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Exchange Rate Determination:
A Model of the Decisive Role of Central Bank Cooperation and Conflict

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Abstract

Opinion is divided on whether it is better to have a single world money or variable exchange rates. Pope, Selten and von Hagen (2003) propose that fresh light would be shed via an analysis that allows for seven complexity impacts on the exchange rate that are underplayed (where not entirely absent) from current analyses: 1) the role of official sector, including its central bank; 2) the numerous official and private sector goals; 3) the disparate degrees of market power of different sorts of private agents; 4) the documentation that essentially all shocks to the exchange rate are generated by human decisions; 5) the non-maximising heuristics that in the complex economy agents use; 6) heterogenous beliefs. This paper analyses a closed form game theoretic solution of version 1 of a model that combines impacts 1 to 4 with the conventional finance assumption that all agents maximise their utility. Impact 1) precludes private agents being able to destabilise the exchange rate against the cooperation of the central banks required by the game theoretic solution. Impact 4) excludes random events and other exogenous shocks such as meteors falling from the sky. The rational maximising assumption in turn precludes all other sources of shocks and thus any need for a variable exchange rate to equilibrate after shocks. We then modify version 1 of our model substituting for the maximising assumption impacts 5 to 7, impacts that allow shocks from humans to be consistently incorporated. We do so by means of an experimental investigation which indicates that central bankers less than fully cooperate, leaving scope for private speculators to support their preferred currency. From the viewpoint of the game theoretic equilibrium, the resultant exchange rate changes render equilibrium unspecified. A single world money avoids disruptive exchange rate changes from less than fully cooperating central banks, exchange rate changes caused by central bank conflicts and that cannot be classified as equilibrating.

Key Words: central bank; cooperation; conflict; exchange rate; experiment; market power; heuristics; heterogenous beliefs; personality; interpersonal dynamics; friendship; complex; destabilising speculators, irrational central bankers.

JEL Classification: F310, F330, B400, B590, C790, C900, C910, C920

Part 1 introduces our team's unusual lines of research into matters that, because they are so complex and unwieldy, have been largely ignored. Part 2 is methodological, on the advantages of presenting a model via the choice (instructions) method rather than

* The general text is written by Robin Pope, with valued improvements on successive drafts from comments of Johannes Kaiser and Reinhard Selten. The important suggestion of Alessandro Sderci and an anonymous referee of this journal to extend the paper with an elucidation of the model and withtheoretical and experimental findings to assist readers in seeing scope for applying the model, has more than doubled its length with the addition of Parts 3, 5, 6 and 7. The participants' instructions were written by Sebastian Kube, translated into English by Reinhard Selten, with minor improvements on these from Robin Pope. The calculations requested by Robin Pope for including in the added Parts 6 and 7 were kindly furnished by Johannes Kaiser. The conflict co-operation model of central banks and its particular parameterisation in this paper is that of Robin Pope and Reinhard Selten, with valued input from Juergen von Hagen on allowing for the distinct input of the government sector. The operationalisation of the parameterised model into a computer-programmed set-up is that of Johannes Kaiser and Sebastian Kube. We thank for research assistance Corinna Wassermann, Daniel Lederer, Andreas Orland, and Laura Frank; and for funding the Center for European Integration Studies and the German National Science Foundation.

the normal impersonal method, and on complexity. Part 3 presents the particular model used in this research in the form of instructions to participants in an experimental set-up, while Part 4 elucidates some of its features (in the normal impersonal way). Part 5 employs the model to uncover the misleading and somewhat inconsistent modelling of shocks in conventional exchange rate models. Parts 6 and 7 use experimental data to delineate why equilibrium as traditionally modelled is unspecified once shocks from humans enter the picture, and to indicate the greater efficacy of a single world money over variable exchange rates in maintaining international competitiveness between countries. Part 7 indicates the scope for investigating other issues using this model and how it nestles within the umbrella of SKAT, the Stages of Knowledge Ahead Theory.

1 Introduction

An exchange rate war has been waging over the last several years on whether China should appreciate. In favour of China appreciating are the US Senate, the EU, and academic economists such as Cline (2005), Simmons (2006) and Zemin (2007), while opposing this are China's government and central bank and academic economists such as Mundell (2003, 2005), McKinnon (2006a, 2006b, 2006c, 2007a, 2007b), and Wang, Hui and Soofi (2007). Opinion is likewise divided on whether the west should have pressured Japan into its appreciations, and on whether the EURO has aided continental Europe. In turn, these controversies stem from divided viewpoints on whether variable exchange rates are desirable, and on whether there is minor or major damage to macroeconomic management from floating exchange rates. There has been now over 35 years of modelling and estimation of the effects of floating exchange rates, without resolution of these issues.

As likely to contribute to the irresolution, Pope, Selten and von Hagen (2003) have proposed the following seven defects in how economists analyse exchange rates:

1 Any pair of fully cooperating official sectors have unlimited power to set their bilateral exchange rate. But the role of official sector cooperation and conflict has been underplayed, *indeed often totally overlooked*, in exchange rate modelling. In this paper for simplicity we restrict ourselves henceforth to the case where the rights of currency intervention and of furnishing the currency both lie with the central bank.

2 Politicians, governments, and central banks have numerous goals, yet exchange rate models rarely embrace more than two – one inflation and one employment target. Likewise the goals are distinct for different sorts of private agents, such as firms and wage bargainers, yet exchange rate models rarely model this goal heterogeneity. The oft-remarked, but tricky to measure uncontroversially, importance of friendships and enmities between central bankers, politicians, government officials and key private players tends to be omitted. Yet these

emotional ties ensure shocks to the system whenever personnel changes in key posts, altering goals of both the official and private sectors.

3 The market power of governments, central banks, major private speculators (such as Soros and, in its heyday, Long Term Capital Management Fund), and wage bargainers is unambiguous but generally ignored. There is widespread usage of *so-called* rational expectations that are in fact irrational, as they ignore such market power entirely. Since fully cooperating central banks are exceedingly rare, the key players are more than the central banks. In the interval of conflict/incomplete cooperation between central banks, the wage bargainers and big funds have significant amounts of market power, Soros (2003). Had Long Term Capital Management better appreciated this and not relied on its zero market power Black Scholes formulae, it might not have needed to face the dramas it actually endured, Merton (2001).

4 Shocks are modelled as exogenous, either as a one-off shock after which there will never be another shock and all know this, eg as in Mundell (1961), or else as if randomly generated, and in each case as if generated by nature, not human choice. In the exceptional occasions where the shocks are modelled as coming from people, eg as having in shock changes in people's work-leisure indifference curves, the nature of the shocks prima facie conflict with the model's rational maximisers assumption. Now shocks from nature happen, such as those underlying the worldwide grain shortage of 1969-70, and the Italian drought escalating the prices of fresh produce at the time of the introduction of EURO notes and coins. For some small developing countries reliant on a single crop such as coffee, these effects are substantial in the case of floating currencies.

But all major shocks to exchange rates of developing countries come from human decisions. The breakdown of Bretton Woods was not caused by an out-of-space meteor, damaged grain crops, or a tsunami. Rather, the breakdown may be sheeted to the way the US funded its Vietnam War, the beliefs of key adviser Milton Friedman and US pride barring a depreciation against gold, not to acts of nature. Likewise subsequent exchange rate crises of the developed world, such as the doubling of the US exchange rate against key European currencies between 1982 and 1985, was the product of human decisions – those of US President Reagan to cut taxes and escalate military spending, of US federal reserve chair Volcker to rein in the US money stock, and of US secretary of the Treasury to endorse the strong US dollar and bar foreign exchange interventions to sterilise these extreme fiscal and monetary policy moves. Again the halving of that exchange rate in the next two years was not that a hurricane had blasted the US economy into misery. It was rather British prime minister Maggie Thatcher's influence on her friend Ronnie Reagan to reverse this doubling, coupled with support from all the other key currencies, resulting in the Plaza Accord among the big five of 1985 and the Louvre Accord of 1987. On this trio of crises and their entirely human decision origins, see eg Paul Volcker's account in Mehrling (2001).

