function of the consumer is

$$(5) \quad e = (1-\theta_2)(P+a_1) + \theta_2[\theta_1(P+a_2) + (1-\theta_1)(P+a_1) + f]$$

The consumer chooses θ_2 to minimize expenditure *e*. The best response correspondence is given by the following rule:

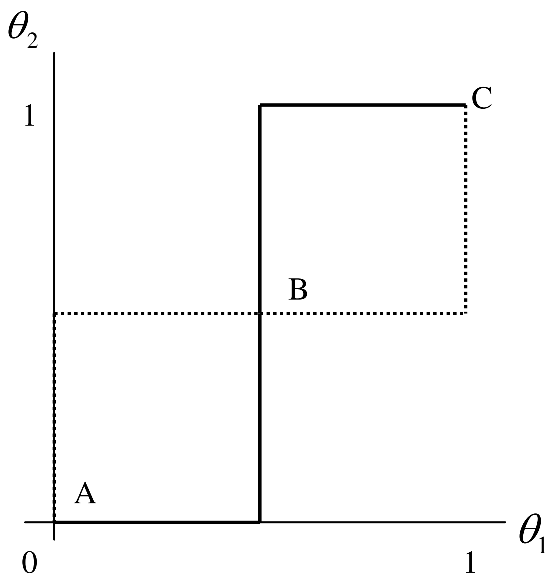
If $f > \theta_1(a_1 - a_2)$, the consumer does not invest;

If $f < \theta_1(a_1 - a_2)$, the consumer invests in the new media; and

If $f = \theta_1(a_1 - a_2)$, the consumer is indifferent.

[10] Here, *f* is total fixed cost. In a more dynamic setup, the representative consumer would repeatedly buy at the shop and *f* would represent the appropriate share of the fixed cost per transaction. However, with this assumption *f* would be a non-decreasing, non-linear function of θ_1 and θ_2 (defined below) complicating the analysis without adding much insight.

Figure 1: Best response correspondence of shop owner (dashed curve) and consumer (solid curve)



who have to decide whether to use the new media of exchange. The best response of either party depends on the action of the other party.

The best response correspondences of the representative agent and the representative shop owner are shown in Figure 1. There are three (Nash) equilibria in this game. In the first equilibrium, A, the new medium of exchange is not used even though it would be less costly for both parties. In the second equilibrium, B, cash and digital cash are used simultaneously and in the last equilibrium, C, only digital cash is used. In the Santomero-Seater approach digital cash would substitute for cash unambiguously. The equilibrium would be C because the shop owner would invest and accept digital cash *per assumption* and the best response of the household would be to invest.

Note further that even with zero investment cost equilibria A prevails. If consumers do not use digital cash, a best response for shops is not to accept digital cash either. And, given that shops do not accept cash, a consumer’s best response is not to use cash, too. We have kept the model as simple as possible. However, even in a more realistic setup the basic problem of strategic interaction remains, i.e., the optimal behavior of one party depends on the expected action taken by the other party.

The model suggests that even when replacement of central bank currency would benefit firms and households, cash wouldn’t be replaced as easily. Issuers of digital money products would have to convince consumers and shop owners that their investment would have a positive rate of return; this basically means that their particular technology would succeed in the market against other digital money schemes and other traditional media. Convincing agents to use digital money products and providing a secure product will make the implementation of a digital money scheme costly. The presence of network externalities suggest that only a few multipurpose digital money schemes will be successfully implemented, most likely by a number of cooperating banks in association with a major credit card company.

2 Monetary Policy Implementation

Monetary control is based on the ability of central banks to determine the conditions that equilibrate demand and supply in the market for bank reserves. In this market central banks are monopolistic suppliers of reserve assets and they can also directly affect demand, for instance, by setting reserve requirements and by shaping and operating key interbank settlement systems (Borio 1997). Central banks can either decide to control the total quantity of reserves or the price at which they are traded among banks. In most countries central banks aim at stabilizing the short-term interest rate at which banks trade these reserves. In the following we study the impact of digital money on the demand for bank reserves (deposits at the central bank) and discuss the implications for monetary control.

