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A MODEL OF CURRENCY EXCHANGE RATES

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ABSTRACT

A volume-independent model for currency-exchange rates in international business gaming simulations is presented that is shown to be stable, simple, and fair. Based on foreign holdings of money, the model pegs exchange rates to allow for currency speculation. The effect of international trade, deposits, loans, and investments are discussed. Proof is given that the model is self limiting and risk compensating. Situations for which the model is more or less suitable are discussed. The purpose of the model, not it correspondence with a particular reality, was the driving concern in its development.

INTRODUCTION

With the adoption of a common currency among most members of the European Union, we are in a time when several different nations share a common monetary unit. This exception circumstance, however, stands out from the rule that a nation must have its own currency. The rule remains important. An international business gaming simulation that respects the rule must allow each represented nation to have its own money. The problem then arises as to how the currency-exchange process should be represented in such gaming simulations.

Processes can be represented in a simulation either by gaming them or by modeling them (Thavikulwat, 1995, 1997). When gamed, the gamed process is a subset of its everyday world counterpart; when modeled, it is a reflection. To game currency exchanges, participants would swap currencies directly with each other on a free-market basis; to model them, participants would buy and sell to a mechanistic entity under terms set by that entity. The gamed process is computer assisted, as distinguished from computer directed, computer based, or computer controlled (Crookall, Martin, Sunders, & Coote, 1986); "in terms of learning possibilities, the [computer-assisted simulation] will have greater scope and potential than other types when social and socially mediated processes and skills are seen as important learning outcomes, [because it leaves] basic interactions . . . between people, and control of important events . . . in the hands of participants, with the computer peripheral to the social situation" (p. 370).

Despite its pedagogical advantages, the gamed process is vulnerable to misunderstandings, antagonisms, and conspiracies among participants that can damage reputations (Jones, 1998) and sidetrack pedagogical objectives (Thavikulwat, 1995). In situations where the process is required for completeness but not itself central to the gaming simulation, a modeled representation may suffice.

This article discusses a modeled representation of the currency exchange process. Criteria for a suitable model are discussed, and the characteristics of the proposed model are explicated.

LITERATURE REVIEW

The literature on gaming simulations is devoid of discussions of exchange-rate models, although an extensive literature exists on models of product demand (Carvalho, 1991, 1992, 1993, 1995; Decker, LaBarrre, & Adler, 1987; Frazer, 1983; Golden, 1987; Gold & Pray, 1984, 1990, 1995, 1998; Goosen & Kusel, 1993; Lambert & Lambert, 1988; Patz, 1993; Teach, 1990; Thavikulwat, 1989, 1991). Within this literature, Gold and Pray's (1984, 1990) exponential model has been shown to be especially stable. Like many other product-demand models, it computes a demand, given prices, promotion, and other product characteristics.

With respect to money, however, the dependent variable is not the demand for it, but the price of it. Moreover, whereas demand is generally a function of factors that a company controls, the price of money is influenced by the uncoordinated actions of all parties, but generally uncontrollable by any one party. Thus, the problem of constructing a model of the currency-exchange process is one of designing an algorithm that derives a price given independent variables that account for the activities of all parties without allowing any party, individually or collectively, to control results.

The problem is made more difficult if exchange rates must be adjustably pegged. Adjustably pegged exchange rates are common in the everyday world. They eliminate small changes in currency prices, at the risk of large changes when the true value of a nation's currency diverges excessively from its pegged price. They allow currency speculators to make substantial gains when rates are adjusted in response to economic forces.

An exchange model that allows participants to make speculative gains must, however, limit the gains that can be made. Actions taken by participants to realize speculative gains should lead to a stable equilibrium wherein further speculative gains are unavailable. The model that will be presented meets this self-limiting requirement, as will be demonstrated.

Moreover, the model presented herein will be shown to be volume-independent and risk-compensating. A volume-independent exchange rate algorithm gives the same exchange rate irrespective of the amount of money a participant may exchange in a single transaction. The extent to which volume independence may be realistic in an everyday-world sense is arguable, but it certainly simplifies the presentation to participants. A risk-compensating algorithm allows greater gains for participants who take greater risks, a characteristic that defines an efficient market. Without it, the knowledgeable participant would have no reason to take risky actions. Before presenting the complete model, however, a simpler subset will be discussed to show why the more complex representation is needed.

