MODELLING INSTITUTIONAL CHANGE IN THE PAYMENTS SYSTEM, AND ITS IMPLICATIONS FOR MONETARY POLICY♦

By F H Capie♣, D P Tsomocos♥ and G E Wood♠

I. Introduction

Many institutional changes have taken place to payments systems. Indeed, they have been in continual change ever since money first emerged as the dominant technology for conducting transactions. Means of settlement between banks have changed: cheques replaced cash in many transactions, and they have in their turn been replaced partially (much more in some countries than others) by cards. Technology is even developing whereby mobile telephones can be used to effect instantaneous settlement of transactions. These have all affected the relationship between the quantity of money demanded and income. But none of the innovations has threatened to move us from a money-using society to one which transacts by some other means.

The implications for monetary policy have therefore been, in theory at least, trivial. And this has also been true in practice. Central banks have remained able to use monetary policy to influence, and to control within surprisingly narrow limits, the course of the price level. Indeed, as the short-to-medium relationship between money and income has become looser (as evidenced by increasing difficulty in fitting well-behaved money demand functions), central bank control of inflation has improved. The changed constitutional relationship between central bank and government that has occurred in many countries appears to have produced benefits which have more than offset the increasing difficulty of using monetary policy to control inflation.

♦ The views expressed here are those of the authors and do not necessarily reflect those of the Bank of England, City University, LSE or the University of Oxford.
The authors are grateful to Peter Andrews, Willem Buiter, Charles Goodhart, Mervyn King, Andrew liliko, Stefan Schmitz, Martin Shubik, seminar participants at the Austrian Academy of Sciences, the Bank of England, the European Central Bank and the 2003 International Conference of Game Theory, Mumbai, India. All remaining errors are ours.
♣ City University.
♥ Bank of England, Said Business School and St. Edmund Hall of University of Oxford and FMG.
♠ Bank of England and City University.

But how long can that benign outcome last? It would be too much to expect still further improvements to inflation control; that would be an excessive demand on monetary policy and central banks. Our concern is whether the present benign situation can persist. Will developments which appear to be on the horizon loosen still further the money-income relationship, or even end it by eliminating money as a transactions technology?

The aim of this paper is to appraise one such possible technological development, and to model both it and money as transactions technologies. By comparing the models, we shall be able to appraise the future of fiat money.

The structure of the paper is as follows. We first set out an outline of the technology that may replace money. Then we provide an informal description of the model we use to appraise both this technology and fiat money as means of conducting exchanges. This is followed by the development of our formal model. We then develop the implications of our analysis for the survival (or otherwise) of fiat money. This leads to a discussion of economic policy, and then to a concluding overview of our findings and policy conclusions.

One preliminary remains: definition. McCallum (1985, 2003) distinguishes very clearly between a monetary system of exchange, a barter system of exchange, and an accounting system of exchange. The first is one which uses a "tangible mechanism of exchange"; a "monetary system of exchange", he goes on, is "… one in which the vast majority of transactions involve money on one side". This he contrasts with barter, "…in which commodities are directly exchanged without any intermediate conversion into money". The third type of system is one in which "… there is no money [by which McCallum means at this point a medium of exchange] but exchanges are conducted by means of signals to an accounting network, with debits and credits to the wealth accounts of buyers and sellers being effected with each exchange." McCallum goes on to say that he regards that system as non-monetary, as a "highly efficient form of barter".

In the present paper we follow him in that. It must be noted, though, that whether such a system would dominate barter conducted electronically but *without* an agreed medium and unit of account should be demonstrated rather than assumed. We do, however, leave for another paper whether electronic barter with a mechanism and a unit of account would dominate electronic barter without these two features. The question is interesting, for only if the former does dominate is the concept and controllability of a price level a logically possible subject for discussion in an electronic barter world. But making the comparison would require detailed modelling of transactions costs in the two systems, and the results would not be relevant to the present paper's conclusions.

II. Technology and Exchange

The development of electronic, and in particular of computer, technology has led to speculation that electronic technology will replace fiat money in facilitating exchange. Just as barter was supplanted first by commodity money and then by fiat money because these were superior transactions technologies, so, it is argued, information storage and transmission will be so facilitated by computer technology that in its turn fiat money will be displaced.

Central to analysis of this proposition is the medium-of-exchange function of money. The crucial distinction is between a money-using economy and a barter economy, whether it is one of primitive or of electronic barter, is that in the former a medium of exchange is used. Our aim in this paper is to establish a simple formal framework which will let us examine the crucial determinants of whether or not a medium of exchange will be used. To do this, we construct a model of exchange with costs of transacting an intrinsic part of it; for if there are no costs of transacting then there are no transactions costs on which a medium of exchange can economise.

As was observed some years ago by George Stigler (1972), a world without transactions costs would seem a very strange place. There would be no firms – and therefore no banks, insurance companies, or other financial institutions. And further, there would be no money. The essence of our argument is that so long as there are transactions costs there will be money, and that even electronic barter will not, except under very special circumstances which we set out below, be able to replace 'fiat' money because it will not be as effective in reducing transactions costs. To develop the economic intuition underlying our model we first argue informally why some form of money to mediate trade in mass anonymous markets evolved as a device to reduce the costs of transacting. Then, we go on to show that once the *concept* of using money had developed, still further cost reductions were achieved by a further development – convergence to a very small number of commodities which were used as money. Indeed, a single money is, subject to certain constraints on its issuance, the optimal outcome. We would remark at this point that while all the subsequent arguments are set implicitly or explicitly in an exchange economy the conclusions would be expected to hold *a fortiori* in an economy with production, for if there is production then the number of exchanges will exceed these in an exchange economy with the endowment that our production economy produces.