Effects on the demand for reserves

Banks hold reserves for two reasons. (1) In many countries they are required to hold a percentage of certain types of deposits as reserves. The percentage and the types of deposits that require the holding of reserves differ from country to country. (2) Banks hold reserves for settlement purposes to cushion costly daylight and overnight overdrafts. Reserves are held as book entries at the central bank and as vault cash, i.e., central bank currency holdings of banks.[11]

On the market for reserves, banks trade reserves to meet reserve requirements and to adjust their settlement balances. The price for these reserves (in the U.S. the Federal Funds rate) is the primary interest rate that central banks influence through their monetary instruments. A permanent change in the price for reserves influences other money and credit rates and, eventually, the real sector of the economy and the price level.

Demand for reserves depends crucially on the institutional arrangements prevailing in a country. Among these arrangements the existence of (binding) reserve requirements, the nature of payment and settlement procedures, the types of eligible reserve assets, and the conditions of central bank assistance (standing facilities) influence the demand for reserves. The characteristics of these institutional arrangements differ from country to country. For an excellent and detailed description of institutional arrangements in several industrial countries consider Borio (1997).

The banking systems' demand for reserves *to meet reserve requirements* depends on the public's demand for reservable deposits and reserve ratios. The demand for reserves would be reduced if digital money were to substitute for reservable deposits. Section 1 suggests that software-based digital money products could reduce the demand for transaction deposits. The

[11] The types of liquid assets that are counted as reserves differ from country to country.

BIS (1996b) report, however, suggests that substitution of reservable deposits would be small: "It is conceivable that a very extensive substitution [of reservable deposits] could complicate the operating procedures used by central banks to set money market interest rates. However, since e-money is expected to substitute mostly for cash rather than deposits, it is highly unlikely that operating techniques will need to be adjusted significantly."

During the 1990s, many industrial countries have radically reduced their reserve requirements. For, example, since 1990 reserve requirements have been reduced in all of the major (G7) industrial countries (Bisignano 1996). Today, in Belgium and Sweden no reserve requirements are in place. Digital money products, particularly, software-based digital money products that facilitate and reduce the cost of transferring value between different types of accounts, banks (and nonbanks), and countries, could reduce the demand for reserves indirectly by adding to this trend.

If bank customers were to use these new payment instruments extensively, the pressure on central banks to reduce reserve ratios and the number of types of reservable liabilities would increase. Particularly, if foreign intermediaries were to increasingly attract (transaction) deposits of domestic residents across public computer networks, central banks would be pressed to lower reserve ratios to help domestic banks to compete for domestic (and foreign) deposits (Berentsen 1997b). Reserve requirements are basically a tax on financial intermediation and banks that are subject to reserve requirements have a competitive disadvantage compared with nonbank financial intermediaries offering close financial substitutes. A study by the Bank of Japan (1995) on the recent reform of reserve requirements in major industrial countries suggests that the main reason for reducing reserve requirements has been to lower the "burden" ("distortion", "inequality") on depository institutions (Bisignano, 1996).

In countries where vault cash is counted as reserves, substitution of central bank currency would reduce the holdings of vault cash thereby increasing the demand for bank reserves (deposits at the central bank) to meet reserve requirements. For example, in France total reserve requirements are FF 20 billion of which FF 13 billion are held in the form of vault cash (Borio 1997). If demand for the French franc were to vanish, French banks would want to convert the FF 13 billion of cash balances into FF 13 billion in reserve holdings at the Banque de France.

Without reserve requirements or when reserve requirements are non binding, the demand for bank reserves is essentially a *demand for settlement balances*. The demand for reserves would be affected if digital money were to change the need for settlement balances. In the absence of reserve requirements, a bank would still want to hold reserves to meet unforeseen liquidity withdrawals by its customers. However, the holding of reserves is costly and banks have to choose the optimal amount of reserves. This basic liquidity management problem is presented in Baltensperger (1980).[12] During a given period, a representative bank faces a stochastic outflow of deposits, X, with density function $f(X)$. At the beginning of the period the bank has reserves R. If at the end of the period $X - R < 0$, the bank has a reserve deficiency and has to bear the cost $p(X - R)$. p measures the cost per unit reserve deficiency. The holding of reserves is costly, too, because reserves could alternatively be invested and earn a rate of return of r.