The exchange rate crises of the early 1990s for the developed world were likewise also entirely of human making. The undesired sterling depreciation and exit of the UK from the process leading into the EURO occurred when the German central bank refused to co-operate with the Bank of England, while France's sufficiently minor depreciation in its crisis the next year and its remaining in the process

leading to the EURO, as enbled by the German central bank cooperating with the Banque de France. On these 1990s crises, see eg Eichengreen and Wyplosz (1993).

The tense exchange rate situation of 2007 wherein the USD has dramatically depreciated against the EURO is likewise of human making. As noted by the Italian member of the European Central Bank's board of directors, Lorenzo Bini Smaghi (2007), the ECB and the US Federal Reserve have between them full power to set this exchange rate. Changes in this rate are not acts of nature, but human decisions. McKinnon (2007) makes a similar observation that the choice of exchange rates rests with humans, not bolts of lightning from nature. His recommendation is that the cooperation should extend beyond the official sectors controlling the USD and the EURO, to those controlling the British pound, the Japanese yen and the Canadian dollar, ie to a five-way agreement to stabilise these key rates. In short, for any major developed country, the stylised fact is that all shocks come from human decisions. That is, the current practice of modelling shocks as exogenous, ie as emanating from nature, is a perverse modelling that is the reverse of the stylised facts.

5 The nonmaximising heuristics that have to be employed by agents in any complex environment are ignored. Firms engaged directly in currency exchanges employ to a marked degree the heuristics of technical analysis. The heuristics can include standard prominent index heuristics such as Sharpe and Treynor ratios and Jensen's alphas. Technical analysis seeks to identify upper and lower barriers beyond which it is deemed to be unlikely that an exchange rate will move. These are barriers at which it is predicted that there will be exchange rate turbulence, reversals of trends. The predictions can involve the judgment in discerning the patterns, in which case it is sometimes termed chartism. Alternatively the predictions can be mechanical, the product of fixed statistical rules. Exchange rate heuristics of traders are however largely ignored in the academic literature that tends to model traders as either informed or uninformed profit maximisers. Exceptions to maximising modelling examining such heuristics are starting to appear and include Neely (1997), Osler (2000, 2003). As regards the official sector, the authors are unaware of any nonmaxising modelling that consciously incorporates commonly used official sector heuristics. Rather the norm is to model Taylor-rule maximising central banks

The norm of private and public sector maximising involve only so-called maximisation as distinct from *genuine* maximisation. This is because it is conducted within an artificially simplified world to the extent that algebra coupled with closed form solutions or simulations or econometric estimates can yield results. The sensitivity of results to which particular heuristics economists use in these so-called maximising models is hinted at in the sensitivity of conclusions drawn as regards which, if any, equilibrium is attained and whether it is stable. In this regard, see eg Grandmont (1985), Chichilnisky (1999), Hahn (1999), Drèze and Herings (2003), Barnett and He (2006), Sordi and Vercelli (2003) and Dieci, Sordi and Vercelli (2006).

6 There is widespread usage of representative agents models and of *so-called* rational expectations that are irrational as they ignore heterogeneity of beliefs on

how markets work. This renders it a farce even if coupled with learning, since the question of what to learn is inadequately unaddressed, Phelps (1999).

Remedying defects 1-3 of current models is fairly straightforward, albeit doing this involves such complicated models that closed form solutions are essentially infeasible, as detailed in Part 5. Remedying features 4 to 7 is difficult to specify in any detail since research on the details has been limited, and because some details are sufficiently idiosyncratic as to be unique. The particular model here presented is accordingly developed in two versions.

One version enables a game theoretic solution since it substitutes for those tricky to specify details involved in features 5 to 7, the standard game theoretic assumption that all agents maximise their von Neumann-Morgenstern utility functions. Since utility maximisers generate no shocks, and since we are abstracting from the exceptional events of shocks from nature, this renders the model and its game theoretic solution determinate. In this determinate situation only ordinal utilities are required for choices. Ordinal utilities are all that is required for any closed form solution. In turn each agent's ordinal utility function is given by that agent's payoff (profit/objective) function.

The second version of our particular model drops this maximising assumption and allows for features 5 to 7. The means of including features 5 to 7 is via an experiment. In an experiment, these features do not need to be *pre*-specified, but are as executed by the experimental participants. The experimental set-up is that of Pope, Selten and Hagen (2003). It was programmed by Johannes Kaiser and Sebastian Kube. The experimental sessions were conducted in 2003 and 2004 in the Bonn University Experimental Economics Laboratory. The participants were advanced economics students.

In summary, the particular model presented in this paper addresses defects 1-7 as follows:

1 by limiting private sector influence to the region of exchange rate aim conflict between the central banks;

2 by including seven common objectives of official sectors;

3 by including five types of agents – governments, central banks, employer and employee wage bargainers, and firms – and by allowing the outcomes to arise from market power, instead of assuming that participants, contrary to fact, decide as if they have no market power;

4 by allowing the participants to determine the personal dynamics, and thus for the importance of these to be manifested in differences among sessions, each of which comprises different individuals;

5 by allowing participants to use their own heuristics to seek to attain their goals in this complex environment where the maximising "right thing to do" is unclear; and

6 by allowing participants' heterogenous beliefs to enter their decisions

7 all shocks being generated by human decisions.

2 Methodological Issues

Choice versus the Impersonal Mode of Model Presentation

In Part 3, we introduce our model in the form of an English translation of the instructions given to experimental participants – not as is the norm, via algebra explained by an omniscient theorist, "it can be seen that" and so forth. To see that remote abstract discourse may impair understanding, consider economists' squeamishness about survey – as distinct from market – evidence. Most economists adopt the revealed preference dogma and deem that choices reveal how people's motives, and so downplay findings from experiments based on "what do you think" compared to findings based on those that ask what would you choose. On the same logic, you the reader can acquire a deeper understanding of a model by asking, as an imaginary experimental participant, how you would act in each role, imagining yourself in each of the varied roles that ensue. Having to think yourself into playing each role may entice a more vivid understanding of assumptions than when you read a model described as is normal in revelatory formulations such as "Let there be *x* ...", or "There is an *x* such that ..."

To see how much more we can comprehend a model when placing ourselves within it, consider the fate of the Mundell (1961) model. This model continues to be frequently used to justify multiple currencies despite Mundell's objective elucidation to the contrary right back in that 1961 paper. Had the model instead been presented to readers as participant instructions, it is possible that even in that simple world of Mundell (1961), readers would have perceived disadvantages in multiple currencies. Imagining having to make the decisions oneself entices often a deeper appreciation of assumptions than simply reading that agents do *x* and *y* happens.

Presenting a model as instructions aids also in another respect. To choose, participants have to look at numbers to assess what is happening to each land – as do real-world official sectors, firms and so forth. The cognitive abilities and analytical methods assumed in purely algebraically presented models are veiled from us if we do not sit down as in reading the below instructions, and consider how on earth could someone

decide given these sets of numbers and the payoff (profit/objective) function that we face in each role as that particular sort of public or private sector agent.

Complexity Warnings

The particular model here presented is light years more complex than either Mundell (1961) or its subsequent extensions. After going over the instructions and imagining your decisions in Part 3, Part 4 offers a third-person account of some key model features. However, reader, please do not use the helicopter approach and skip over the instructions of Part 3. The helicopter approach robs you of appreciating the complexity of real world choice – and complexity's implications for modelling choice under uncertainty and implications for choice of exchange rate regime.

Bear in mind too that our model is far simpler than the real world. It had to be simple enough to be comprehensible for upper level economics students after an hour and fifteen minutes of instructions – comprehensible enough for participants not to lose so much money by so many mistakes that the game had to be prematurely ended, negating up to ten hours of time invested by 18 participants and three supervisors. This indeed proved to be the case, in part through Sebastian Kube's expert participants' instructions sheets, and the elucidation of these to participants by Sebastian Kube and Johannes Kaiser. None of our nine sessions had to be abandoned for this reason, even if one firm's losses were very extreme. This of course reveals that our set-up is much less complex than that of the real world where giant multi-nationals and hedge funds continue to go into receivership due to exchange rate mistakes, and official sectors continue to lose billions of taxpayers' funds through their exchange rate mistakes.