Barter, whether with or without electronic accounting, involves the double coincidence of wants. The buyer must want what the seller is selling – and *vice versa*. That could be eliminated by what Meltzer (1998) calls 'barter credit' – supplying goods now in exchange for a promise of goods later. But such transactions are rare even in economies with developed and reliable legal systems. Why? The reason is that there is a cheaper way of transacting. Credit, whether barter credit or not, requires the seller to know about the buyer – about his or her creditworthiness, and the features (such as income) which contribute to that. If a money which is widely accepted and recognised is available, then the personal attributes of the buyer become irrelevant. All that matters is what he is offering. *Less information has to be gathered, so trade becomes cheaper*. This expands the possibilities for trade, so both buyer and seller gain. (The analogy with a tariff reduction is clear.)

For something to *evolve* as the *sole* medium of exchange of a society, rather than be imposed as such, two conditions have to be satisfied. These are as follows. First, not all goods are equally suitable for use as money; the costs of acquiring information must depend on the good selected. Second, the marginal cost of acquiring information about whatever is used in exchange falls the more frequently it is used. These two features let us explain the once widespread use of precious metals as a means of payment. Such metals can be assayed for fineness, are divisible, can be readily quantified by weighing, and are homogeneous – an ounce of gold of a certain fineness is identical to another ounce of that fineness. Alternative monies – cattle, stones, and tablets of salt – did not possess these attributes to anything like the same extent. These are the attributes that guide us towards the monetary commodity. But, it should be emphasised, the information-economising attribute is crucial. Precious metals are not always available. If they are not, something else is used. Cigarettes were used as money in German prisoner-of-war camps in the Second World War (Radford (1945)). They were used because everyone could recognise them, and knew that everyone would accept them in any exchange.

We can thus see that a society will tend to evolve towards the use of a very few commodities as money, given the assumption that not all commodities are equally good at satisfying the medium of exchange function; and that one good will come to dominate if the marginal cost of acquiring information about that good falls the more it is used.

Not only does the use of money eliminate the need to know about the buyer in a transaction. When it has evolved into use as a unit of account, another saving is achieved. Without a medium of account and unit of account, any transactor must know the bilateral exchange value of each commodity for every other commodity.[1] 'If there are n commodities, there are at least $(n(n-1))/2$ separate values. The number of bilateral exchange ratios (prices) rises quickly. With n = 100 commodities, there are at least 4,950 prices to know. At n = 500, the number if 124,750, and with 1,000 commodities there are at least 499,500 prices. Without a unit of account, trade would be very limited by costs of information. Use of a unit of account to express value reduces the number of prices from $(n(n-1)/ 2$ to n.' Meltzer (1998).

So far we have argued that evolution to the use of a few commodities and subsequently to one commodity as money, is beneficial. Subject to certain constraints going beyond that brings still further benefits. Paper money, so long as there is not overissue that leads to inflation, brings a resource saving if it substitutes in whole or in part for the commodities which heretofore had served as money.

---

(1) McCallum (2003) emphasises that the choice of a *medium* of account is of great importance and that once that choice has been made, the subsequent choice of a *unit* of account is of little significance. The example he gives is that the choice of gold or silver as a medium of account can be vital, but once that choice is made, the quantity of it which is the unit of account in unimportant. The debate over bimetallism in the US in the run up to the Presidential Election of 1896 makes the point.

To summarise, we have argued that the concept and use of money emerged through a process of search and discovery. Its advantage over barter credit, which has some advantages over simple barter, is that it reduces transactions costs still further by shifting attention from the qualities of the prospective purchaser of a good to the qualities of what he is offering to pay for it. From (in Allen Meltzer's words, *op cit*) 'a unique and possibly obscure set of attributes to a common and widely known set of attributes'. A money-using society requires less information than a bartering society.

Before going on to develop a formal demonstration of the above conclusions, and then to show their relevance to the future of electronic barter and paper money, it is useful to place the above arguments in their historical context, for the view of the development and role of money set out above is not new. A thorough exposition of it was provided over 100 years ago, by Carl Menger (1892).[(2)] He maintained that money was a 'social' creation, a product of the invisible hand. His was an example of an invisible hand explanation – in contrast to a government-based explanation – of a social institution (see Latzer and Schmitz (2002)). The basic point was not original to Menger, either. (It is a bold writer who asserts that he has found the original inventor of any economic concept!) Adam Smith had made the point in the *Wealth of Nations*.

'In order to avoid the inconvenience of such situations [where the would-be seller of a good does not want what the would-be buyer offers] every prudent man in every period of society, after the first establishment of the division of labour, must naturally have endeavoured to manage his affairs in such a manner, as to have at all times by him, besides the peculiar product of his own industry, a certain quantity of some one commodity or other, such as he imagined few people would be likely to refuse in exchange for the product of their industry.' (1981 ed., pages 37-38).

And that money was originally a social institution, although it had subsequently become a government one, was also noted by Keynes (1935, pages 4-5).

'Thus the Age of Money had succeeded to the Age of Barter as soon as men had adopted a money-of-account. And the Age of State money was reached when the state claimed the right to declare what thing should answer as money to the current

---

[(2)] The complete text of this paper has recently been translated in English and is available in Latzer and Schmitz (2002).

money of account – when it claimed the right not only to enforce the dictionary but also to write the dictionary.'[3]

Now, it is not logically necessary for the medium of exchange to serve also as the medium of account. But as several authors (Wicknell, 1935; Niehans, 1978; and McCallum, 1985) have emphasised, if they do not coincide the "computational benefits" of having a medium of account are incomplete unless the simple step of having it coincide with the medium of exchange is taken. Severe inflation can disrupt this, but it does need to be severe; the two seem to continue to coincide even at inflation rates well into three figures per annum.

III. Strategic Market Games: A Bird's Eye View

Strategic market games provide a framework to rigorously introduce money, other financial instruments as well as financial intermediaries to closed models. The need for accounting clarity, institutional detail and the criterion of 'playability' is such that minimal institutions (e.g. clearinghouses, central banks and other financial intermediaries, credit, default etc) and well-defined price formation mechanisms (sell-all, bid-offer, double auction) naturally emerge as logical necessities in the rules of the game and the equilibrium concept used. Ultimately, this class of games contributes to the development of formal micro foundations to money, financial economics and macroeconomics.