In the absence of reserve requirements the bank chooses its reserve level such that marginal cost of reserve holdings, r, equal marginal return of holding additional reserves, i.e.,

$$(6) \qquad r = p\int_{R}^{\infty} f(X)dX$$

Digital money would affect the demand for reserves if it were to change the cost of reserves, r, the unit cost of reserve deficiency, p, or the probability that a reserve deficiency occurs $\int_{R}^{\infty} f(X)dX$. There is no reason to believe that digital money per se would affect either of these parameters. The rate of return on loans, r, is determined by demand and supply in the market for loans and should be not affected by the emergence of digital money products. Equally, the unit cost of reserve deficiency, p, is determined by the conditions of central bank assistance and the cost of selling illiquid assets at short notice, and should as well not be affected by digital money products. And finally, digital money products per se should not affect the probability that a reserve deficiency occurs.[13]

Thus, the liquidity management approach suggests that digital money would not reduce the demand for settlement balances importantly. This implies that even with zero reserve requirements or even when digital money products extensively substitute for reservable deposits, the settlement function of central banks would continue to guarantee an ongoing demand for reserves. Reserves may not be used as a medium in which to store value overnight and longer, but it still will be required as a vehicle for transferring value during a day (Jordan-Stevens, 1996). Havrilesky (1987) suggests that this demand would be sufficient for the monetary base to remain a viable policy instrument and that open-market operations would work as they do today.

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[12] Many authors have modeled in different variations the liquidity management problem of banks (see Baltensperger 1980). The discussion that follows is based on his exposition.

[13] Note, however, that Berentsen (1997b) suggest that network money could increase the variability of bank deposits, which could increase the demand for reserves.

In summary, a widespread use of digital money could affect demand for reserves as follows:

- It would reduce demand if digital money were to substitute for reservable deposits. However, the reduction should be moderate because digital money is expected to substitute mainly for central bank currency.
- It could reduce demand by forcing central banks to reduce the number of reservable liabilities and to lower reserve ratios.
- It would increase demand if banks were to substitute vault cash for reserves held at the central bank to meet reserve requirements.
- The demand for settlement balances is likely to be unaffected by digital money because digital money does neither affect the need for settlement balances not the opportunity cost of holding reserves.

Supply of reserves (monetary control)

Initially, substitution of central bank currency would increase cash holdings of banks since customers would return excess cash. Banks would observe that their cash holdings exceed the optimal amount and they would return cash to the central bank, thereby increasing their reserves at the books of the central bank. Consequently, substitution of central bank currency would increase total supply of reserves. Therefore, substitution of central bank currency is equivalent to an *expansionary* open market operation that provides additional reserves to the banking system (Berentsen 1997a).

Central banks could be forced to step in and absorb these reserves by selling central bank assets. Because central bank currency is by far the largest liability of central banks, an extensive substitution could reduce the monetary base to the extent that it would adversely affect monetary policy implementation. This concern has been raised by BIS (1996b):

> Since cash is a large or the largest component of central bank liabilities in many countries, a very extensive spread of e-money could shrink central bank balance sheets significantly. The issue is at what point this shrinkage might begin to adversely affect monetary policy implementation. The relatively modest size of open market operations on normal days suggests that a relatively small balance sheet might be sufficient. However, special circumstances could arise in which the central bank might not be able to implement reserve-absorbing operations on a large enough scale (for example, to sterilize the effects of large purchases in the foreign exchange markets) because it lacked sufficient assets on its balance sheet.

The special circumstances mentioned in the BIS report refer mainly to times when exchange rate commitments of central banks are challenged by market forces. To keep exchange rates in line, central banks intervene in the foreign exchange markets by either buying or selling foreign currency for domestic. These exchange rate operations affect the liquidity in the system. In fact, the net creation of liquidity through foreign channels can be huge, amounting in some cases to large fractions of the outstanding stock of policy instruments (Borio 1997).

When exchange rates come under upward pressure, the main problem is to absorb excess liquidity created by the selling domestic currency for foreign. The main risk is that the central bank may not have enough assets to sell to withdraw the liquidity. When exchange rates come under downward pressure, central bank purchases of domestic currency for foreign absorbs liquidity. In this case, the risk is that central banks may not succeed in injecting sufficient funds to meet the minimum settlement balance needs of banks, effectively losing control over short-term rates and disturbing the settlement process (Borio 1997).