In reality, payoff functions involve large margins of doubt adding to the complexity of evaluation and choice. Did, for instance, the UK Treasury guess how much of its power would be transferred to the Bank of England after its failed attempt to hold the pound in the early 1990s? Did Italian speculators dream that their bank accounts would be raided after the government's losses in an earlier failed attempt to resist an attack on the Lira? One of the simplifications of our set-up is that each participant knows exactly without any doubt his payoff function. This allows the inferences made later in the paper concerning the effect of multiple currencies under the conventional finance assumption of choosers maximising their utilities.

However, the set-up is sufficiently complex to mimic a feature of the real world, namely that even were the agents to know their utility function exactly, essentially none could work out how to maximise it. There is thus a certain degree of comedy, as will be further discussed in Part 5, in reaching a conclusion on what a utility maximising agent would do. For the present, simply consider that economics routinely

assumes maxima are costlessly and instantly calculable, and in each role in this set-up that is so much simpler than reality, consider if you the reader can discern the maximising act. Should you instead feel that you need to reach for heuristics to evaluate alternative and reach a decision, then you conform to feature 5 of our alternative model. If your heuristics might differ from those of others, you conform also to feature 6 of our alternative model, and if you feel that you cannot fully anticipate what the next round will bring, you grant feature 7 of our alternative model, of shocks from human decisions.

3 The Model in the Form of Participant Instructions

This experiment has 18 participants.

There are two countries in the experiment
– country *A*
– country *B*

At the beginning of the experiment you will be randomly assigned to one of these countries.

In each of the two countries there are nine players with five different roles:
– government
– central bank
– labour union
– employers' association
– five firms

The firms are numbered from 1 to 5. Each country has its own currency. Your role in this experiment will be randomly assigned to you.

The game runs over several rounds. Each round consists of several steps:
– government decision
– central bank decisions
– wage bargaining between union and employers' association
– decisions of firms on production quantities
– decisions of firms on currency transactions

At the above five steps participants playing these roles make their decisions. Three further steps then follow:
– currency market: determination of the exchange rate
– round payments and determination of account balances
– transfer of the firm accounts

In these three steps, players make no decisions. The outcomes of these three steps are calculated by the computer.

The steps in detail

In the following everything is described from the point of view of Country *A*. Everything is analogous for Country *B*. However, the value for Country *B* will be marked by an asterisk, *. Decisions are always made for the current round.

Government decisions

By means of fiscal policy, not modelled in detail, the government in each country determines that country's amount of total expenditure, D and D^*, respectively. This total expenditure is spent entirely on a consumption good produced by firms in that country.

Central bank decisions

Each central bank has to fix three decision parameters:

– *the interest rate*
  Note that 1+interest rate = interest factor, r and r^*, respectively. Eg an interest rate of 8% corresponds to the interest factor 1.08. Firms can take short run loans and make short run money investments at this rate.
– *the target price* for the next round, p_+ and p_+^*, respectively.
  This is the price that the central bank would like to see as the price for the domestic good in the next round. So the current target price p has been set in the prior round, and p_+ is now set for the next round.
– *the exchange rate aim*, f and f^*, respectively.
  The exchange rate aim states how many units of own currency that the central bank would like to receive for one unit of the foreign currency. What is actually received after the exchange rate market operates, is the actual exchange rate, e and $e^*=1/e$, something not fixed by each central bank alone but is the result of the currency market's operation. The central banks intervene on the currency market to defend their exchange rate aims. This happens automatically and results in a final exchange rate e between f and $1/f^*$.

Wage bargaining between union and employers' association

In this step the union and the employers' association in each country negotiate the wage rate, w and w^*, respectively, for the current round. This is done by exchanging text messages (chatting) and wage offers. These wage offers are not permitted to be lower than the official minimum wage, $w_0= 0.14p$. Bargainers have 10 minutes for the wage negotiations. If no consensus is reached, there is a strike in that country. In the event of a strike, production capacity and demand are lower than normal in this round, and the wage rate is equal to the minimum wage rate w_0.

Decisions of firms on production quantities

Firms have to make two decisions. The first is to choose a quantity Q_i (here i is the number of the particular firm) of the consumption good to produce and sell. The maximum quantity is 60, but in the case of a strike, the maximum is 45. The minimum quantity is 20. Three inputs are needed for production:

– *Home raw materials*
  For one unit of the consumption good, one needs one unit of home raw materials purchasable on the home material market at a cost of $m=wr$. (This is because each unit of raw materials is produced with a unit of labour that costs w. Then interest paid on prepaid wages increases the total unit cost to wr.)

– *Foreign raw materials*
  For each unit of the consumption good produced a firm uses one unit of foreign raw materials, bought on the foreign material market at a cost of $m^*=w^*r^*$ in foreign currency.

– *Labour*
  Running a firm requires 15 units of labour plus 1 unit of labour for each unit of the consumption good produced. Workers can only be hired on the home labour market where the wage rate is w per unit hired.

If one has decided to produce Q_i units, then one needs:
– $M_i(=Q_i)$ units of home raw materials at a total cost of $M_i m$
– $M_i^*(=Q_i)$ units of foreign raw materials at a total cost of $M_i^* m^*$ in foreign currency
– L_i units of labour with $L_i=15+Q_i$ at a total cost of $L_i w$

Decisions of firms on currency transactions

Each firm has a home account and a foreign account. All transactions are entered on the relevant account. Thus the home account is charged with the wage expenses $L_i w$ and the foreign bank account is charged with the costs $M^*_i m^*$ for foreign raw materials. The existence of two accounts makes currency transactions possible after the production quantity has been fixed.

A firm can:

– *offer home currency X_i*
  Here the firm takes a loan of X_i at an interest inclusive cost of r from its home bank and for this it receives $X_i e^*$ in foreign currency. After earning foreign interest on this foreign currency, the firm has an amount of $X_i e^* r^*$ on its foreign bank account.

*or offer foreign currency X_i**

Here the firm borrows on its foreign account an amount X_i* at an interest inclusive cost of r*. This money is then exchanged on the currency market and the firm receives X_i*e in home currency, on which it earns interest at the rate r on its home bank account.

– *or offer no currency*

This means not being active on the currency market

Take into consideration:

– A firm cannot offer both currencies at the same time

– The amount of currency transactions is limited by how much the firm decided to produce, since a firm must cover its costs for material, labour etc.

The *maximum amount of home currency* a firm can offer is $(80\text{-}L_i)w$

The *maximum amount of foreign currency* a firm can offer is $20w$*

– When a firm offers a currency, it is not yet decided how many units of the other currency it will receive, since it does not get them at the exchange rate for the last round. The currency offers of all firms may have an influence on the exchange rate in the current round. The amount flowing to a firm account in the other currency is calculated at the exchange rate of the current round.

– At the end of the round, the balance on both of a firm's accounts will show what it has earned, however, in different currencies. In the next round the firm's foreign account will be automatically offered at the currency market and will be exchanged to its own currency and this offer may again influence the exchange rate. The value of its foreign account balance in its own currency will be determined by the currency market of the next round. A firm should pay attention to this in connection with its own currency transactions.

– If you are a firm, you can make use of a *profit calculator* as a decision support. Here you enter your exchange rate expectations for the current round and the next round, how much you want to produce, and what you expect the other four firms will produce together. On the basis of these expectations, the computer provides a table with an adjustable scale. In this table you can see your profits obtained if all your expectations come true. At the same time the computer determines which currency you should offer if your exchange rate expectations turn out to be exactly correct.

Currency market

After all players have made their decisions for the current round, the currency market determines the current *exchange rate*. The exchange rate is not randomly determined, but depends on the decisions of the firms and the automatic interventions of the central banks. It is determined in such a way that the demand for a currency becomes equal to the supply of this currency.