MONEY EXCHANGER MODEL

Consider a model that prices money according to the relative quantities held by money exchangers, which shall be called the money exchanger model. In this setting, money is priced in inverse proportion to the quantities of each that the money exchange system holds. Thus, if the system possesses \$2 million and £1 million, then the dollar is priced at half a pound, in other words, the exchange rate is \$2 to £1. The formula is as follows:

$$X_{A,B} = \frac{Q_A}{Q_B} \qquad (1)$$

where

$X_{A,B}$: Exchange rate of Nation A's (e.g., \$) currency for Nation B's (e.g., £)[1]

Q_A: Quantity of A's money held by the money exchange system

Q_B: Quantity of B's money held by the money exchange system

Trade

The money exchanger model adjusts exchange rates such as to create incentives towards trade equilibrium, consistent with the classical arguments of Hume (1752/1985). When trade takes place between nations, the importer gives the exchanger the importer's money for the goods received, whereas the exporter takes from the exchanger the exporter's money for the goods delivered. As a result, the money exchange system will hold more of the importer's money and less of the exporter's, giving rise to an adjustment of the exchange rate in the exporting na-

[1] For a mnomenic, think of A as America and B as Britain. Thus, Nation A's currency is the dollar; Nation B's, the pound. This correspondence is used in all the examples that follow.

tion's favor. Thus, if the money exchange system initially held \$10 million and £5 million, for an exchange rate of \$2 to £1, the export of \$2 million dollars worth of products by Nation A to Nation B causes the system to disburse \$2 million to the exporter and receive £1 million from the importer, resulting in a new balance of \$8 million and £6 million, for a new exchange rate of about \$1.3 to £1. With the dollar having risen relative to the pound, Nation B's products become less expensive relative to Nation A's, creating a favorable condition for Nation A to import more from, and export less to, Nation B, thereby returning to equilibrium.

Incorporating initial balances and trade formally into the model means that Q, the quantity of a nation's money held by the money exchange system, is defined as follows:

$$Q = \text{Initial Balance} + \text{Imports} - \text{Exports} \qquad (2)$$

Speculation

The money exchange model is vulnerable to speculative attack. For example, assume the money exchanger has on hand \$10 million and £5 million. Assume also that a money-speculating participant has \$2 million with which to buy £1 million, at the prevailing exchange rate of \$2 to £1. Following the purchase, the money exchanger will have \$12 million and £4 million, giving rise to the new exchange rate of \$3 to £1. The participant can now return the £1 million to the money exchanger for \$3 million, thus realizing a gain of \$1 million on the two transactions. The money exchanger is left with \$9 million and £5 million. The participant gains, the money exchanger loses, and the cycle can be repeated until the money exchanger is out of dollars. Clearly, the model is unstable.

The instability of the model can be resolved either by varying the exchange rate depending upon the amount of money the participant wishes to exchange, or by expanding the scope of what is include in the exchange rate computation. Varying the rate, however, would complicate the presentation to participants and misdirect their attention to the model per se. Expanding the scope resolves the problem by taking account money's unusual character, as an intangible created and destroyed by central and commercial banks at virtually no cost an in virtually no time. This approach directs participant's attention appropriately to money's inherent character. It will be discussed next.

FOREIGN HOLDINGS MODEL

Consider a model that prices money according to the relative quantities held by foreigners,[2] including money exchangers, currency speculators, and banks, which shall be called the foreign holdings model. Following the form of the previous model, money is priced in inverse proportion to the quantity owned by foreigners, including also the money that the banking system itself creates and destroys in the course of business. The pricing formula thus becomes:

$$X_{A,B} = \frac{F_A}{F_B} \qquad (3)$$

where

$X_{A,B}$: Exchange rate of Nation A's currency for Nation B's

F_A: Quantity of A's money (e.g., \$) owned, without encumbrance, by foreigners

[2] In this context, a foreigner is defined operationally, rather than legalistically, as any party that deals in foreign currencies. Thus, all money exchangers, currency speculators, and banks that accept and remit international currencies are foreigners. The model does not account for money in local hands because those monies are considered not readily available for international exchange. In other words, foreign money is hot; local money, cold. The model considers only hot money.

F_B: Quantity of B's money (e.g., £) owned, without encumbrance, by foreigners

Although identical in form to the previous one, this equation's greater comprehensiveness gives rise to different consequences.