The potential contraction of balance sheets is non-trivial. For example, in 1994, total liabilities of the Federal Reserve amounted to 412,606 millions of dollars of which 359,698 millions were Federal Reserve notes. Thus, a complete substitution of central bank notes would have reduced total liabilities and assets by 87 percent. Table 2 lists total liabilities and central bank currency in circulation for a number of industrial countries.

Table 2: Total liabilities (or assets) and currency in circulation*

Countries	*Total assets and liabilities in local currency(in thousands)*	*Currency in circulation (in thousands)*	*Currency-to-total assets ratio*
Belgium	945,716,598	412,189,699	0.44
Canada**	30,200,600	28,777,700	0.95
France	668,846,000	266,659,000	0.40
Germany**	354,447,470	248,363,466	0.70
Italy	356,359,672,000	100,024,826,000	0.28
United States	412,606,000	359,698,000	0.87

*Source of data in the first and second columns: Moody's International Manual (1996); for the United States BoG (1994). Data are from 1994. **Data from 1995.

A final note is required, here. There is some concern that digital money could also affect monetary control by reducing the independence of central banks. Today, central bank independence is based on their ability to generate (more than) sufficient seigniorage income to pay for their operations. Widespread substitution of central bank currency could reduce seigniorage revenue to the extent that central banks would have to turn to other income sources such as government subsidies. However, the share of seigniorage income that is used by central banks to pay for their expenses is small, which suggests that even an extensive substitution would not force central banks to rely on other income sources. See Boeschoten-Heblink (1996) who studies the potential seigniorage loss of central banks in the G-10 countries.

3 The Monetary Transmission Mechanism

This section considers the potential effects of digital money on the monetary transmission mechanism. It examines how digital money affects the income velocity of base money and the narrowly defined stock of money.

Velocity of money

The income velocity of money is of interest to central bankers who rely on monetary aggregates either as indicators or as ultimate targets. Stable velocity of money is crucial to them. The theoretical background underlying the use of these aggregates is provided by the quantity theory, which focuses on the following equation:

$$(7) \quad M \cdot V = P \cdot Y$$

According to (7), the stock of money, *M*, times its velocity, *V*, equals nominal GNP, $P \cdot Y$. If *V* and Y are known in advance, the central banks can control the price level, *P*, by choosing the appropriate level for the money stock, *M*. To do so, however, two requisites must be satisfied. (1) The velocity of money must be predictable and stable. (2) The central bank must be able to determine the money stock. The next subsection discusses problems in controlling the stock of narrowly defined money. Here we study the implications of digital money for the level and the stability of the income velocity of money of the monetary base.[14]

Level effects. The preceding sections suggest that digital money could substantially replace central bank currency. This would, assuming central bank reserve-absorbing operations, reduce the monetary base. Consequently, the income velocity of base money will increase. Jordan-Stevens (1996) suggest that the income velocity of base money could approach infinity:

> The kernel of the money question beginning to emerge to on the 21st century horizon is not just about the predictability of changes in velocity, or even the instability induced by ever-higher velocity. Rather, what may be new and different about the 21st century is the possibility that the velocity of central bank money might approach infinity – that is, that there will be no appreciable domestic demand at all for central bank money – whether currency or banks' deposit balances at reserve banks.

A large increase in velocity is troublesome, even if measured correctly. Failures in achieving monetary targets have larger unwanted effects on nominal income, as suggested by the quantity equation. That is, higher velocity of money makes it more difficult to maintain

[14] Digital money could also affect the income velocity of the narrowly defined stock of money, *M1*. However, the effect depends on the actions taken by central banks. In principal, they have the means to offset any change in *M1*. See the following subsection.

financial stability, unless there are comparable increases in the precision with which the central bank can control the supply of its monetary liabilities (Jordan-Stevens 1996).

Variability. During the transition to a cashless society, the various velocity measures could be less stable. This could complicate monetary policy decision making for countries that rely on monetary aggregates as targets or indicators because they would be more difficult to define and achieve (Jordan-Stevens 1996). However, the transition from cash to digital money could take a long time, and there is a priori no reason why this transition should be accompanied by large unexpected short-term variations in the income velocity of money. Moreover, during the initial stage, the substitution is expected to be rather moderate, which would allow central banks enough time to observe developments and take necessary steps.

