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Arbitrageur, Speculator, and Liquidity Trader: A Behavioral Spot Exchange Rate Model

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Abstract

This study builds a model of spot exchange rate determination based on the specifics of market activities from an explicitly micro perspective. Given the net position of liquidity traders, this paper examines the interaction of the behavior of two different camps in the foreign exchange market: the arbitrageurs and the speculators. The model is cast in a flexible framework so that it can explain a variety of exchange rate regimes, ranging from the floating to the fixed rate systems. With elaborate specifications on the behavior of arbitrageurs, the model is especially suitable for probing the operations of the gold standard and variations of currency board arrangements (CBAs), both of which are heavily dependent on arbitrage efficiency in locking the spot exchange rate. Finally, this paper also has implications for studying the determinants of the exchange rates of crypto currency against official currency such as the US dollar. Since crypto currency markets are operated in a decentralized environment, the equilibrium spot exchange rates are entirely dependent on the market mechanisms. With appropriate modifications, the analytical framework of this study could be adapted to explore cryptocurrency markets in future research.

Keywords

Spot Exchange Rate, Arbitrage, Speculation, Gold Standard, Currency Board, Hong Kong, Crypto Currency

1. Introduction

Exchange rates play an instrumental role in international transactions. They allow consumers to evaluate the prices of goods and services produced in different countries. They also allow investors to compare the cross-country asset prices. Exchange rates are determined at foreign exchange markets where importers and exporters have demand and supply of domestic and foreign currencies. They are fundamental liquidity traders in the foreign exchange markets. Corporations engaged in foreign direct and portfolio investments also have demand and supply of domestic and foreign currencies and are also fundamental liquidity traders in the foreign exchange markets. Financial intermediaries such as banks and institutional investors also provide liquidity to the currency markets on behalf of their clients, including consumers and firms (Greenwood, Hanson, Stein, and Sunderam [1]).

Recent macroeconomic exchange rate models therefore mainly focus on the behavior of these fundamental liquidity traders in the currency markets to model the floating exchange rate systems. For example, Fang and Liu [2] develop a portfolio balance model in foreign exchange markets, emphasizing the role of financial intermediaries such as banks and institutional investors. Akinci and Queralto [3] study dynamics of exchange rate from the perspective of imperfect financial markets due to asymmetric information and transaction costs. Lustig and Verdelhan [4] build an exchange rate model with incomplete international financial markets where investors cannot fully access or trade all possible financial assets across countries due to barriers like regulatory restrictions, transaction costs, or lack of financial instruments.

Whilst these newly developed macroeconomic models have been fruitful in explaining the floating exchange rate systems, it is challenging to model the fixed and semi-fixed exchange rate systems as they tend to vary vastly over time and across countries. To the best of the author's knowledge, this paper is among the first to develop a behavioral exchange rate model that explicitly examines the interactions of arbitrageurs and speculators, given the positions of liquidity traders in the foreign exchange market. The new model is cast in a flexible framework so that it can explain a variety of exchange rate regimes, ranging from the floating to the fixed rate systems, and most importantly, the success and failures of government interventions in the foreign exchange markets.

Basically, fixed and semi-fixed exchange rate systems can be categorized into two types (Tsang [5]). The first type includes those regimes maintained by foreign exchange controls, in particular capital account controls. Typical examples of this type include mainland China (Song, Storesletten, and Zilibotti [6]; Clayton, Dos Santos, Maggiori, and Schreger [7]) and Malaysia in response to the Asian crisis (Ma [8]). Countries without imposing capital account control had to rely on frequent central bank interventions in foreign exchange markets, e.g., the previous European Exchange Rate Mechanism (ERM) (Krugman [9]; Svensson [10]).

The second type fixed or semi-fixed exchange rate regime covers those systems underpinned by the market mechanism. It can be divided into two sub-types: 1) the old gold standard of the 19th century and the early 20th century (Farhi and Maggiori [11]; Velde and Weber [12]; Fernández-Villaverde and Sanches [13]), and 2) the currency board arrangements previously practiced in British colonies and currently maintained in economies such as Hong Kong SAR, Dominica, and

Grenada (US dollar anchor), Macao SAR (Hong Kong dollar anchor), Bulgaria (Euro anchor), and Brunei (Singapore dollar anchor) (IMF [14]; Greenwood [15]; Williamson [16]; Tsang [5]).