Strategic market games are related to the design of resource allocation methods introduced by Hurwicz (1960, 1973). They were formally introduced by Dubey and Shubik (1978, 1980), Shapley (1976), Shapley and Shubik (1977), Shubik (1973) and Shubik and Wilson (1977). Three main price formation mechanisms were introduced: one-sided Cournot type of model, a two-sided Cournot type and a double auction (or

---

(3) The most fully developed modern statement of the 'transactions cost' theory of money can be found in the work of Karl Brunner and Allan Meltzer. The most detailed statement of their view is given in Brunner and Meltzer (1971). Alchian (1977) also develops the argument and Yeager (1968) draws out the implications of it for the behaviour of the macroeconomy. The argument that money evolved as a result of private initiative of course leaves unexplained why all money is now state money. Some scholars (eg Goodhart (2000)) argue that state money is an inherently superior 'institutional symbol of trust' (to use Shubik's definition of money), while others (eg Glasser (1989)) point to the successful existence of private mints until they were extinguished by law and maintain the opposite. A formal model of an explanation for the dominance of state money can be found in Monnet (2002). An additional factor which may predispose a society to state rather than private fiat money is the comparative irrelevance of the solvency of the state. See also footnote 14.

two-sided Bertrand-Edgeworth model). Fiat or commodity money is used and other market structures are also modelled. For example, foreign exchange markets whereby no natural *numéraire* or fiat money as a medium of exchange then one can employ a modified price formation where trading posts between any two instruments or commodities are set and consistent prices that clear all markets are determined via a giant clearinghouse.

Endogenous default, credit, financial intermediaries and incomplete asset markets are introduced and, therefore, one can formally model and analyse payment systems, monetary, fiscal and regulatory policies. For an excellent presentation of these models one can consult, Shubik (1990, 1999), and for a more technical analysis Giraud (2003). In principle, inefficiency in this class of models arises due to insufficient liquidity, or oligopolistic effects, or institutional restrictions. Hence, active policy has non-neutral effects and possibly, but not always, ameliorates welfare losses because of the transactions technology present in the models. Last but not least, abstracting from the oligopolistic effects, there exists a large literature on monetary general equilibrium models which is akin to the strategic market games one since money and institutions are introduced into the standard Arrow-Debreu model (e.g. Drèze and Polemarchakis (2000), Dubey and Geanakoplos (1992, 2003), Grandmont (1983), Lucas (1980)).

In sum, since the institutions of society in general, and the financial institutions in particular are the carriers of economic process a *mathematical institutional economics* is needed as it has been argued by Martin Shubik. This is what strategic market games attempt so that to achieve a better understanding of production, distribution, policy and, more generally, of political economy.

IV. Formal Model

We use the strategic market game developed in Shubik and Tsomocos (2002). Money depreciates (ie it wears out through deterioration of notes and coins' quality) when used in exchange, and its replacement is costly.[(4)] The stipulated means of exchange is fiat money and all transactions need cash in advance (see footnote 11 for the

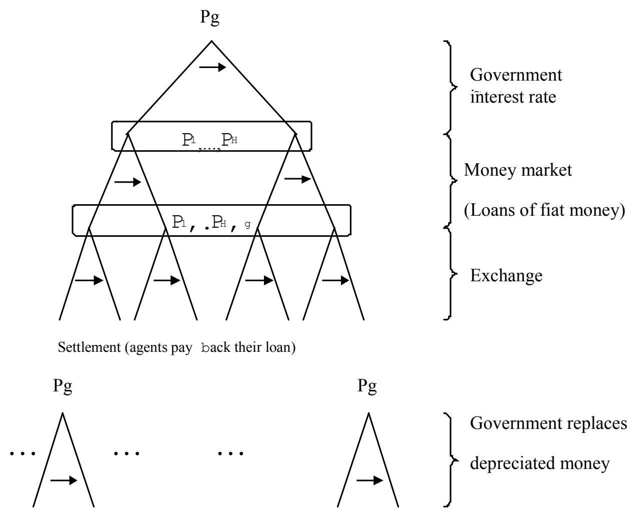
---

(4) Calculations of the rate of depreciation of various types of money can be found in Shubik and Tsomocos (*op cit*).

motivation of this constraint). Thus, agents borrow fiat money to make their transactions. The government extracts seigniorage costs from the players in the form of interest rate payments. In order to do so, it participates in exchange and bids to provide for its inputs of production. The objective function of the government for the purposes of our argument, without loss of generality, is to minimise the interest rate subject to the requirement to replace worn out fiat money used in exchange, and the interest rate which is a choice variable of the government determines its revenues. We assume that the initial money supply enters exogenously. Figure 1 shows the

Figure 1

Trade with seigniorage cost of fiat money



(Note that the labelling $P_1,\ldots,P_H$ and similarly $P_1,\ldots,P_H$, P_g indicate that all agents move simultaneously. Also, the arrows indicate that there is a continuum of their respective strategies.)

extensive form of the game. The exchange game is a one-period game with four subperiods. At each subperiod, as we explain below, an agent or a group of agents move. We first modify the game to admit both fiat money and electronic barter. We conceptualise electronic barter mediated as through a giant clearing house run by an institution, perhaps the government. We then analyse the condition under which fiat money dominates electronic barter.

At the first move the government P_g, determines the interest rate. At the second move, individuals, $P_1,\ldots,P_H$, obtain fiat money in the money market at the predetermined interest rate. At the third move, individuals exchange commodities and the government buys inputs of production to be used in the replacement of depreciated fiat money. We maintain simplicity of strategy sets by assuming a continuum of traders, simultaneous moves, and a minimum of information at the second and the third stage. Then traders pay back their loans, and finally the government replaces depreciated money.

The government levies seigniorage costs to replenish depreciated money and also participates in exchange.[(5)]

Let $h \in H = \{1,...,H\}$ be the set of agents and $l \in L = \{1,...,L\}$ be the set of tradable commodities. Each agent is endowed with a vector of commodities $e^h \in \Re^L_+$.