The *supply* of home currency is composed of:

– The home currency offers of foreign firms (from their point of view the home currency is the foreign currency) and home currency offers of domestic firms (=*X*)

– Money amounts on the foreign accounts of foreign firms at the end of the preceding round, offered in this round, in order to exchange it into their domestic currency (=*K*)

– Possible interventions in home currency of the domestic and the foreign central bank (=*I*)

The *demand* for the home currency is composed of:

– The foreign currency offers of foreign firms (offers of domestic currency from their point of view) and foreign currency offers of home country firms (=*X**)

- Money amounts on foreign accounts of home country firms at the end of the preceding period, offered in order to exchange it into home currency (=*K**)

– Possible interventions in foreign currency of the domestic and the foreign central bank (=*I**)

Therefore the preliminary exchange rate ê is determined by $X+K+I = \hat{e}\ (X^*+K^*+I^*)$

Central banks and the currency market

The above exchange rate is only preliminary, since the central banks intervene in two ways. At first, each central bank makes precautionary offers in order to defend its own exchange rate aim against that of the other central bank. However, these interventions are limited in the form of a dependence on the preceding round's material price, *m* and *m** respectively.

There can be two kinds of conflict:

– Each central bank wants a lower value for its own currency than the other bank does, ie $f>1/f^*$. In this case, the home country central bank offers $I=600m\_$ of its home currency and the foreign central bank offers $I^*=600m\_^*$ of its currency.

– Each central bank wants a higher value for its own currency than the other central bank does, ie $f<1/f^*$. In this case the home country central bank offers $I^*=500m\_^*$

of the foreign currency and the foreign central bank offers I=500m_ of the home currency (the foreign currency from its point of view).

It is possible that the preliminary exchange rate $\hat{e}$ is outside the interval between the two exchange rate aims. In this case the two central banks cooperate in order to keep the exchange rate in this interval:

– If the preliminary exchange rate $\hat{e}$ is smaller than f and 1/f*, then the final exchange rate will be the smaller of the two values, f and 1/f*

– If the preliminary exchange rate $\hat{e}$ is greater than f and 1/f*, then the final exchange rate e is the greater of these two values.

If the preliminary exchange rate $\hat{e}$ is between f and 1/f* or at one of these values, then it is also the final exchange rate.

Round payoffs and account balances

In each round you receive a number of points, your round payoff, which depends on your decisions and those of the other participants and on your role. You are credited with these points on your payoff account, an account with a balance in points not usable as a resource in the game.

– Firms

After each round, the account balances of each firm are transferred to its owners. The owners exchange accounts in foreign money to their home currency, but only in the next round. Therefore firms – as also employers' associations – obtain their payoffs for this round only in the next round. Firms and employers' associations receive the value of the domestic account plus that of the foreign account at next round's exchange rate. The domestic component plus the remitted foreign component together comprise the profit of a firm. The round payoff of a firm is profit divided by total domestic expenditure, D or D*, respectively.

Determination of Firm account balances (see Table 2) if you are a Firm

- Home bank account

1) Wage payments and offers of home currency are deducted from your home bank account
2) If you have offered foreign currency you are credited on your home bank with the amount into which this converts into your home currency
3) This credit on your home bank account is multiplied up by the domestic interest factor
4) You are credited on your home bank account with the value of your sales (The determination of this value is described below)
5) The costs for domestic materials are deducted from your home bank account

Consequently, the final balance on your home bank account is

$Q_i q + r(X_i^* e - L_i w - X_i) - M_i m$

- *Foreign bank account*

1) If foreign currency is offered, the amount is deducted from your foreign bank account
2) If you have offered home currency, you are credited on your foreign bank account
3) This credit is multiplied up by the foreign interest factor.
4) The costs of foreign materials is deducted

Consequently the final balance on your foreign bank account is
$r^*(X_i e^* - X_i^*) - M_i^* m^*$

How sales are determined

The total amount produced is always sold. However, the sales price q depends on many factors. Normally the price q is total domestic expenditure divided by total domestic production, ie $q=D/Q$

In the case of a strike, demand is decreased, and the price is lower, $q=0.6(D/Q)$

Once more we want to direct your attention to the profit calculator. It facilitates your decisions by making all these computations for you. It computes the price resulting from your prediction, deducts variable cost per unit for labour and materials, and then computes your gross profits. The fixed labour costs for running firm are deducted from this. Since labour costs arise before interest is paid, the profit calculator also takes account of the opportunity costs arising thereby. In the fields of the table you can see your operating profit. This is *not* your payoff, but only the part of your profit due to your production decision.

Unions and employers' associations

If agreement is not reached in wage bargaining, then there is a strike and you receive no payoff in this round. If, however, you agree on a wage rate, then you receive the following payoffs.

Union

Your success is measured by the wage rate divided by the current target price. You receive $U=w/p$

Employers' association

Your success only indirectly depends on the wage rate. You receive the sum Π of profits in your country divided by the total expenditure, $V=\Pi/D$

Since the sum of profits will only be determined in the next round, you receive the payoff for this round in the next round.

Government and central bank

You pursue several goals including price stability and adequate employment. Your payoff function is as follows.

$$B = 5 - 4\left(\frac{p_+}{p}-1\right)^2 - 4\left(\frac{q}{p}-1\right)^2 - 4(r-1.05)^2 - 2\left(\frac{m}{em^*}-1\right)^2$$
$$- 2\left(\frac{e}{f}-1\right)^2 - .02\,|\,600 - L\,|_+ - .01\,|\,L - 720\,|_+$$

Here L denotes total labour demand in your country, ie labour demand of domestic firms for production purposes ($5*15+Q$) and the labour demand in the domestic materials industry ($M=Q+Q^*$).

The notation $|X-Y|_+$ has the following meaning

$$|X-Y|_+ = \begin{cases} X-Y & for\ x>0 \\ 0 & else \end{cases}$$

Your payoff is at its maximum if you attain all of your seven goals.

Final payoffs

After the end of the experiment you receive the sum of your points (your round payoffs) at a conversion factor depending on your role:

- as a government or central bank, you receive 1 Taler for 1 point
- as a union you receive 19.6875 Taler for 1 point
- as an employers' association you receive 50 Taler for 1 point
- as a firm you receive 250 Taler for 1 point

The number of Talers is then paid in EURO according to the following rule

Sum in Talers between	*Conversion into €*
0 and 60	x
60 and 100	$60 + 0.5\ (x - 60)$
100 and 200	$80 + 0.3\ (x - 100)$
200 and 300	$110 + 0.2\ (x - 200)$
over 300	$130 + 0.1\ (x - 300)$

You can always look at your decisions in the preceding rounds. You start in an already existing world and thus in round 2 and you can see how the world functioned in the preceding round, round 1. This look back serves to orient you with examples of decisions that you could encounter others taking, to reveal to you choices that you could take yourself, and to see what ensues (exchange rate, payoffs etc) from such a set of decisions. We now turn to a set of such decisions in the example below, and give you practice interpreting the decisions made in it by the governments, central bankers, employer and employee representatives and firms.

Table 1: Example

Explanations:

- / : not relevant here
- Values with * eg: If you are in Country *A*, then the *D* of Country *B* is *D** for you

		Land *A*	Land *B*
Values from the preceding round	Material price in the preceding round m_-	2.666664	3.733338
	actual target price p = that targetted for this round in the preceding round	10	14
g overnment	total expenditure *D*	2000	2800
central bank	interest rate *r*	1.05	1.05
	next period's target price p_+	10	14
	exchange rate aim *f*	0.71429	1.4
wage bargaining	Strike	no	no
	wage rate *w*	2.53968	3.55556
firm 1 as example	production decision Q_1	40	/
	home currency offer X_1	0	/
	foreign currency offer X_1*	0	/
firm decisions summed for the whole country	total home production	200	200
	total home currency offer	0	0
	total foreign currency offer	0	0
materials industry	demand for materials *M*	400	400
	materials price *m*	2.666664	3.733338
Markets	final exchange rate *e*	0.71429	1.4
	consumption goods price *q*	10	14
Payoffs	home bank account of firm 1	146.66692	/
	foreign bank account of firm 1	-149.33352	/
	payoff of firm 1 in this round if $e_+=e$	0.02	/
	union payoff	0.253968	/
	profit sum	200	/
	payoff of employers' association	0.1	/
	payoff of central bank	5	/
	payoff of the government	5	/