Deposits

For the example above, the Nation-A participant who presents \$2 million in exchange for £1 million would transfer \$2 million from a local bank to a foreign bank, and receive from the foreign bank a demand deposit account of £1 million, which is money the foreign bank creates[3] in response. If before the transaction, the exchange rate of \$2 to £1 was based on foreign ownership of \$10 million (F_A) and £5 million (F_B), then after the transaction, first, foreign ownership of dollars will have risen to \$12 million, because the foreign bank now owns the \$2 million that had belonged to the participant, and second, foreign ownership of pounds will have risen to £6 million, because the foreign bank created £1 million that the participant, a foreigner with respect to pounds, now owns. As a result, the exchange rate remains constant at \$2 to £1, F_A being \$12 million and F_B, £6 million. Because the rate is unchanged, the participant cannot gain by reversing the transaction, but because the deposit raises foreign ownership of both nation's money, the value of both falls relative to that of other nations.

Loans

If participants can have foreign-currency deposits, then they also should be able to have foreign-currency loans. Reworking the example above, the Nation-A participant borrowing £1 million and selling them in exchange for dollars will receive \$2 million at the exchange rate of \$2 to £1, given initial foreign holdings of \$10 million (F_A) and £5 million (F_B). With the \$2 million deposited in a local bank, foreign holdings in dollars after the transaction will fall to \$8 million. Foreign holdings in pounds depends on what the loan covenant encumbers. If it encumbers exactly the £1 million borrowed, then the encumberance sets aside £1 million in foreign holdings, because that amount loses its availability as exchangeable money so long as the loan remains open. Thus, foreign holdings after the transaction will be \$8 million and £4 million, giving rise to the exchange rate of \$2 to £1, what it was prior to the transaction.

If the loan encumbers only £0.8 million, the £0.2 million difference has the character of a gift, and should therefore be treated as such. The post-transaction foreign holdings will be \$8 million and £4.2 million, giving rise to the exchange rate of about \$1.9 to £1. The dollar rises in value against the pound. On the other hand, if the loan encumbers more than the loan amount, the difference is an expropriation that would cause the dollar to fall against the pound.

Although the effect of a loan on exchange rates depends upon the loan covenant, if the average loan encumbers the average loan amount, then like international deposits, international loans do not affect the money exchange rate between the nations involved. Mirroring deposits, loans lower foreign ownership of both nation's money, thereby causing their values to rise relative to those of other nations.

Investments

A foreign investment occurs when a participant of one nation buys transferable assets located in another, such as real estate, drilling rights, and stocks. To make the purchase, the investor exchanges local currency for foreign currency, causing the money exchanger to hold more of the subject nation's money and less of the target nation's. The investment appears to have the same monetary effect as an import, except that ownership of transferable assets permits the investor to reverse the exchange at any time, for more or

[3] Money is created because a demand-deposit bank account is money.

less as the case may be. Essentially, that asset is a wildcard. If the average investment is the monetary equivalent of the average amount of money used to acquire it, then the investing nation got as much as it gave up and the disinvesting nation gave up as much as it got, with no consequential effect on exchange rates.

Extended Definition

Incorporating deposits, loans, and related considerations formally into the model means extending the definition of F (Equation 3) beyond that of Q (Equation 2), as follows:

$$F = IB - CB + (DA + FD) - (LA + FL) + (IA - VB) - (FI - VS) \tag{4}$$

where

- IB: Initial Balance
- CB: Current Balance (Exports – Imports + Foreigner's Gifts + Our Expropriations of Foreigner's Assets – Gifts Sent Abroad – Foreigner's Expropriations of Our Assets)
- DA: Deposits placed abroad by our nationals in foreign currencies
- FD: Foreigner's deposits in our nation's currency
- LA: Loans from abroad, denominated in foreign currency
- FL: Foreigner's loans, issued in our nation's currency
- IA: Investments abroad
- VB: Value bought with investments abroad
- FI: Foreigner's investments
- VS: Value sold for foreigner's investments

Thus far, the examples discussed assume that actual exchange rates coincide with true currency values, as derived by the model. When exchange rates are adjustably pegged, rates and values generally will diverge. An algorithm for adjustably pegging exchange rates is discussed next, followed by a discussion of deposits and loans under the circumstance.