The utility functions of agents are of the form $u^h : \Re^L \to \Re$.

The following assumptions hold:

(i) $\sum_{h \in H} e^h >> 0$

(ie every commodity is present in the economy).

(ii) $\boldsymbol{e^h} \neq 0, \forall \quad h \in H$

(ie no agent has the null endowment of commodities).

(iii) $\boldsymbol{u^h}$ is continuous, concave and strictly monotonic $\forall \quad \boldsymbol{h} \in \boldsymbol{H}$.

(ie the more consumption the better).

[(5)] A more extensive presentation and discussion can be found in Shubik and Tsomocos (2002).

Agents maximise their utility of consumption subject to the following constraints:

$$\sum_{l \in L} b_l^h \leq v^h \tag{1}$$

(ie expenditures in commodities ≤ borrowed money).

$$q_l^h \leq e_l^h \quad , \quad \forall \quad l \in L \tag{2}$$

(ie sales of commodities ≤ endowment of commodities).

$$(1+r)\, v^h \leq \sum_{l \in L} p_l q_l^h + \Delta(1) \tag{3}$$

(ie loan repayment ≤ receipts from sales of commodities + money at hand).

where, $b_l^h \equiv$ money bid of *h* for the purchase of commodity $l \in L$,

$q_l^h \equiv$ quantity of commodity $l \in L$ offered by *h*,

$v^h \equiv$ loans contracted by *h*,

$r \equiv$ loan interest rate,

$p_l \equiv$ commodity price of $l \in L$ and

$\Delta(1)$ is the difference between the right and left-hand sides of equation **(1)**.

As can be seen from the budget constraints **(1)** and **(3)** receipts from sales of commodities cannot be used contemporaneously for financing purchases of other commodities. This is the essence of the cash-in-advance constraint which can also be thought as a liquidity constraint.

The exogenously fixed money supply M depreciates at a rate η. Thus, if the total amount of fiat money borrowed by the agents from the government (or central bank) is $\sum_{h \in H} v^h = \overline{\mu}$ and the expenditure of the government for the purchase of inputs of production is $\overline{g}$ then $\eta\left(\overline{\mu} + \overline{g}\right)$ is the depreciated amount of money, since $\left(\overline{\mu} + \overline{g}\right)$ is the total amount of money in circulation.

The government's production function for money exhibits decreasing returns to scale in order to generate a unique optimum.(6)

$$z_{L+1} = F\left(x_1^g, ..., x_L^g\right) \qquad \textbf{(4)}$$

with

$z_{L+1} \equiv$ amount of fiat money produced,

$x_l^g \equiv$ inputs of production.

We impose the standard technical assumptions on the government's production set, $y^g \in \Re_+^L$, that guarantee feasibility and the existence of a solution to the government's maximisation problem.

(iv) $0 \in y^g$,

(v) y^g is convex and closed

(vi) $\exists \quad B > 0 \ni if \ \left(x_1^g, ..., x_L^g; z_{L+1}\right) \in y^g$ then $x_l^g \in B, \quad \forall \quad l \in L$ and $z_{L+1} \leq B$.

The government seeks to minimise interest rates because it simply aims to levy the necessary seigniorage to replace depreciated fiat money. Thus the government's optimisation problem becomes,(7)

(6) For example, a Leontief production technology with coefficients $\gamma_l, \forall\, l \in L, z_{L+1} = \min[\gamma_1 x_1^g, ..., \gamma_L x_L^g]$. If another technology were chosen, a unique equilibrium could be guaranteed by an exogenous institutional constraint, such as a price level target.

$$\max_{r, b_l^g, l \in L} \text{(8)} \qquad -r$$

s.t
$$z_{L+1} = \eta \left[\sum_{h \in H} v^h + \sum_{l \in L} b_l^g \right] \qquad \textbf{(5)}$$

$$\sum_{l \in L} b_l^g = r \sum_{h \in H} v^h \qquad \textbf{(6)}$$

Where **(5)** is the amount of depreciated money that needs to be replaced, and **(6)** is the budget constraint of the government (ie its expenditures to finance the cost of production come from seigniorage).

The final allocations for the agents and the government are:

$$x_l^h = e_l^h - q_l^h + \frac{b_l^h}{p_l} \quad , \quad \forall \quad \boldsymbol{l} \in \boldsymbol{L} \qquad \textbf{(7)}$$

(ie consumption = initial endowment – sales + purchases).

and

$$x_l^g = \frac{b_l^g}{p_l} \qquad \textbf{(8)}$$

(government's inputs of production = money offered / prices).

Note that the relation between η and r is a complicated one and depends on gains from trade that in turn determine the volume of transactions. The interest rate r is set by the government to raise seigniorage revenue for the financing of fiat money production so as the replace depreciated money.

---

(7) Government purchases are all used in the production process, ie government does not obtain utility from consumption.

(8) Mathematically, minimisation of r is equivalent to maximise $-r$.

Finally, a Nash equilibrium (NE) or $\Gamma\left(H, u^h, e^h, \eta, M, x^h, x^g\right)$ is a set of strategy choices,

$s = \left(s^h, s^g\right) = \left(b_l^h, q_l^h, x_l^h; b_l^g, p\right)$; $\forall$ $h \in H$ and the government, and $\alpha = \left(\alpha^h, \alpha^g\right) \in \sum = \underset{h \in H}{\mathrm{X}} B^h \times B^g$, ∍

$$\Pi(\boldsymbol{s}/\alpha) \leq \Pi(\boldsymbol{s}) \qquad \textbf{(9)}$$

where $\boldsymbol{B^h}, \boldsymbol{B^g}$ are the choice sets of the agents and the government (ie $B^h = \langle (b_l^h, q_l^h, v^h)_{l \in L} : (1)-(2) \text{ hold} \rangle$ and $B^g = \langle (r, b_l^g)_{l \in L} : (5)-(6) \text{ hold} \rangle$), and $(\boldsymbol{s}/\alpha)$ is s with either $\boldsymbol{s^t}$ or $\boldsymbol{s^g}$ replaced by any other strategy choice $\boldsymbol{a^t}$ or $\boldsymbol{a^g}$.(9) Also, $\Pi(\cdot)$ represents the payoff functions of agents ($\Pi^h(\cdot) = u^h$) and of the government ($\Pi^g(\cdot) = -r$) .