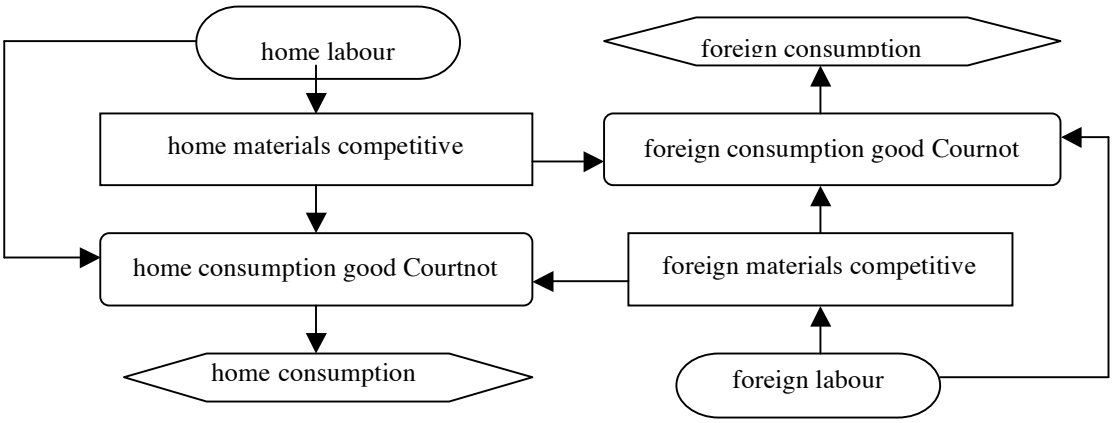
Table 2 : Development of Account Balances of Firm i

Home Bank Account	Foreign Bank Account
0	0
$-L_i w - X_i$	$-X_i^*$
$X_i^* e - L_i w - X_i$	$X_i e^* - X_i^*$
$r\,(\,X_i^*\, e - L_i\, w - X_i\,)$	$r^*\,(\,X_i e^* - X_i^*\,)$
$Q_i\, q + r\,(\,X_i^*\, e - L_i\, w - X_i\,)$	$r^*\,(\,X_i e^* - X_i^*\,)$
$Q_i q + r\,(\,X_i^* e - L_i w - X_i\,) - M_i m$	$r^*\,(\,X_i e^* - X_i^*\,) - M_i^* m^*$
0	0

4 Features of the Model

It may be useful to lay out explicitly key features implied by the instructions to participants. This version of Pope, Selten and Hagen (2003) was devised to yield insights on the adoption of the EURO. It has two countries, each with its own currency, symmetric in every respect as regards the real economy, and thus suggestive of say Italy and Germany. In each country there is: one government, one central bank, one union representative, one employer representative, and five firms, all of which buy local and imported materials produced under competitive conditions (and thus made by a vast number of firms not represented by players in our laboratory). These imported materials are used in fixed proportions to produce a homogenous final good sold in a Cournot market,[1] with nominal demand set by the government as per Figure 1.

Figure 1: Commodity Flows



As regards the financial side of real production, firms buy their imports on credit, and must pay for them only next period. They face fixed costs, must produce at least a minimum amount, and face a capacity constraint on the maximum that they can produce. They act as their own financial intermediaries in any hedging or speculating that they do in the current period, prior to its exchange rate being determined, and thus face uncertainty concerning both the current and the future exchange rate. Firm importing and hedging/speculative activity helps determine the exchange rate whenever the two central banks conflict on their exchange rate goals.

Central Bank Intervention

If they have identical exchange rate aims, the two central banks set the exchange rate. In the event of a conflict between the exchange rate aims of the two central banks, the amounts of each country's central bank intervention to attain its exchange rate target

[1] Field and empirical studies reveal that oligopolies with five or more participants have difficulty attaining systematic collusion, the lack of which, broadly speaking, characterises corporatist EURO bloc production. The EUC has been helpful in reducing the corporatist, collusive character of Europe over the past decades.

depends on its import or exports price. It automatically intervenes up to a set proportion, ζ_2, of its export price in the form of selling its own currency, if seeking to depreciate its currency against the wishes of the other central bank (termed a high aim conflict). It automatically intervenes up to a set proportion, ζ_1, of its import price in the form of buying the foreign currency, if seeking to appreciate its currency against the wishes of the other central bank (termed a low aim conflict).

Since countries have more limited scope to intervene in an effort to appreciate against the wishes of other central banks (this requiring foreign reserves) than in an effort to depreciate (this requiring them only to produce more of their own currency), $\zeta_1 > \zeta_2$. The actual exchange rate ensuing in these conflict situations is the ratio of offers made by both firms and central banks of each currency as long as this ratio is between the exchange rate aims of the two central banks. Otherwise, since the two central banks cooperate if it lies outside the exchange rate aim of either, the exchange rate is that of the nearest of these two exchange rate aims.

Official Sector Tasks and Instruments

In addition to the government setting nominal expenditure, the official sector, in the form of its central bank, sets its interest rate and announces its target price for the next period and its exchange rate aim. Thus between its government and central bank, a country's official sector has four instruments of macromanagement. In having only four instruments, it is, as in real life, under-instrumented for meeting goals. In having the official sector short on instruments, we offer reasonable scope for the popular view to be demonstrated that adding an exchange rate change instrument helps macro-management.

The goals are seven: 1) keeping prices steady; 2) meeting its price target; 3) keeping its ideal interest rate; 4) maintaining its ideal level of competitiveness in its cost structure relative to the other country; 5) meeting its exchange rate target, a goal absent in the one currency case; 6) avoiding unduly low employment; 7) avoiding unduly high employment. This latter goal is less important than underemployment, and accordingly is given less weight in the overall objective function. Although the decisions on instruments were allotted (as in most countries) either to the government or the central bank, the payoff was joint: both work for the national good, with penalties for the official sector deviating from each of its goals as in listed in Part 3 above.

Exchange Rate Targeting and Shocks

As in the 1961 Mundell model, central banks can target (manipulate) exchange rates so as to re-equilibrate the economy after shocks. But we shed fresh light on the issue by dropping the assumption of the existence of a single shock, or else (in models that extend Mundell) a set of shocks produced by a random generator and in each case external to the system, as it were from outer space. In such Mundellian models, the central bank knows perfectly the source of the shocks and exactly where the new equilibrium is. We replace these false assumptions about shocks and knowledge of the new equilibrium in our laboratory experiment, having instead all shocks generated by the domestic official and private sectors in the two countries. Thus in our laboratory set-up central banks and governments can be as fallible and error-prone as has been the Bank of England in its exchange rate policy according to Cobham (1994, 2002a, 2002b, 2006). In our laboratory set-up, firms as in real life can attempt to make a profit out of exchange rate dealings if they think that one country's central bank has adopted an untenable position as regards its joint choice of exchange rate aim and interest rate relative to the other central bank. Being also fallible, in our laboratory set-up, if firms misjudge the situation, they may lose funds on a grand scale (like Long Term Capital Management), or on a small scale (like some British universities with overseas campuses). Out of this mix of varied fallible moves by members of the private and public sectors in the two countries, our experiment offers a fresh perspective on whether central banks really are able to use the extra instrument of the exchange rate to improve macroeconomic management, to restore equilibrium.

The Private Sector

Each official sector announces to all in each country its decisions on aggregate nominal expenditure, on the interest rate and its target price for next period. In one treatment each official sector also announces its exchange rate target to all. This might lead to a moderation of exchange rate moves – to the exchange rate staying more toward the middle of the range between the two central bank goals. This could happen as often the interest rate incentive to shift funds will conflict with the exchange rate incentive indicated by the official sectors generating either smaller private capital flows or two-way counterbalancing flows.

In another less transparent treatment, exchange rate goal information is shared only with the other country's central bank. Here for the firms, the interest rate incentive is unconstrained by exchange rate information from the official sector. Thus private sector capital flows might more often tend to push the exchange rate largely toward the

extreme of one central bank's goal, and this might in turn accentuate exchange rate instability.

After each official sector has set its four instruments, and made all or three of these instruments available as public knowledge, private sector decisions commence. Firstly, in each country, the union and employer representative bargain over nominal wages. The union representative's payoff is real wages measured as nominal wages divided by the announced official sector target price, while that of the employer representative, is the profit sum of the firms. If an agreement is not reached after the set time allowed of 10 minutes, there is strike, with both negotiators receiving zero pay, a government set wage, and firms subject to a lower maximum production level and a cut in nominal demand relative to that announced by the government.