Monetary aggregates

Substitution of central bank currency would affect all monetary aggregates. The largest impact, however, would be on the narrowly defined stock of money, *M1*. We will, therefore, confine our attention to changes in *M1*. To simplify the analysis, *M1* consists only of central bank currency, *C*, and transaction deposits, *D*. For some purposes we also include digital money balances, *EM*, in the definition of *M1*.

Conversion of central bank currency into digital money balances would affect *M1* through two channels. Obviously, a substitution of central bank currency would affect *M1* most directly through a reduction in the stock of central bank currency. Conversion, however, would also change the *reserve position* of banks and, eventually, the size of deposits, *D*. This second channel could be of more importance because it potentially has a larger impact on *M1*.

The liquidity effect of a conversion of central bank currency into digital money balances depends on whether *binding reserve requirements* are in place. Banks expand their deposits by making loans. When a bank makes a loan, this is automatically matched by an equal increase in deposits. Banks are willing to make loans if the marginal return on loans is larger than the marginal costs of deposits. With binding reserve requirements, this condition is met but their reserve position prevents the provision of further loans and, correspondingly, a further expansion of deposits. Thus, with binding reserve requirements, the marginal rate of return on loans is larger that the marginal costs of deposits and banks would be willing to expand their deposits at the prevailing rate of return and costs, respectively.

The following analysis, therefore, distinguishes two scenarios. (1) A setup with zero or non-binding reserve requirements and (2) a setup with binding reserve requirements.

Zero or non-binding reserve requirements

Let us first consider the liquidity effect of a conversion of one unit of central bank currency into one unit of digital money balances when zero or non-binding reserve requirements are in place. With zero or non-binding reserve requirements, the market for deposits and loans is in equilibrium and the marginal return on loans equals marginal costs of deposits. Banks have some market power, i.e., a bank increasing its supply of loans will marginally reduce the rate of return on loans resulting in a loss.[15] Thus, at the prevailing rate of return on loans and the prevailing costs of deposits banks are not willing to increase deposits by providing additional loans.

The conversion implies that the total amount of currency in circulation, *C*, decreases by one unit and, at the same time, that the banking system's stock of central bank currency (vault cash) increases by one unit. The bank receiving the currency unit can either hold it as vault cash or return it to the central bank, thereby increasing its reserves at the central bank by one unit.

It is likely that the bank is not willing to hold the unit as vault cash because the rate of return on vault cash is zero while the rate of return on reserves at the central bank is positive because it reduces marginally the probability that the bank has to borrow funds for settlement purposes. Although, banks holding returned currency as vault cash is a rather simplistic story, this assumption, nevertheless, is often used to evaluate the effect of digital money on the money supply. For example, the CBO (1996, p. 42) study on digital money suggests that "if the issuers hold 100 percent cash reserves for balances on stored-value cards […] the money supply will not change."

Since banks are not willing to expand their deposits and the prevailing rate of return on loans and costs of deposits, to affect *D* substitution of central bank currency must either change the rate of return on loans or the costs of deposits. Because the conversion of currency into digital money balances does not affect the banking system's demand for settlement balances (reserves), the increase in the supply of reserves would marginally decrease the interest rate for settlement balances. That is, banks are only willing to hold the additional unit of reserves when the price for settlement balances decreases marginally.[16]

The lower costs of settlement balances decrease the costs of making deposits. Consequently, banks would marginally increase lending and deposit taking. Thus, *D* would increase unambiguously. The overall effect on *M1*, however, is not determined because central

[15] In many models of the banking firm deposit rates are a function of the deposit level. That is, it is assumed that banks have some market power and their actions affect the price in the deposit market. For a discussion of this assumption and a survey of banking firm models, consider Baltensperger (1980).