Prices are formed using the Dubey and Shubik (1978) price formation mechanism. Prices are by that mechanism formed as the ratio of the aggregate cash bid in a particular market to the aggregate quantity of commodities offered for sale. This is equivalent to an equilibrium condition; its accounting clarity allows for cash flows in the economy to be traced precisely.

Thus,
$$p_l = \begin{cases} \dfrac{\sum_{h \in H} b_l^h + b_l^g}{\sum_{h \in H} q_l^h}, & if \sum_{h \in H} b_l^h + b_l^g ; \sum_{h \in H} q_l^h > 0 \\ 0 \quad , & otherwise \end{cases} \qquad \textbf{(10)}$$

The existence and inefficiency theorems for these outcomes are stated and proved in Shubik and Tsomocos (2002). Here we will focus our attention on the relative efficiency of using alternative means of payments (on fiat money versus electronic barter).

(9) Without loss of generality, we consider the case of perfect competition (ie a continuum of agents). Thus, agents regard prices as fixed in the optimisation problems.

V. Trade with fiat money versus electronic barter

We conceptualise exchange using fiat money as follows. Consider a simple case in which L=4. Fiat money can be exchanged against every commodity but commodities cannot be exchanged with each other. Figure 2 describes the situation. The arcs connecting m with commodities 1, 2, 3, and 4 indicate that money can be exchanged against all commodities. On the other hand, commodities cannot be exchanged with each other (ie there are no arcs connecting them).[10]

Figure 2

Trade with fiat money

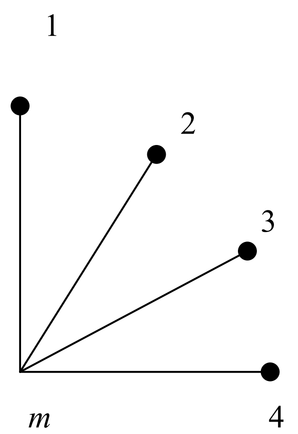
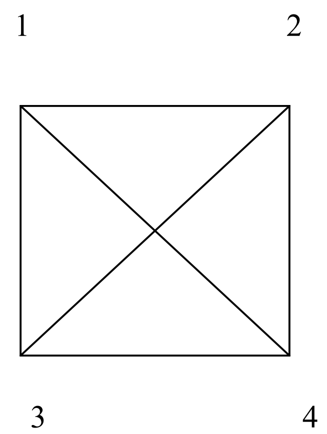


Figure 3

Trade via electronic barter



Thus, there exist four markets. If on the other hand we want to conceptualise 'electronic barter' we assume that commodities can be exchanged with each other, perhaps via an accounting device of e-barter, which now becomes the stipulated means of exchange, through a clearing house that matches demand and supply. In this case there will be $\frac{L(L-1)}{2}$ markets, ie, six markets altogether.[11] Thus, in Figure 3 arcs connect all commodities with each other indicating that exchange occurs via electronic barter.

---

[10] Note that the constraint that goods cannot be directly exchanged for goods is not imposed but naturally emerges as a consequence of our prior argument that trade with money dominates primitive barter.

[11] Extensive discussion on various market structures and how these affect exchange is contained in Shubik (1999).

Let us assume that the combined cost of gathering and then processing information on each transaction is *c*. On the other hand trade with fiat money, by virtue of its anonymity, divisibility, fungibility and its other properties does not require any additional costs except its production and replacement costs. These are covered in its production process as described in **(4)**. Also, information costs concerning the creditworthiness of borrowers in a fiat money economy are dealt by commercial banks and not by the original issuers of money (ie central banks) or by those who accept money in exchange for goods or services. These costs cannot be avoided by the operators of the central clearing house (or a similar transactions institution) that implements electronic barter. Then the total cost of exchange with e-barter is:

$$\overline{C} = \frac{cL(L-1)}{2}(H+1) \tag{11}$$

[12]

We note that each agent participates in only one side of the market since wash sales (ie the same individual participating in both sides of a particular market) are not profitable in a strategic market game without oligopolistic effects. If we assume that set-up costs for establishing either of the two market structures are negligible we have proposition 1. We also note that the total cost of fiat money and of electronic barter is endogenously determined; both depend on the volume of transactions; see equations **(6)** and **(11)**.

Proposition 1:

The cost of exchange with fiat money is lower than exchange with e-barter provided that,

$$\frac{\boldsymbol{L}(\boldsymbol{L}-1)}{2}\boldsymbol{c}\,(\boldsymbol{H}+1)-\boldsymbol{r}\,\boldsymbol{M}>0, \text{ where } \boldsymbol{M}=\sum\nolimits_{\boldsymbol{h}\in \boldsymbol{H}}\boldsymbol{v}^{\boldsymbol{h}}$$

Proof:

The cost of exchange with fiat money is $r\sum_{h\in H} v^h$ (∗), since replacement of depreciated money is financed by seigniorage which is levied by interest rates.

---

[12] We implicitly assume that we are in equilibrium such that agents participate in all markets.

Hence, **(11)** – (∗) = $\frac{\boldsymbol{L}(\boldsymbol{L}-1)}{2}\boldsymbol{c}\,(\boldsymbol{H}+1)-\boldsymbol{r}\sum_{h\in H}\boldsymbol{v}^{h}$ represents the cost difference of exchange with electronic barter versus fiat money. □

One point can usefully be made here about this relationship. If we imagine technical progress lowering *c*, the very same process is likely to increase the number of commodities, *L*. Indeed, over time we have seen a proliferation of traded commodities most of them being associated with technical progress. Note also that while the lower bound of *r* is zero, that of *c* is inevitably above zero.(13)

Proposition 1 underlines the fact that fiat money is a decoupling device that economises on transaction costs regardless from where they emanate (ie processing, information acquisition etc). On the other hand, electronic barter is a centralised accounting mechanism that requires detailed knowledge of every transaction. Thus, it inevitably entails higher aggregate costs in complicated market systems with multiple markets and commodities. It is not a coincidence that the advent of money (or equivalently the decline of barter) occurred contemporaneously with the development of the market system.