Once the wage rate (from bargaining or a strike) is announced for both countries, firms decide on output and on the amounts of a currency (home or foreign) to borrow in order to offer on the foreign exchange market in order to either hedge or speculate. The currency market then operates, setting the period's exchange rate, followed by the consumer market, determining the consumer price, followed by firms paying for last period's imported materials, and profits flowing to the firms' owners.

5 Equilibria with Utility Maximisers

This particular parameterisation for the central bank cooperation-conflict model of Pope, Selten and von Hagen (2003) is sufficiently complex that Reinhard Selten was unable to ascertain if it had a game theoretic equilibrium. He needed to construct a new concept of an incomplete equilibrium whereby branches that could not improve payoff are not investigated. Under plausible selection criteria, the incomplete equilibrium that is symmetric a regards the real economy is, he demonstrated unique, and could be a reasonably traditional economic modelling benchmark.

The need for a new equilibrium concept to derive a closed form solution and the deployment of selection criteria puts an element of comedy into equilibrating claims for exchange rates. The economist's notion of an exchange rate equilibrium is close to empirically empty when that economist can only discern it by ignoring issues 1 to 3, namely ignoring the market power of co-operating central banks, ignoring the multiple and distinct goals of distinct agents, and ignoring the market power of key private sector players. Once we as economists exclude so-called rational expectations (that irrationally ignore these matters of market power), we need the new incomplete equilibrium concept. We need more than that to have the equilibrium unique. We need also plausible, but not altogether uncontroversial, selection criteria to render the

symmetric equilibrium unique. We need all these in a model that, even if complex, is far simpler than reality.

When we inspect this equilibrium's features, we find that once in an equilibrium, for utility maximisers, the equilibrium never changes, and the equilibrium involves keeping the exchange rate fixed, indicating no need for multiple currencies, as also no harm from having them either. There are no disequilibrating shocks. It might be objected that this is simply because our model lacks exogenous shocks. Indeed this is the case. The only scope for shocks in our model comes from people. Utility maximisers however create no shocks.

Let us then ask how to connect our model to the real world. Let us connect it to the shocks of the 1980s when Reagan's military expenditures and tax cuts for the wealthy combined with Volcker's tight monetary policy coincided with an unanticipated doubling of the US dollar. Let us connect our model also to the shocks of the drop in the US dollar vis-a-vis the EURO in the wake of the subprime crisis of 1997. Two examples suffice. According to version 1, our model could not occur. Utility maximisers make none of the mistakes of people of the 1980s or of 2007.

To incorporate these shocks it might be thought that we need traditional models. But these real world shocks are patently caused by people's decisions, not by the meteors from outer space and other forms of random shock conventionally modelled. To incorporate the stylised fact that virtually all shocks to the exchange rates among developed countries are caused by people, we need version 2 of our model. We need to incorporate its features 5 to 7 that allow for individual personalities, their heuristics, their group dynamics and their mistakes. These are far too unknown and multitudinous for us to explicitly model. We get a fresh handle on them from our experimental results.

6 Non-Maximisers Causing Shocks Render Equilibrium Unspecified

Our participants were started in the symmetric equilibrium. The particular parameterisation for the central bank cooperation-conflict model of Pope, Selten and von Hagen (2003) employed in the experimental set-up is so simplistic that in this symmetric incomplete equilibrium, both consumer goods purchasing power parity and interest parity hold, whereas even in any reasonably realistic and complex neoclassical model, neither are predicted to hold in. Our participants thus were introduced to our experimental set-up displaying the simplistic features of an equilibrium exchange rate that conformed to both purchasing power parity and to interest parity.

Nevertheless, unlike the hypothetical utility maximisers of Part 5, our participants did not discern that they had started in equilibrium. Despite its unrealistic simplifications, our experimental set-up was so complex that there is no evidence of participants better discerning equilibria, their optima, by the 20th round either. Indeed by the 20th round, with the wild deviations of government fiscal policy from what would be equilibrium fiscal policy, the equilibrium exchange rate is not even specified. This is rather as in the external world where private speculators and central banks alike exhibit little that is discernible as learning where an equilibrium is, or even whether an equilibrium is specified. Today, despite 35 plus years of experience with floats, as when Bretton Woods dissolved in the early 1970s, private and public sector agents alike express puzzlement at unanticipated exchange rate changes.

Table 1 of Part 4 above on which participants learned the set-up for an hour and fifteen minutes, and which pertains at the start of round 1, is the equilibrium. In equilibrium, expectations are fulfilled. Thus the consumer goods actual price must be for countries *A* and *B* respectively p and p^* , ie the consumer price level announced by the central bank as its target for this round in the preceding round. Fiscal policy sets *D* and *D**, respectively the nominal demand in countries *A* and *B*, and thereby influences the *actual* consumer price level pertaining in each country. In each country the government announces it fiscal policy prior to the central banks setting their exchange rate aims. Hence for the equilibrium exchange rate to be specified, let alone selected as the aim of both central banks, fiscal policy in each round in both countries must be selected to be compatible with its country's already in the prior round announced central bank's target price, respectively p and p^* .

For round 1, for countries *A* and *B* respectively P=10 and p^* =14 are as given in Table 1 above, as are the equilibrium values for fiscal policy of D and D*. These are respectively, D=200P=2,000 and D*=200p^* =2,800. In round 1, only two of the sessions had a pair of governments that chose these equilibrium fiscal policy values. The degree of deviation from equilibrium of the government in country B in session 1 was 79%. The average deviation from the equilibrium fiscal policy in round 1 over all sessions was 12%. Thus in the entire 9 sessions, only two, sessions 7 and 8, had pairs of governments that set equilibrium values for their fiscal policies, and thereby allow the equilibrium exchange rate to be specified. For the other sessions, no action of central banks can be classified as equilibrating or non-equilibrating. See Table 3.

Table 3
Fiscal Policy Choices *D* and *D** of Governments in Countries *A* and *B* in Round 1
(each stated in own currency)

	Country A			*Country B*			
Session	*Actual D*	*Equilibrium D=200p and p is 10*	*Deviation of D from its Equilibrium*	*Actual D**	*Equilibrium D*=200p* and P* is 14*	*Deviation of D* from its Equilibrium*	*Average Absolute Deviation from equilibrium*
1	2000	2000	0.00%	600	2800	-78.57%	39.29%
2	1990	2000	-0.50%	2800	2800	0.00%	0.25%
3	2050	2000	2.50%	2850	2800	1.79%	2.14%
4	1000	2000	-50.00%	2820	2800	0.71%	25.36%
5	2100	2000	5.00%	2750	2800	-1.79%	3.39%
6	2200	2000	10.00%	2000	2800	-28.57%	19.29%
7	2000	2000	0.00%	2800	2800	0.00%	0.00%
8	2000	2000	0.00%	2800	2800	0.00%	0.00%
9	1500	2000	-25.00%	2400	2800	-14.29%	19.64%
Overall Average	1871	2000	-6.4%	2424	2800	-13.4%	12.2%

As regards the exchange rate, in equilibrium, purchasing power parity holds for consumer goods, and interest parity also holds. From Table 4, for country A, the equilibrium purchasing power parity choice of a value for *f*, its exchange rate aim, where specified by compatible fiscal policy, is, p/p^*=0.71429 as regards the number of units of its own currency needed to buy a unit of country B's currency. For country B the equilibrium value of its exchange rate aim *f**, where specified, is its reciprocal. But in sessions 7 and 8, for whom the equilibrating choice of exchange rate aim is specified, the central banks chose non-equilibrium exchange rate aims. The exchange rate aims in sessions 7 and 8 are incompatible with both consumer goods purchasing power parity in equilibrium, and interest parity in equilibrium. Table 4 details their deviations from the purchasing power equilibrium exchange rate aim. It also details the deviations of the other sessions from what their central banks should have chosen – had equilibrium been specified. The average absolute deviation from p/p^*in this first round was 15%.

Each of the 9 sessions contained different participants and so constituted one independent observation, as regards computing significance. Our nine independent sessions each of 20 periods means that we have a huge advantage over field data with its time series and cross sectional interdependencies. Our field data stem from a single world and a single history, rendering it tricky, to say the least, to decode the effects of shocks. Our nine independent sessions, nine world histories thus permit us insights into what is unique in actual world history, namely the role of individual personalities resulting in different heuristics used to cope with a complex situation.