[16] On the market for reserves, banks trade reserves to meet reserve requirements and to adjust their settlement balances. The price for these reserves, in the U.S. the Federal Funds rate, is the primary interest rate that central banks influence through their monetary instruments. The substitution of central bank currency increases the total supply of reserves in the economy. Because the demand for these reserves hasn't changed, the price for these reserves must fall.

bank currency, *C*, would be reduced by one unit. However, because the effect of a conversion on deposits is equivalent to the effect of an expansionary open market operation, it is more likely that the increase in *D* would offset the decrease in *C*; consequently, *M1* would increase.[17]

The picture changes slightly if digital money balances are included in the definition of *M1*. In this case, *M1* would increase unambiguously because the reduction in *C* would be matched by an offsetting increase in *EM* and *D* would increase unambiguously. Thus, if electronic money balances are not included in the definition of *M1*, the change of the narrowly defined stock of money depends on whether the increase in *D* offsets the decrease in *C*. If digital money balances are included in the definition of *M1*, *M1* increases unambiguously. A summary of the results is given in Table 3.

Table 3: Changes in *M1* with non-binding reserve requirements*

Definition of M1	*Change in M1*
$M = C + D$	Not determined, increase more likely
$M = C + D + EM$	Increase

* Changes in *M1* with no or non-binding reserve requirements. If digital money balances are not included in the definition of *M1*, *M1* will either increase or decrease. The sign of the change will depend on whether the decrease in currency, *C*, outweighs the increase in deposits, *D*. If digital money balances are included in the definition of *M1*, the conversion would lead to a marginal increase of *M1* because the decrease in *C* would be matched by an equal offsetting change in digital money balances, *EM*, and deposits, *D*, would increase marginally.

Binding reserve requirements

In the following analysis binding reserve requirements are in place and banks are willing to make loans and expand their deposits at the prevailing rate of return on loans and costs of deposits. Again, conversion directly affects *M1* through a reduction in *C* and indirectly through a change in the reserve position of the bank receiving the unit of currency.

The following analysis, based on the notion of a money multiplier, relies on a simple model of money creation. Money multipliers describe the relation between the various monetary aggregates and the *monetary base*. The monetary base consists of central bank currency in the hands of the public plus reserves of deposit institutions, i.e., banks. The relation between the monetary base and *M1* is described as:

(8) $M = m \cdot H$

[17] In principle, substitution of central bank currency is equivalent to an expansionary open market operation because both events increase the supply of reserves. Thus, the effect of these two events on the size of deposits must be equivalent. Effectiveness of monetary operations relies on the assumption that a change in reserves results in a multiple change in deposits.

M is the stock of narrowly defined money ($M1$), H is the monetary base, and m is the money multiplier. In its simplest form, the money multiplier is derived by using the following relations:

$$(9) \quad M = C + D + (EM)$$

$$(10) \quad H = R + C + E$$

$$(11) \quad R = r_D D + r_{EM} EM$$

C is currency in the hands of the public, EM are digital money balances, D are demand deposits, R are required reserves, and E are excess reserves. r_D is the required reserve ratio on demand deposits and r_{EM} is the required reserve ratio on digital money balances.

According to (9), the stock of narrowly defined money consists of currency holdings, demand deposits and, if included, digital money balances. According to (10), the monetary base consists of required reserves, currency and excess reserves and, according to (11), required reserves are reserves on demand deposits and reserves on digital money balances.

Banks are willing to provide loans if the marginal return on loans is larger than the marginal cost of deposits. An implicit assumption of the money creation process, i.e., the multiplier model we study here is that this condition is always met.[18] In this case, banks find it profitable to make loans whenever they have excess reserves. The size of deposit expansion depends on the reserve ratio on demand deposits, r_D, and on the reserve ratio on electronic money balances, r_{EM}. The results are presented in Table 3.[19]

Table 3: Changes in *M1* with binding reserve requirements*

Definition of M1		$r_{EM} = 0$	$r_{EM} = r_D$	$r_{EM} = 1$
$M = C + D$	$\frac{\partial M}{\partial C} = -\frac{1 - r_D - r_{EM}}{r_D}$	$\frac{\partial M}{\partial C} = -\frac{1 - r_D}{r_D}$	$\frac{\partial M}{\partial C} = -\frac{1 - 2r_D}{r_D}$	$\frac{\partial M}{\partial C} = 1$
$M = C + D + EM$	$\frac{\partial M}{\partial C} = -\frac{1 - r_{EM}}{r_D}$	$\frac{\partial M}{\partial C} = -\frac{1}{r_D}$	$\frac{\partial M}{\partial C} = -\frac{1 - r_D}{r_D}$	$\frac{\partial M}{\partial C} = 0$

*Changes in *M1* when banks expand their deposits as much as possible. The effect on *M1* depends on the reserve requirements on digital money balances and the reserve requirements on deposits.