Most of the literature on fixed and semi-fixed exchange rates has focused on the first type and attempted to explain it by a macroeconomic approach, e.g., the target zone literature on the ERM. Such an approach has not been particularly successful (see Svensson [10]; Ma and Kanas [17]). Chang and Velasco [18] and Ma [8] developed macroeconomic models to analyze the Asian financial crisis of 1997.

In contrast, there has been a lack of theoretical modeling for the second type of market-driven regimes. This is unfortunate because the ability of these regimes to fix the spot exchange rate has been phenomenal, regardless of the ultimate sustainability and optimality of the peg in the light of economic fundamentals (Tsang [5] [19]). Perhaps one of the few exceptions is Tsang and Ma [20] who apply a Markov-switching model to estimate the durability of the currency board system of Hong Kong. They find that the no-attack regime turned out to be the most durable one under the currency board arrangement in Hong Kong, which is robust against both currency speculation and currency substitution. Another piece of work is Ma, Meredith and Yiu [21] who developed a macroeconomic model of the currency board system of Hong Kong. Feng, Fu, Ho, and Ho [22] further extend the Markov-switching model of Tsang and Ma [20] to cover six current and previous currency board arrangements of Argentina, Bulgaria, Estonia, Hong Kong SAR, Latvia, and Lithuania. However, the micro foundation of the currency board system is yet to be established.

This paper explores the micro behavior of the market from the perspectives of the arbitrageur and the speculator. In particular, this study investigates how the spot exchange rate can be "fixed" to either an official parity or the fundamental value through mechanisms that facilitate the activity of the arbitrageur, as against that of the speculator, who may hold different or diversified expectations.

Arbitrage can be performed in any market. If the prices for the same product or asset in two sub-markets differ from each other, a market participant can engage a "buy low and sell high" arbitrage strategy to make a risk-free profit: buy it at a low price in one sub-market, and then sell it in the other sub-market at a higher price. A profit, discounted for the transaction cost, will be obtained at no risk. If a sufficient number of market participants perform similar arbitrage and the markets are efficient, prices across sub-markets should equalize.

From this perspective, the spot exchange rate can be fixed if a suitable arbitrage mechanism between a definition of narrow money (over which the authority has sufficient foreign reserves) and a broad definition of money (e.g., bank deposits) can effectively function. This is the core principle behind market-driven regimes including the old gold standard, as well as currency board arrangements that are still practiced by a number of economies like Hong Kong (Tsang [5] [19]). This study will show that in the case of a fully effective and market-driven fixed exchange rate system, such as the modern currency board regime, arbitrage will lock the spot rate firmly to the official parity.

How effective is arbitrage in fixing or stabilizing exchange rates at the fundamental value or the official parity? There are three strands in the literature on the empirical testing of arbitrage efficiency. The first strand tests goods-market arbitrage based on PPP (Lothian and Taylor [23]; Ong [24]). The second tests interest rate arbitrage in the forward market based on covered interest parity (CIP) (Keller [25]; Augustin, Chernov, Schmid, and Song [26]), and uncovered interest parity (UIP) (Gali [27]; Engel, Kazakova, Wang, and Xiang [28]). See also Mark and Wu [29] who developed a noise trader approach to model the failure of UIP.

The third strand of literature investigates the arbitrage efficiency and robustness of the second type of market-driven fixed exchange rate regimes, *i.e.*, the old gold standard and currency board systems. The efficiency of the old gold standard has been tested (Farhi and Maggiori [11]; Velde and Weber [12]; Fernández-Villaverde and Sanches [13]). On the other hand, the currency board system has apparently achieved an even higher degree of arbitrage efficiency (Tsang [5] [19]). However, there has not been rigorous theoretical treatise to explain the success of these market-driven systems.

This paper builds a theoretical spot exchange rate model from a microeconomic behavioral perspective that directly addresses the issue of arbitrage efficiency. The significance of this study is four-fold. Firstly, it provides an alternative explanation of both the deviation of the spot exchange rate from its fundamental value in the case of a floating exchange rate system, or the deviation from its official central parity under a fixed exchange rate system. Secondly, it provides new insight into the efficiency of the old gold standard subject to the transaction costs. Thirdly, it shows the inefficiency of the cash arbitrage mechanism of the classical currency board system and the efficiency of the electronic arbitrage mechanism of the modern currency board system (Tsang [5] [30]). Finally, it pinpoints the dilemma faced by the government in trying to stabilize the exchange rate market with discretionary intervention. The requirement of a transparent rule in the fixed exchange rate regime is consistent with findings such as Morris and Shin [31].