Proposition 2:

The equilibria of $\Gamma\left(H,u^{h},e^{h},\eta,x^{h},x^{g}\right)$ with trade with fiat money coincide with those of the corresponding game with e-barter only if *r* = 0 and *c* = 0.

Proof:

If $\boldsymbol{r}=0$ and $\boldsymbol{c}=0$ the two alternative methods of financing trade produce same commodity allocations. To get the same prices and allocations set

$$\frac{\sum_{h\in H}\boldsymbol{b}_{l}^{h}}{\sum_{h\in H}\boldsymbol{q}_{l}^{h}}=\boldsymbol{p}_{l} \text{ and } x_{l}^{h}=e_{l}^{h}-q_{l}^{h}+\frac{b_{l}^{h}}{p_{l}} \qquad \forall\ l\in L,\ \ h\in H.$$

(13) Why money is replaced by barter as a result of hyperinflation is summarised in the above relationship. In hyperinflation, the nominal interest rate rises enormously. See Capie (1986) for a review of some such episodes.

Then, regardless whether trade is conducted with fiat or through electronic barter the same equilibrium obtains. □

Proposition 2 underlines the fact that alternative methods of financing become distinct only when transactions costs are present in the economy. Unless one introduces process and the organisational details of market transactions, it is difficult to delineate the differences between alternative media of exchange. Both of them, without transactions costs, are identical units of account. Money is both neutral and super-neutral. Trade, no matter how organised, generates the same allocations. Whenever $\boldsymbol{r} = 0$ and $\boldsymbol{c} = 0$ then money is a 'veil'. For more on this see Shubik and Tsomocos (2002) and Tsomocos (1996), (2003a, 2003b). Even in the case of bimetallism or multiple means of exchange as long as there are determinate conversion rates among the media of exchange the analysis can be conducted in terms of a 'primary' means of payment. However, the allocations generated by the two methods of financing trade are not unambiguously Pareto ranked whenever r, $c \neq 0$. It remains an open question to determine the conditions on r and c that allow one method to generate Pareto superior allocations over the other.

A natural question that emerges from this analysis is whether it is possible for fiat money and electronic barter to coexist in equilibrium; in particular, whether fiat money can be used for a subset of commodities and electronic barter for the rest. This issue is complicated and beyond the scope of our present analysis, since the volume of transactions with each medium of exchange is endogenously determined and in turn determines the subset of commodities whose trade might occur with each medium of exchange. Also, the gains from trade of each commodity influence the marginal benefit and cost using different methods of financing trade. For example, if there exist big gains from trade in a specific commodity, the government may reduce the marginal cost of trading in that market by introducing electronic barter and thus avoiding depreciation of fiat money used in this particular very liquid market. We plan to explore this question in future research.

VI. The price level – meaningful and determinate

The intrinsic informational superiority of central bank issued base money will ensure that demand for it is not extinguished by the growth of e-barter. Demand will remain from the non-bank public, and, because of that, derived demand will remain from the banking sector. The central bank will thus retain control of short-term interest rates.[14] This might seem at first glance sufficient for it to retain control of the price level; for in many models a short rate is the sole transmitter of monetary policy actions. For example, much recent work on monetary policy uses small macroeconomic models which include an IS function analogous to that in a basic IS-LM model. These can be backward looking, and thus very close to the traditional specification (eg Fuhrer and Moore (1995)), or forward looking, embodying rational expectations (eg McCallum and Nelson (1999a)). But whatever the specification, a common feature is that demand for current output is a function of the real rate of interest, and that rate in turn is typically assumed to be a short-term nominal rate. There is a crucial assumption of slow price level adjustment; monetary policy in such models affects output and inflation only through its effects on the real rate of interest.

This is surely a somewhat hazardous assumption in the present context. Sluggish price adjustment is a result of price adjustment being costly. In a world where transactions costs have been drastically reduced by technical progress, it would be strange to assume that the costs of price adjustment remained unaffected. Accordingly, it also seems strange to continue to argue that monetary policy depends crucially for its effectiveness on prices being statutory.

It is all the stranger since no such dependence is necessary.

Viewing the short rate as the sole transmitter of monetary policy is unnecessarily restrictive both theoretically and empirically. Allan Meltzer (1999a) has recently summarised the body of theory and evidence which considers that specification to be inadequate. He argued that although so long as prices are sticky the real interest rate is indeed affected by central bank operations, so too is the real monetary base, and

---

[14] We do not imply that without such demand it would lose control of short rates. The argument in Goodhart (*op cit*) that the central bank can control rates through its being able to sustain losses seems to us to be correct, despite objections of Selgin and White (2002).

changes in the latter affect aggregate demand in ways additional to the effect of changes in the real interest rate. Meltzer (1999b) reports empirical results for the United States which support this argument, as does Nelson (2000) for the United Kingdom. (The result is not novel; earlier work (eg Mills and Wood (1977)) found a relationship between the base and the price level over long runs of data in the United Kingdom.) Nelson (*op cit*) provides a clear summary of his results as follows:

"The common feature of the regressions is that for the United States and the United Kingdom, real money growth enters output regressions sizeably, positively, and significantly. The real interest rate generally enters with a negative sign, though both the sign and the significance of the real interest rate term appear to be less consistent across sub-samples than those of the money growth terms?" (page 13, emphasis added.)

These empirical results are consistent with two quite distinct bodies of analysis. One is on an approach which assumes utility is non-separable in consumption and real money holdings. This justifies a real money balance term in the IS function as a result of optimising behaviour. Koenig (1990) reports results which support this; but others (eg McCallum (1999)) suggest that the coefficient on real balances is likely to be small).