ADJUSTABLE PEGGING ALGORITHM

Adjustably pegging an exchange rate means allowing it a range within which the underlying true value may sit without changing the actual pegged rate of exchange. For consistency and to avoid the occasion for arbitrage, the endpoints of each range must not depend on how the rate is quoted, for example, as dollars per pound or pounds per dollar. This condition is not met, however, when the pegged rate is arithmetically centered within each range. For example, if the range is \$1.5 to \$2.5 dollars per pound, pegging the rate at the arithmetic center of the range would mean an exchange rate of \$2 per pound. Quoting in pounds to the dollar, however, the range is £0.4 to about £0.67 per dollar, and the pegged rate at £0.5 per dollar is off from the arithmetic center of about £0.53 per dollar. When the endpoints of the range are the same both ways, the arithmetic centers are not the same; when the pegged rate is the same both ways, the endpoints cannot be both the same and equidistant from the pegged rate.

The problem is resolved if the rate is pegged at the geometric center instead. In this case, if X is the true rate and Y is the pegged rate, then the range is as follows:

$$\frac{Y}{1+r} \le X \le Y(1+r) \tag{5}$$

where

r: increment parameter.

For example, if the range parameter is 0.25 and the pegged rate is \$2 per pound, then the pegged range is between \$1.6 and \$2.5 per pound. Quoted the other way, the pegged rate is £0.5 per dollar and the range, from £0.4 to £0.625 per dollar. The pegged rates are geometrically centered both ways and the corresponding endpoints are the same.

The geometrically centered peg rate can be found by computation, given the true rate and a base. If the base is unity, so that:

$$Y = (1 + r)^n \tag{6}$$

where
n: an integer value,

then the applicable pegged rate given any true rate must be the one closest to it, thus,

$$(1 + r)^n \cong X \tag{7}$$

Taking the logarithm of both sides of Equation 7, isolating n on the left, and rounding to the closest integer gives:

$$n = \text{round}\left[\frac{\log X}{\log(1 + r)}\right] \tag{8}$$

Thus, the procedure for computing the pegged rate based at unity involves three steps:

1. find the true rate, X (Equation 3)
2. compute the integer, n (Equation 8)
3. compute the pegged rate, Y (Equation 6)

To the extent allowed by the increment parameter (r), the pegged rate will vary from the true rate. The likelihood of an exchange-rate adjustment increases as the true rate approaches an endpoint of the pegged range. Under some conditions, speculative actions by themselves can be sufficient to move the true rate past the endpoint, thereby causing a repegging of the exchange rate. This will be explained next.

RISK COMPENSATION

Different methods of currency speculation are associated with different levels of risk. The buyer of foreign money obtains a deposit abroad, incurring a risk limited to the amount of the deposit. The seller obtains a loan, for which the risk, however, is unlimited, for if the seller's currency becomes worthless the seller will require a mathematically infinite amount of it to repay the loan. Because the seller's risk exceeds the buyer's, the seller's potential rewards from currency speculation should be greater. This is risk compensation.

Consider the case when a participant of Nation A has deduced that Nation B's currency is undervalued relative to its own. Mathematically, the relationship is represented thus:

$$Y_{A,B} < X_{A,B} \tag{9}$$

where, as before
$X_{A,B}$: True value of Nation A's currency (e.g., \$) relative to Nation B's (e.g. £)
$Y_{A,B}$: Pegged exchange rate of Nation A's currency for Nation B's

Because $Y_{A,B}$ is therefore more likely to rise than to fall, the astute participant will deposit money in Nation B's bank so that in the event $Y_{A,B}$ rises as anticipated, the participant could withdraw the deposit and receive more of the participant's currency than the participant had initially put down for the deposit. The deposit itself, however, moves the true value of Nation B's currency ($X_{A,B}$) closer to the pegged rate ($Y_{A,B}$), an effect that will be demonstrated by an example, and then proved.

For the example, assume the exchange rate is pegged at \$2 per pound when its true value is deduced to be \$2.4 per pound, based on foreign holdings of \$12 million and £5 million. Assume also that the participant exchanges \$2 million for £1 million pounds at the pegged rate of \$2 per pound, depositing the proceeds in Nation B's bank. The resulting foreign holdings will then be \$14 million and £6 million, and the new true value of Nation B's currency will be about \$2.3 per pound, closer to the pegged rate of \$2 per pound than it was before at \$2.4 per pound.