[18] The multiplier model we study, therefore, implicitly assumes interest rate rigidity. That is, an increase in the supply of loans or an expansion of deposits does not affect the rate of return on loans or the costs of making deposits. One explanation for this price rigidity would be interest-rate ceilings of the "regulation Q" type seen until quite recently in the U.S. (Spencer, 1986).

[19] The derivations of the derivatives are in the appendix.

The first row of Table 3 describes changes in *M1* when digital money balances are not included in the definition of the narrowly defined stock of money. Change in *M1* depends on the reserve requirements on digital money balances, r_{EM}. If $r_{EM} < 1 - r_D$, *M1* increases. If $r_{EM} = 1 - r_D$, a conversion of central bank currency into digital money balances is neutral, it does not change *M1*. For large reserve requirements, if $r_{EM} > 1 - r_D$, the narrowly defined stock of money decreases. For example, if $r_{EM} = 1$, the stock of narrowly defined money decreases by one unit. Change in *M1* depends also on the reserve requirements on deposits, r_D. The larger r_D, the smaller is the change in *M1*.

The second row of Table 3 describes changes in *M1* when digital money balances are included in the definition of the narrowly defined stock of money. In this case, the stock of narrowly defined money increases if the reserve requirements are not equal to one. If $r_{EM} = 1$, a conversion of central bank currency into digital money balances is neutral. Again, the larger the reserve requirements on deposits, r_D, the smaller is the change in *M1*.

A final note is required, here. The results of Table 3 implicitly assume that demand deposits and, if so, electronic money balances are the only reservable liabilities of banks. If other liabilities were subject to reserve requirements, some of the excess reserves created by the substitution of central bank currency would be used to expand these other types of liabilities. This would reduce the potential of expansion of *M1* and change the derivatives in Table 3.

In the remainder of this paper we consider measures central banks can take to prevent potential changes in *M1*. They have four:

- They can limit the proliferation of digital money products to prevent replacement of central bank currency.
- They can issue digital money products and treat digital money balances in the same way they handle central bank currency.
- They can apply high reserve requirements on digital money balances.
- They can absorb -- sterilize -- the excess liquidity created by appropriate monetary operations.

Legal restrictions to prevent proliferation of digital money products will be difficult to justify, especially in light of efforts to deregulate and improve the efficiency of the financial sector. Moreover, measures that prevent development of digital money products will result in a competitive disadvantage. Nations that develop these products will thereby take a lead in a crucial technological sector. In addition, digital money easily crosses international borders and it will be difficult to control foreign digital money products that could eventually emerge as a medium of exchange in the home country.

Central banks could provide digital money in the same way as they provide paper currency right now. The Bank of Finland, for example, is developing a cash-card system through its corporate subsidiary, Avant Finland Ltd. (Bernkopf 1996). Most central banks, however, remain passive in this respect. There is concern that central banks issuing digital money products could limit competition and reduce incentives in the private sector to innovate further digital money products (BIS 1996b).

Central banks could require reserves on digital money balances. High reserve requirements can make digital money products neutral with respect to changes of the narrowly defined stock of money. However, since the main incentive to issuing digital money products is the interest-free debt financing that digital money balances provide, high reserve requirements will make it less profitable to issue digital money and will hold back its development.

The drawback of the first three measures is that they reduce the private sector's incentive to invest in the development of digital money products. It is, therefore, likely that central banks will hold the money supply constant by appropriate monetary operations, thereby gradually shrinking the monetary base.

Summary

Section I studied digital money's potential to replace central bank currency. It suggested that digital money poses a credible threat to paper currency because it is specifically designed to make small value payments in retail transactions and because it would reduce transaction costs for consumers and businesses. The main obstacle to its success, beside legal restrictions, are network externalities, i.e., the benefit of using a particular digital money product depends on the number of its users. If few merchants accept digital money, the benefits to households to use digital money products are low. Similarly, if few consumers use digital money, a merchant has little incentive to accept digital cash. These network externalities suggest that even though use of digital money would benefit firms and households, paper currency will not be replaced easily. Issuers of digital money products will have to convince consumers and shop owners that their product will succeed in the market against other digital money schemes and other traditional media.