A <u>direct</u> role for money is perhaps better defended and explained by an approach with much earlier origins. David Hume (1752) thought that money affected the economy through a wide variety of channels, and expressed this thought in a metaphor - water flowing from one place to another - that frequently recurs in the discussions of the money transmission process.[15]

'Money always finds its way back again by a hundred canals, of which we have not notion or suspicion….For above a thousand years, the money of Europe has been flowing to Rome, by one open and sensible current; but it has been emptied by many secret and insensible canals.' (page 48, 1955 reprint).

---

[15] See Wood (1995) for a discussion of the development of the quantity theory and the history of the 'water' metaphor.

The many channels view is also articulated by Friedman and Schwartz (1982, pages 486-87).

'…The attempt to correct portfolio imbalances (resulting from an increase in the money stock) raises the prices of the sources of service flows relative to the flows themselves which leads to an increase in spending both on the service flows and then produce a new source of service flows….Sooner or later the acceleration in nominal income will have to take the form of rising prices, since the initial position was assumed to be one of equilibrium and we have introduced nothing to change the long-run trend of nominal income.'

This argument is also expressed in Brunner and Meltzer (1993) and was stated very succinctly in Meltzer (1999b), as follows:

'Monetary policy works by changing relative prices. There are many, many, such prices. Some economists erroneously believe….monetary policy works only by changing a single short-term interest rate.'

He also argues (1999a) that money balances are crucial in the transmission mechanism. He sees '…the gap between desired and actual real balances as a measure of the relative price adjustment required to restore full equilibrium'.

Our formal model (Section IV) which compared fiat money with electronic barter (Section V) also yields the result that control of the issue of fiat money controls the price level without any intermediation through an interest rate channel. Our model manifests *real* as well as *nominal* determinacy as has been shown in Tsomocos (1996, 2003a, 2003b). This is unlike the classical competitive model which possesses a 'finite' number of equilibria with respect to real allocations; only relative prices can be determined. Our model resolves nominal indeterminacy through the presence of *private liquid wealth* (Tsomocos (1996)). By liquid wealth we mean a commodity or a monetary instrument which can be used interchangeably with money in real, financial, or bank transactions, and its conversion rate is institutionally predetermined. The essence of the determinacy argument and consequently of the non-neutrality result is that monetary policy affects nominal variables, yet if private liquid wealth is non-zero then monetary changes affect directly the endowments of agents resulting in different optimisation choices and consequently different real consumption. The issues of determinacy and money non-neutrality are intimately connected and are analytically equivalent.

Finally, if a model does not possess equilibria that are nominally determinate then any discussion of exchange with a particular means of payment (either fiat or e-barter) is not legitimate. If multiple price levels support the same equilibrium real allocations then it is impossible to compare the relative virtues of exchange with different means of payment.[16]

VII. Conclusion

In this paper we first set out the argument (a very traditional one) that money evolved to reduce transaction costs by economising on information.

A formal model in which money existed by virtue of that property was then developed and the costs of operating a fiat money system were compared with the costs of operating a system of electronic barter. The key cost parameters were identified. It was shown that within this framework fiat money dominates – is cheaper than – electronic barter, unless inflation drives up the nominal interest rate. Secondly, increases in the number of commodities increase the costs of electronic barter faster than they do the costs of using fiat money; and finally that the lower bound to the cost of using fiat money is always below that of electronic barter. Thus fiat money is a superior transaction technology to electronic barter; transaction chains that use it have intrinsically lower information requirements. The resulting demand for fiat money by the non-bank public will in turn give rise to demand by the banking sector. Their joint demands will ensure both that central banks survive, and that they will retain control of a price level measured in the money they issue. Institutional change in the payments system will no doubt have quantitative implications for central bank operations, but it will not have qualitative implications for them.

[16] McCallum (2003) reaches this same conclusion by a different route. It is, however, clearly related to the above argument in that it focuses in a voluntary demand for base money on the part of banks – that is, of demand for it in the absence of reserve requirements. He, as an alternative, suggests that payment of interest in reserves could also achieve such a demand.

References

Alchian, A A (1977), 'Why money?', *Journal of Money, Credit and Banking*, Vol. 9, No. 1, pages 133-40.

Brunner, K and Meltzer, M (1971),'The uses of money: money in the theory of an exchange economy', *American Economic Review*, Vol. 61, December, pages 784-805.

Brunner, K and Meltzer, A (1993), *Money and the economy: issues in monetary analysis*, Cambridge University Press, Cambridge.

Capie, F H (1986), 'Conditions in which very rapid inflation appears', *Carnegie-Rochester Conferences on Public Policy*, Spring, Vol. 24, pages 115-65.

Capie, F H and Gomez, Y (2002), 'Electronic money: a survey of 'potential users', *Economic Trends: Finland.*

Clower, R W (1969), 'Introduction', in Clower, R W (ed), *Readings in monetary theory*, Penguin, London.

Drèze, J and Polemarchakis H M (2000), 'Monetary equilibria', in: *Economic essays: a fetschrift for Werner Hildenbrand.* Springer, Heidelberg.

Dubey, P and Geanakoplos, J (1992), 'The value of money in a finite-horizon economy: a role for banks', in Dasgupta, P and Gale, D *et al* (eds), *Economic analysis of markets and games*, Cambridge: MIT Press.

Dubey, P and Shubik, M (1978), 'The non-cooperative equilibria of a closed trading economy with market supply and bidding strategies', *Journal of Economic Theory*, Vol. 17, pages 1-20.

Dubey, P and Shubik, M (1980), 'A strategic market game with price and quantity strategies', *Zeitschrift für Nationalokonomie*, Vol. 40, pages 25-34.

Friedman, M (1956) (ed), 'The quantity theory of money: a restatement', *Studies in the quantity theory of money*, University of Chicago Press, Chicago.

Friedman, M and Schwartz, A J (1962), A Monetary History of the United States, Princeton UP, Princeton.