This topic is important. According to the IMF's [14] Classification of Exchange Rate Arrangements, only 63 economies implemented floating exchange rate systems in 2023, the remaining 127 economies opted for fixed or semi-fixed exchange rate regimes, including 12 of them adopted currency board arrangements.

The remainder of the paper is organized as follows. Section 2 sets up the model based on heterogeneous expectations. Section 3 presents the model solution based on arbitrage mechanism and its theoretical implications. Section 4 discusses the institutional and empirical relevance of the new findings for different exchange rate regimes. Finally, Section 5 concludes.

2. A Model of Spot Exchange Rate Determination Based on Heterogeneous Expectations

This study considers a foreign exchange market with K heterogeneous speculators whose objectives are profit maximizing. There are also some liquidity traders such as exporters/importers, international investors, and consumers who just need a fixed volume of transactions independent of the spot exchange rate. There may or may not be government intervention to move the spot rate to an official parity or its fundamental value. All agents can observe the actual spot exchange rate (s) in the spot market, where s is defined as domestic currency per unit of foreign currency. Without loss of generality, the domestic currency is defined as 'HKD' and the foreign currency as 'USD'. This implies that a rise in the spot rate s indicates a devaluation or depreciation of domestic currency HKD against foreign currency USD.

The model starts with a general framework in which the exchange rate regime can be fixed or floating, or anything in between. It is assumed that market agents may not have perfect information about the true official intervention level or the fundamental value, $\bar{s}$. A speculator, k, intends to drive the spot exchange rate to his perceived official intervention level or his perceived fundamental value s_k. However, there is uncertainty associated with the level of s_k due to exogenous noise in the spot market, or the non-transparency of government intervention. Therefore, s_k is known to the speculator as a random variable with perceived mean $\bar{s}_k$ and perceived variance σ_k^2. Information is imperfect in the spot market so that $\bar{s}_k$ may not be equal to the true official intervention level or the fundamental value, $\bar{s}$.

Furthermore, information is private. It is neither verifiable nor exchangeable. As it will be shown in the next section, the potential misperception in $\bar{s}_k$ and the uncertainty represented by σ_k^2 are two of the main factors that the observed equilibrium spot rate, s, fails to be locked at its official central parity (under a fixed rate system) or the fundamental value (in a floating rate regime), *i.e.*, $\bar{s}$. And the nature of private information is the key that renders the failure of government intervention.

It is innocuous to sort the $\bar{s}_k$ of different speculators in ascending order (of devaluation or depreciation) so that $\bar{s}_1 \le \bar{s}_2 \le \cdots \le \bar{s}_{K-1} \le \bar{s}_K$ but $\bar{s}_1 < \bar{s}_K$. The assumption that $\bar{s}_1 < \bar{s}_K$ is important. Because if $\bar{s}_1 = \bar{s}_K$, then $\bar{s}_1 = \bar{s}_2 = \cdots = \bar{s}_{K-1} = \bar{s}_K$, then it implies that there is no trade among speculators. On the other hand, suppose there exists a sub-group of speculators $k_1, (k_1+1), \cdots, k_c \le K$, they hold identical perceived $\bar{s}_{k_1}$ such that $\bar{s}_{k_1} = \bar{s}_{k_1+1} = \cdots = \bar{s}_{k_c}$. Since the subscripts are different for each of these agents, their respective σ_k^2 and risk preferences may still be different. That is, even they hold the same $\bar{s}_{k_1}$, they may still be heterogeneous in other aspects. Finally, the assumption that $\bar{s}_1 < \bar{s}_K$ guarantees that there are at least two heterogeneous agents in the model.

For simplicity, suppose that the K speculators in the spot market hold a wide range of diversified perceptions regarding the fundamental value of the spot rate (s) such that the spot rate lies within the interval $\left[\bar{s}_1, \bar{s}_K\right]$, *i.e.*, $\bar{s}_1 \le s \le \bar{s}_K$. Furthermore, suppose s falls in the N_a-th grid of $\left[\bar{s}_1, \bar{s}_K\right]$, *i.e.*, $\bar{s}_{N_a} < s < \bar{s}_{N_a+1}$. This implies that there are N_a speculators who believe that the USD (HKD) is overvalued (undervalued) at the observed spot rate s, and $N_b = K - N_a$ speculators who believe that the USD (HKD) is undervalued (overvalued). Define the former as speculator group a and the latter as group b. As a result, the speculator group a expects that the USD to depreciate against the HKD, whilst speculator group b is expecting the opposite to happen. In other words, speculators of group a will try to buy the undervalued HKD and sell the overvalued USD in the spot market, whilst the speculators of group b holding the opposite views will do the opposite. Hence, there is trade in the foreign exchange spot market between the two speculator groups, given the exogenous net position of liquidity traders. The model basically investigates an exchange rate regime with interactions of these heterogeneous speculators and liquidity traders such as exporters/importers, international investors, consumers, as well as possible government interventions.