Section I also suggested that even in a cashless society, demand for digital money would be low and demand for network money would be negligible. Low demand for digital money, as predicted by Baumol-Tobin type models, is due to the low cost of transferring value from a transaction deposit on a smart card or computer.

Section II examined the impact of digital money on the demand for bank reserves and on the implementation of monetary policy. A widespread use of digital money could affect demand for reserves as follows: (1) It would reduce demand if digital money were to substitute for reservable deposits. However, the reduction should be moderate because digital money is expected to substitute mainly for central bank currency. (2) Digital money products, particularly, software-based digital money products could increase the pressure on central banks to reduce the number of reservable liabilities and to lower reserve ratios to help domestic banks compete against foreign intermediaries that may increasingly attract (transaction) deposits from residents across public computer networks. (3) It would increase demand if banks were to substitute vault cash for reserves held at the central bank to meet reserve requirements. (4) The demand for settlement balances is likely to be unaffected by digital money because, as suggested by liquidity management approach models, digital money does neither affect the need for settlement balances not the opportunity cost of holding reserves. This implies that even with zero reserve requirements or even when digital money products extensively substitute for reservable deposits, the settlement function of central banks would guarantee an ongoing demand for reserves.

Section II also suggested that implementation of monetary policy could be complicated by an extensive substitution of central bank currency. In many countries a complete substitution of central bank currency would shrink the monetary base to less than one half; in Canada, for example, it would shrink approximately by 95 percent. The small size of open market interventions in normal days suggests that even in this extreme case the monetary base would remain a viable policy instrument and that open-market operations would work as they do today. However, in turbulent times, in particular, when exchange rates commitments are challenged by market forces, central banks may not be able to successfully sterilize liquidity generated by foreign market intervention. Consequently, central banks may be less able to commit to a particular exchange rate while simultaneously following other monetary policy goals.

Section III considered digital money's effect on the income velocity of base money and on the narrowly defined stock of money. Shrinkage of the monetary base suggests an ever-increasing velocity of base money. Moreover, during the transition period, velocity of base money could be less stable. High levels of velocity and unpredicted variations are troublesome for countries that rely on monetary aggregates either as targets or as indicators.

Digital money's effect on the narrowly defined stock of money would depend on the reaction of central banks. Without sterilization, a replacement of central bank currency would increase the supply of bank reserves and, therefore, the effect on the narrowly defined stock of money would be equivalent to an (expansionary) open market operation that provides additional reserves to the banking system. Central banks, therefore, face a trade-off: Either they hold the monetary base constant, thereby accommodating the expansionary effect of a higher reserve level, or they sterilize the additional reserves, thereby shrinking the monetary base. It is most likely that central banks would absorb the excess liquidity by selling assets. However, to avoid erosion of the monetary base, central banks could be tempted to resort to alternative measures. They could limit the proliferation of digital money products. They could issue digital money themselves or they could apply high reserve requirements on digital money balances. The drawback of these measures is that they would reduce the private sector's incentives to invest in the development of digital money products.

Appendix

<u>Binding reserve requirements</u>

Digital money is not included in the definition of M1.

Totally differentiate (2) to get $dM = dC + dD$. An increase in vault cash, *VC*, can either be used to expand deposits, *D*, digital money balances, *EM*, or it adds to excess reserves, *E*: $dVC = r_D dD + r_{EM} dEM + dE$. Because $dVC = -dC$, which implies that $dC = -r_D dD - r_{EM} dEM - dE$. By assumption, $dE = 0$ and $dC = -dEM$, which implies that $dD = -\frac{1-r_{EM}}{r_D} dC$. Hence, $dM = dC - \frac{1-r_{EM}}{r_D} dC$ and $dM = -\frac{1-r_D-r_{EM}}{r_D} dC$.

Digital money is included in the definition of M1.

Totally differentiate (2) to get $dM = dC + dD + dEM$. Again $dC = -r_D dD - r_{EM} dEM - dE$. By assumption $dE = 0$, $dC = -dEM$, which implies that $dM = dC - \frac{1-r_{EM}}{r_D} dC - dC$ and $dM = -\frac{1-r_{EM}}{r_D} dC$.

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