Table 4
Central Bank Exchange Rate Aims in Round 1

Session	*f Exchange Rate Aim of Country A*	*1/f* Exchange Rate Aim of Country B*	*Deviation of Country A from p/p* of 0.71429*	*Deviation of Country B from p/p* of 0.71429*	*Absolute Average Deviation from p/p**
1	1.000	0.667	40.00%	-6.67%	23.33%
2	0.800	0.714	12.00%	0.00%	6.00%
3	0.750	1.250	5.00%	75.00%	40.00%
4	0.900	0.714	26.00%	0.00%	13.00%
5	0.850	1.000	19.00%	40.00%	29.50%
6	0.720	0.714	0.80%	0.00%	0.40%
7	0.720	0.714	0.80%	0.00%	0.40%
8	0.850	0.833	19.00%	16.67%	17.83%
9	0.705	0.714	-1.30%	0.00%	0.65%
Overall Average	0.811	0.813	13.50%	13.90%	14.57%

In Table 4, it can be seen that the inter-session divergence from purchasing power parity was marked, from under nil to a massive 75%, indicating how crucial personality and group dynamic influences are. Nothing else differs in each session. In each session for each agent in a given role, there is the identical institutional and economic set-up and each has an identical utility function. Under traditional modelling their choices ought be identical. Econometrics, limited by a single world history, cannot discern what is here discerned, namely the extreme impact of personalities on choices made when the situation is too complex for anyone to engage in the maximising calculations posited in traditional neoclassical and game theoretic models.

A round is the above sequence of decisions and their outcomes played by both the official and private sectors. A round was played by the same participants 20 times, with a lunch break, typically after the 8th period. By round 20, governments in countries *A* and *B* have had 19 prior periods in which to learn to set their equilibrium fiscal policy at 200*p* and 200*p** respectively, where *p* and *p** are as announced by their country's central bank for round 20 in prior round 19. Table 5 reveals that by round 20, divergence of their fiscal policy decisions from equilibrium had become more widespread and on average nearly twice as marked as in round 1. The average absolute deviation had risen from 12 to 20%.

For not a single session did a pair of governments select equilibrium fiscal policies. Thus for not a single session is the equilibrium exchange rate even specified. In session 1, this deviation was extreme, over 100%. Only in one session, session 11, was the deviation from equilibrium modest.

Table 5
Fiscal Policy Choices of Governments in Round 20

Session	*P*	*Actual D*	*Equili-brium D=200P*	*Deviation of D from its Equilibrium*	*p**	*Actual D**	*Equili brium D*= 200p**	*Deviation of D* from its Equilibrium*	*Average Absolute Deviation from equilibrium*
1	7	3750	1400	167.86%	10.5	3350	2100	59.52%	113.69%
2	12.3	2700	2450	10.20%	12.5	2850	2500	14.00%	12.10%
3	10.3	2100	2060	1.94%	12.5	2850	2500	14.00%	7.97%
4	16	3000	3200	-6.25%	16.0	3000	3200	-6.25%	6.25%
5	10.8	2150	2160	-0.46%	13.0	2572	2600	-1.08%	0.77%
6	11.2	2500	2240	11.61%	11.5	2300	2300	0.00%	5.80%
7	10.6	2400	2120	13.21%	15.4	3500	3080	13.64%	13.42%
8	14.5	3000	2900	3.45%	19.0	2700	3800	-28.95%	16.20%
9	12.1	2100	2420	-13.22%	11.5	2200	2300	-4.35%	8.79%
Overall Average	11.6	2633	2328	20.90%	13.5	2814	2709	6.70%	20.60%

Table 5 reveals that by round 20, there was not a single session for which the equilibirum exchange rate was specified. By round 20 also, deviation from that indicated by purchasing power parity in the form of $p/p^*$was about as marked for every session. The sessional average deviation from p/p^*had fallen only from 12% to 11%. The minimum deviation had more than doubled, from 0.4% to over 1%, and the maximum deviation had risen a little, from under 24% to over 27%. See Table 6.

Table 6: Central Bank Deviations from p/p^* in Round 20

session	*Exchange rate aim f of country A*	*Exchange rate aim 1/f* of country B*	p/p^{**}	*Deviation of Country A from p/p**	*Deviation of Country B from p/p**	*Absolute Average Deviation from p/p**
1	0.900	0.833	0.6667	35.00%	25.00%	30.00%
2	0.850	0.909	0.9800	-13.27%	-7.24%	10.25%
3	0.900	0.833	0.8240	9.22%	1.13%	5.18%
4	0.889	0.879	1.0000	-11.10%	-12.13%	11.61%
5	0.840	0.840	0.8308	1.11%	1.15%	1.13%
6	0.992	0.992	0.9739	1.86%	1.86%	1.86%
7	0.720	0.720	0.6883	4.60%	4.67%	4.64%
8	1.200	0.714	0.7632	57.24%	-6.40%	31.82%
9	1.100	1.000	1.0522	4.55%	-4.96%	4.75%
overall average	0.932	0.858	0.864	9.90%	0.34%	11.25%

7 Non-Maximisers Causing Shocks in the Form of Central Bank Conflicts

Since the ratio $1/f^*$ transforms country B's central bank aim into comparable currency units to those of the exchange rate aim announced by country A, were there no conflict in exchange rate aim, this inverse would be equal to f, the exchange rate aim of country A's central bank. But in failing to maintain the equilibrium exchange rate goal in the first round, Table 7 shows that in every one of the nine sessions, conflict occurred right at the beginning, in round one, between the exchange rate aims of the pair of cental banks. The overall average level of conflict was in the range of 16-17%. The degree of conflict varied markedly, from under 1% to over 66%. The institutional and economic set-up and the utilities for agents in each role were identical across sessions. The explanation thus for these differential degrees of conflict lies in differences in individual heuristics and in the group dynamics engendered in complex situations. None of the conflict, and hence also none of the variation in degree of conflict, is explicable with standard modelling.

Table 7: Central Bank Exchange Rate Conflicts in Round 1

Session	*f Exchange Rate Aim of Country A*	$1/f^*$ Inverse of *Exchange Rate Aim of Country B*	The Extent of Conflict from the viewpoint of Country A $\lvert f-(1/f^*)\,f\rvert/$	The Extent of Conflict from the viewpoint of Country B $\lvert f-(1/f^*)\rvert/(1/f^*)$
1	1.000	0.667	33.33%	50.00%
2	0.800	0.714	10.71%	12.00%
3	0.750	1.250	66.67%	40.00%
4	0.900	0.714	20.63%	26.00%
5	0.850	1.000	17.65%	15.00%
6	0.720	0.714	0.79%	0.80%
7	0.720	0.714	0.79%	0.80%
8	0.850	0.833	1.96%	2.00%
9	0.705	0.714	1.32%	1.30%
Overall Average	0.811	0.813	17.1%	16.43%

By round 20, central bankers have had 19 prior periods in which to learn form each other, from their governments and from the behaviour of the private sector in response to their exchange rate aim decisions. Table 8 shows that by round 20, divergence of central bank aims from equilibrium was more marked for every session. The sessional average deviation from equilibrium had risen from 12% to 23%. The minimum deviation had more than doubled, from 0.4% to over 0.8%, and the maximum deviation had risen from under 24% to over 41%. By round 20, the degree of conflict between central banks had abated in most sessions, and was down on average from over 19% to now just over 11%. However 11% is still substantial, and in one session, conflict had escalated to 68%.

Table 8: Central Bank Conflict in Round 20

session	*f Exchange Rate Aim of Country A*	*1/f* Inverse of Exchange Rate Aim of Country B*	*The Extent of Conflict from the viewpoint of Country* A (*f*-1/*f**)/*f*	*The Extent of Conflict from the viewpoint of Country B* (*f*-1/*f**)/(1/*f**)
1	0.900	0.833	7.41%	8.00%
2	0.850	0.909	6.95%	6.50%
3	0.900	0.833	7.41%	8.00%
4	0.889	0.879	1.15%	1.17%
5	0.840	0.840	0.04%	0.04%
6	0.992	0.992	0.01%	0.01%
7	0.720	0.720	0.06%	0.06%
8	1.200	0.714	40.48%	68.00%
9	1.100	1.000	9.09%	10.00%
overall average	0.932	0.858	8.1%	11.3%

Note that each country's exchange rate is expressed as the number of domestic currency units required to purchase a unit of the other country's currency, and hence that in equilibrium, each country's central bank goal is the reciprocal of that of the other central bank's equilibrium exchange rate, and thus that in the absence of conflict, $1/f^* = f$.