For the proof, let $X'_{A,B}$ stand for the value of Nation B's currency in dollars per pound after the deposit. Then, following Equation 3,

$$X'_{A,B} = \frac{F_A + DY_{A,B}}{F_B + D} \qquad (10)$$

where

D: Amount of deposit in Nation B's bank in Nation B's currency.

Defining *m* such that

$$Y_{A,B} = mX_{A,B} \qquad (11)$$

and incorporating Equations 3 and 11 into Equation 10 by substituting for $Y_{A,B}$ and F_A gives

$$X'_{A,B} = X_{A,B}\left(\frac{F_B + mD}{F_B + D}\right) \qquad (12)$$

Incorporating Equation 11 into Equation 12 by substituting for $X_{A,B}$ gives

$$X'_{A,B} = Y_{A,B}\left(\frac{\frac{F_B}{m} + D}{F_B + D}\right) \qquad (13)$$

It follows from Equations 12 and 13 that if $m < 1$, the case of Equation 9, then

$$Y_{A,B} < X'_{A,B} < X_{A,B} \qquad (14)$$

and if $m > 1$, the converse case, then

$$Y_{A,B} > X'_{A,B} > X_{A,B} \qquad (15)$$

Thus, if the true value of a currency differs from its pegged rate in any direction, deposits will move the true rate closer to the pegged rate. Deposits cannot by themselves cause a rate adjustment. On the contrary, they generally make it more unlikely.

Loans have a mirror effect. In the case when a participant of Nation A has deduced that Nation B's currency is overvalued relative to its own, thus that

$$Y_{A,B} > X_{A,B} \qquad (16)$$

Then the astute participant's sensible course of action is to borrow from Nation B's bank so that in the event $Y_{A,B}$ falls as anticipated, the participant could repay the loan with less of the participant's currency than the participant had initially received from the loan. Mirroring a deposit, the loan moves the true value of Nation B's currency ($X_{A,B}$) further away from the pegged rate ($Y_{A,B}$).

The mathematical proof mirrors the proof for the case of a deposit, so the conclusions mirror that case. If, the true value of a currency differs from its the pegged rate in any direction, loans will move the true rate further away from the pegged rate. Unlike deposits, loans can by themselves cause a rate adjustment; they generally make an adjustment more likely.

Thus, the riskier the method, the higher the potential reward. Participants who speculate by the less-risky deposit method generally modify the situation such that the likelihood of an anticipated revaluation is lowered. Participants who speculate by the riskier loan method increase by their actions the likelihood of success, provided their assessment is correct. If they should make the wrong call, however, such as surmising that a currency is overvalued when it is undervalued, their loans will increase the discrepancy, even to the point of causing a revaluation subjecting them to a speculative loss. The model is fair.

CONCLUSION

The foreign holdings model discussed has been shown to be self limiting, volume independent, and risk compensating, characteristics that promote stability, simplicity, and fairness. These are suitable objectives for a model that may be used for completeness in an international business gaming simulation focused more closely on other issues. The model would be inadequate, however, if the focus of the exercise is on the substance of the model, for the essential component of human intelligence is missing. The model responds to what participants do; it does not respond to how participants feel or what they intend to do. It does not have intelligence. To capture intelligence, the process cannot be modeled; it must be gamed.

The model is not essential in batch-process gaming simulations that are run for only a few cycles, generally four (Rollier, 1992) to twelve (Anderson & Lawton, 1997). In these situations, the game may be too short-lived for participants to notice even serious flaws (Wolfe & Jackson, 1989). Two international-business games of this type (*INTOPIA* and *THE MULTINATIONAL MANAGEMENT GAME*) make do with exchange rates fixed by the administrator.

The model was developed for a continuous-process game that runs typically at the average rate of 100 periods a week for 10 weeks. In this long-life situation, fixed exchange rates would be aberrant, and flaws in the model would be dangerous. Thus, the guiding objective was to find a simple model that was not aberrant.

Validation, in the sense of binding the model to a particular reference system (Peters, Vissers, & Heijne, 1998) or a simuland (Stanislaw, 1986), was not a driving concern. The world is flawed, reality is stranger than fiction, and as former U.S. president Jimmy Carter wisely observed, life is not fair. A pedagogical gaming simulation, however, especially one that may be taken seriously enough to be the basis for important life decisions (Ifill, 1994), should be flawless, friendly, and fair. It's not reality, but a fiction that serves a purpose.

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