Fuhrer, J C and Moore, G R (1995), 'Monetary policy trade-offs and the correlation between nominal interest rates and output', *American Economic Review*, Vol. 85(1), pages 219-39.

Giraud, G (2003), 'Strategic market games: an introduction', *Journal of Mathematical Economics*, Vol. 39, pages 355-375.

Glasser, D (1989), *Free banking and monetary reform*, CUP Cambridge and London.

Gomez, Y (2001), 'Electronic money and the monetary system', unpublished PhD thesis, City University, London.

Goodhart, C A E (2000), 'Can central banking survive the IT revolution?', *International Finance*, Vol. 3, July, pages 189-202.

Grandmont, J-M (1983), *Money and value*. Cambridge University Press, Cambridge.

Hume, D (1752), 'Of money', reprinted in Rotwein, E (ed), *Writings on economics*, Nelson, London, 1955.

Hurwicz, L (1960), 'Optimality and informational efficiency in resource allocation processes', in: K.J. Arrow, S. Karlin, and P. Puppes, eds., *Mathematical methods in the social sciences.* Stanford University Press.

Hurwicz, L (1973), 'The design of mechanisms for resource allocation', *American Economic Review*, Vol. 63, pages 1-30.

Keynes, J M (1935), *A treatise on money*, Vol. 1, Macmillan, London.

King, M (1999), 'Challenges for monetary policy: new and old', in *New challenges for monetary policy*, Federal Reserve Bank of Kansas City.

King, M (2002), 'No money, no inflation – the role of money in the economy', *Bank of England Quarterly Bulletin*, Summer, pages 162-74.

Koenig, E F (1990), 'Real money balances and the timing of consumption: an empirical investigation', *Quarterly Journal of Economics*, Vol. 105(2), pages 399-425.

Latzer, M and Schmitz, S W (2002), *Carl Menger and the evolution of payment systems*, Cheltenham, Edward Elgar.

Lucas, R E (1980), 'Equilibrium in a pure currency economy', in: J.H. Kareken and N. Wallace, eds., *Models of monetary economies*, Federal Reserve Bank of Mineapolis, Mineapolis.

McCallum, B (1985), 'Bank Regulation, Accounting Systems of Exchange, and the Unit of Account: A Critical Review', *Carnegie-Rochester Conference Series on Public Series 23, 13-45.*

McCallum, B (1989), *Monetary economics: theory and policy,* Macmillan, New York.

McCallum, B (1999), 'Theoretical analysis regarding a zero nominal bound for interest rates', *Journal of Monetary Economics*, Vol. 32, pages 163-72.

McCallum, B (December 2003), 'Monetary Policy in Economies with Little or No money', National Bureau of Economic Research working Paper.

McCallum, B and Nelson, E (1999a), 'An optimising IS-LM specification for monetary policy and business cycle analysis', *Journal of Money, Credit and Banking*, Vol. 31(3), pages 296-316.

Meltzer, A H (1998), 'What is money?' in Wood, G E (ed), *Money, prices and the real economy*, Edward Elgar, Cheltenham.

Meltzer, A H (1999a), 'The transmission process', *Working Paper*, Carnegie-Mellon University.

Meltzer, A (1999b), 'A liquidity trap', *Working Paper*, Carnegie-Mellon University.

Menger, C (1892), 'On the origin of money', *Economic Journal*, Vol. 2, June, pages 239-55.

Mills, T C and Wood, G E (1977), 'Money substitutes and monetary policy in the UK 1922-1971', *European Economic Review*, Vol. 10, pages 19-36.

Mills, T C and Wood, G E (1982), 'Econometric evaluation of alternative UK money stock series, 1870-1913', *Journal of Money, Credit and Banking*, May, pages 245-67.

Monnet, C (2002), *Optimal public money*, typescript.

Nelson, E (2000), 'Direct effects of base money on aggregate demand: theory and evidence', *Bank of England Working Paper no. 122*.

Radford, R A (1945), 'The economic organisation of POW camp', *Economica,* Vol. 12, pages 189-201.

Selgin, G and White, L H (2002), *Mengerian perspectives on the future of money*, in Latzer and Schmitz (*op cit*).

Shapley, L (1976), 'Noncooperative general exchange', in: Lin , ed.., *Theory of measurement of economic externalities.* New York: Academic Press.

Shapley, L and Shubik, M (1977), 'Trade using one commodity as a means of payment', *Journal of Political Economy*, Vol. 85, pages 937-68.

Shubik, M (1973), 'Commodity money, oligopoly, credit and bankruptcy in a general equilibrium model', *Western Economic Journal*, Vol. 10, pages 24-38.

Shubik, M (1990), 'A game theoretic approach to the theory of money and financial institutions', in: B.M. Friedman and F.H. Hahn, eds., *Handbook of monetary economics*, North Holland.

Shubik, M (1999), *The theory of money and financial institutions*, Cambridge: MIT Press.

Shubik, M and Tsomocos, D P (2002), 'A strategic market game with seigniorage costs of fiat money', *Economic Theory*, Vol. 19, No. 1.

Shubik, M and Wilson, C (1977), 'The optimal bankruptcy rule in a trading economy using fiat money', *Zeitschrift für Nationalokonomie*, Vol.37, pages 337-354.

Stigler, G J (1972), 'The law and economics of public policy: a plea to scholars', *Journal of Legal Studies.*

Tsomocos, D P (1996), 'Essays on money, banking and general economic equilibrium', unpublished PhD thesis, Yale University.

Tsomocos, D P (2003a), 'Equilibrium analysis, banking, contagion, and financial fragility', *Bank of England Working Paper* No. 175.

Tsomocos, D P (2003b), 'Equilibrium analysis, banking and financial instability', *Journal of Mathematical Economics*, Vol. 39, pages 619-655.

Wood, G E (1995), 'The quantity theory in the 1980s', in Eltis, W (ed), *The quantity theory of money: from Locke and Hume to Friedman*, Edward Elgar, Cheltenham.

Yeager, L B (1968), 'Essential properties of the medium of exchange', *Kyklos*, Vol. 21, pages 45-69.