In short, Table 7 reveals that central bankers often became more cooperative with repeat interaction. By round 20, the results also reinforce the findings of round one, that individual differences matter. By round 20 it is evident that group dynamics serve to reinforce, not eliminate, the central role of individuals and their idiosyncratic heuristics for dealing with complexity. The average degree of conflict in exchange rate aim in this first period was 20%. The inter-session variation in degree of conflict was extreme, from 0.8% up to nearly 67%, again indicating the crucial role of individual personalities resulting in different heuristics used to cope with a complex situation.

Conflict between central banks was not merely the norm in the opening and closing rounds, but throughout, as can be seen from Table 8.

Table 8: Overview of Conflicts in Central Bank Aims During the Entire 20 Rounds

Session	*Rounds in which there was a Conflict*		*Rounds in which there was Equilibrium*	
	total number	*% of all rounds*	*total number*	*% of all rounds*
1	18	90.00	0	0.00
2	20	100.00	0	0.00
3	20	100.00	0	0.00
4	20	100.00	0	0.00
5	20	100.00	0	0.00
6	20	100.00	1	5.00
7	14	70.00	0	0.00
8	20	100.00	0	0.00
9	12	60.00	1	5.00
overall average	18	90.00	0.222	0.011

The findings of Tables 2-8 endorse the need to shift to models like that of Pope, Selten and von Hagen (2003) in putting in the forefront, the role of central bank cooperation and conflict together that of the personalities of those in key roles of private and public sector market power. It is inappropriate as at present to ignore the *non*-equilibrating conflict-cooperation strategies of central bankers in analysing exchange rate determination.

The findings of Tables 2-8 do not imply, however, that firms are irrelevant to the exchange rate derived for the particular parameterisation of the central bank conflict-cooperation model of Pope, Selten and von Hagen here investigated. To the contrary, the more conflict there is between central banks, as in reality, the more scope there is for firms' investment (hedging and speculative) activity – together with their payments for goods – to influence the exchange rate outcome. The extent to which the firms in total press with their exchange rate offers toward the direction of one of the two conflicted central banks determines the final exchange rate.

Where firms' joint capital and current account activities do not too markedly favour the aims of one or other of the two conflicted aims of the central banks, the resultant exchange lies *between* the conflicted aims of the central banks. Such a situation was however infrequent. The firms however generated one *between* these two aims on average only a bit under 12% of the time. In every session, the norm was for the firms' joint capital and current account activities to markedly pressure for an exchange rate in the direction of one of the two centrals banks. This uneven exchange rate supply and demand pressure of the private sector was extremely uneven. It was so uneven that, without further central bank response, it would have pushed the exchange rate further from the exchange rate aim of that central bank not supported by the speculators than even was the aim of the central bank being endorsed by this private sector pressure. See Table 10.

Table 10: Firm Influence on the Exchange Rate

Session	*Rounds in which Firms Generate a Compromise Exchange Rate between the Conflicted Central Banks*	
	total number of rounds	*% of rounds*
1	2	10.00
2	3	15.00
3	2	10.00
4	2	10.00
5	2	10.00
6	1	5.00
7	1	5.00
8	7	35.00
9	1	5.00
overall average	2.333	0.117

The exchange rate in such circumstances was only kept to that of the central bank whose aim was more in line with that of the private sector pressure by *additional cooperative action of the pair of central banks*. Again, recall the legal power of central banks to print their own currency and offer it on the exchange market. In turn this implication that no private speculator has the power to countermand such joint cooperative central bank intervention.

In the central bank cooperation/conflict model of Pope, Selten and von Hagen (2003) here experimentally investigated for a particular parameterisation, this logical implication of powers of central banks to print their own currencies is honoured. Prior models have focussed on the media advertised role of the private sector, and been swayed by Friedman's accounts in which the central banks can be ignored. In reality, by contrast the private sector matters, but only to the extent of whether the resultant exchange rate is in the compromise range of the two central banks' aims, or at a boundary, the aim of one of that pair of central banks.

Our experimental results thus serve to highlight the crucial but overlooked matter of central bank cooperation and conflict. They serve also to delineate the extreme difficulties in modelling this in a manner to yield predictions. The differences among sessions underscore the necessity of knowing fine details of the heuristics of different personalities and group dynamics.

This application of the Pope, Selten and von Hagen (2003) model to an investigation of central bank behaviour tells decisively against equilibrating maximising modelling of central bank behaviour. As central bankers humbly report in reality, they do not use maximising decisions, and as our results show when equilibria are beyond human capacity, central bankers do not somehow miraculously manage to drive the exchange rates into equilibria. Our results concerning central bank behaviour suggest that central bankers can increase their cooperation over time so long as the set of personalities in the private and public sector stays constant, but not in an equilibrating direction, and only to a moderate degree. But of course in reality, there is a flux of public and private sector personnel so that our findings of increasing cooperation over time cannot be taken to be the norm in the external world, only a possibility that is occasionally realised (as happened in the middle 1980s).

A single world money avoids the shocks caused by the disequilibrating actions of central bankers – and the international conflicts that arise from the typical situation, central banks with conflicting aims. The year of writing up these results, 2007, is in this sense representative with the acute conflict at present in exchange rate aims of the People's Bank of China and those of other key developed country currencies.

Advocates of a single world money include Mundell, not only in his writings of this millennium, eg Mundell (2003), but also back in Mundell (1961), and others such as Bonpasse (2006).

8 Other Applications of the model

The experimental data garnered has also shed light on other issues. One set of issues concern firm behaviour in the face of exchange rate uncertainty, Kaiser and Kube (2005, forthcoming). A second set of issues concern how official sectors had significantly more success in maintaining international competitiveness with a currency union, and better overall success in their macromanagement, Pope, Selten, Kube and von Hagen (forthcoming). Yet other issues concern the benefits of stable fiscal policy, the benefits of a transparent exchange rate policy, the benefits of dirty over dirty floats, and on the role of prominent numbers and individuals in exchange rate determination, Pope, Selten, Kaiser, Kube and von Hagen (2006a, 2006b, 2007, 2007b), Pope, Selten, Kaiser and von Hagen (2006). An array of sources of evidence, including several from our experiments, are collected together in Pope, Selten and von Hagen (2007) to delineate how omission of complexity effects have beguiled economists into seeing exchange rate changes as equilibrating.

More generally, complexity effects indicate the value of modelling, as in this paper's model, within the umbrella of SKAT, the Stages of Knowledge Ahead Theory of Pope 1996/7 and Pope, Leitner and Leopold-Wildburger (2007). Complexity renders non-trivial the various stages through which a chooser progresses before the risk and uncertainty is resolved. In this paper's model and experimental set-up, the focus is on the evaluation stage before reaching a decision. The difficulties of evaluating and reaching a good decision in a complex world made even more complex by variable exchange rates result in better macro-management without variable exchange rates. The difficulties in modelling how people generate shocks through their idiosyncratic heuristics and mistakes in the evaluation stage is part of the reason for economists mis-modelling shocks as simpler in origin – and in the process misconstruing exchange rates as equilibrating.

The purpose of putting this model into the public arena is to introduce readers to a new perspective on exchange rate determination and encourage them to use this new tool to investigate exchange rate issues with the model as is. Researchers can modify the basic model prior to experimental use in order to test parameter sensitivity or variations in the exchange rate regime by enlarging or contracting the set of official sector objectives, or also by altering the degree of official sector transparency, ease, or difficulty of official sector cooperation or private sector collusion, and so forth. Banks

can use it as a bank game for assessing exchange rate effects. Banks and universities can also use it as an instruction tool in helping participants to get a handle on the complex world of variable exchange rates. Control experiments with only a single central bank assist in delineating events without variable exchange rates and their attendant uncertainties.

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