2.1. Speculators of Group *a*

A speculator, i ($i = 1, 2, \cdots, N_a$), intends to drive the spot exchange rate up to her perceived fundamental value or the official intervention level (in case of the fixed exchange rate), s_{ai}, which is a random variable with perceived mean $\overline{s}_{ai}$ and perceived variance σ_{sai}^2. It is a "buy low and sell high" strategy with risk. As the N_a speculators hold the view of a potential appreciation of HKD, they will short the USD and long the HKD in the spot market. This is illustrated in Panel A of Table 1. Having observed that the HKD is undervalued compared with their perceived value, *i.e.*, $s > \overline{s}_{ai}$, speculators of group a expect the HKD to appreciate against USD soon. To make a speculative profit, suppose the speculation fund mobilized by speculator i to long domestic currency HKD is a_i and short foreign currency USD in the amount of a_i/s (column 1). This transaction incurs a cost of $a_i t$ in HKD (column 2), which is assumed to be proportional to the transaction volume a_i.

Table 1. Transaction record of speculators.

	At current spot market		At the spot market in the future		Profits (ω) (5) (=(1) + (2) + (3) + (4))
	Trade volume (1)	Transaction cost (2)	Trade volume (3)	Transaction cost (4)	
	Panel A. Speculators of group a with $\overline{s}_{ai} < s$				
HKD	$+a_i$	$-a_i t$	$-a_i s_{ai}/s$	$-t a_i s_{ai}/s$	$a_i\left[(1-t)-(1+t)s_{ai}/s\right]$
USD	$-a_i/s$		$+a_i/s$		0
	Panel B. Speculators of group b with $\overline{s}_{bj} > s$				
HKD	$-b_j$	$-b_j t$	$+b_j s_{bj}/s$	$-t b_j s_{bj}/s$	$b_j\left[(1-t)s_{bj}/s-(1+t)\right]$
USD	$+b_j/s$		$-b_j/s$		0

This table shows the transaction records of speculators. "+" indicates a purchase and "−" indicates a sale or a payment. s is the observed spot exchange rate, s_{ai} and s_{bi} are perceived spot rates in the future, which are random variables with mean of $\overline{s}_{ai}$ and $\overline{s}_{bj}$ by speculators of group a and b, respectively. t is the unit transaction cost, which is assumed to be paid in HKD. All profits are denominated in HKD for simplicity.

To close her position, the speculator i may reverse the transaction when the spot rate moves to her perceived level s_{ai}. This is illustrated in Panel A of **Table 1**. The reverse transaction is to sell domestic currency HKD in the amount of $a_i s_{ai}/s$ and to buy foreign currency USD in the amount of a_i/s (column 3). This transaction incurs a cost of $ta_i s_{ai}/s$ in HKD (column 4). As s_{ai} is a random variable, the reverse transaction is associated with uncertainty.

Assume that there is a variable transaction cost, which includes the net financing cost to finance the speculation. The net financing cost may be negative, *i.e.*, a net gain. This is because suppose the speculator initially borrowed USD to go short, got the HKD, which she would probably place as a deposit. So the LIBOR-HIBOR interest differential represents the net financing cost. In reversing the transaction, she withdraws the HKD deposit, and uses it to buy back the USD, repaying it to the initial lender. She may actually get a net gain if the amount of USD she buys in the spot market exceeds the principal plus interest of the original USD loan, with which she started speculating. To simplify the analysis, it is assumed that the transaction cost is charged at the domestic currency HKD. The speculator's profit in HKD is given as:

$$\omega_{ai} = a_i\left[(1-t)-(s_{ai}/s)(1+t)\right],\ i=1,2,\cdots,N_a. \tag{1}$$

Profits made in the USD can also be modeled in a similar way.

Speculators are assumed to maximize their expected utility Eu_{ai}, which is defined as:

$$Eu_{ai} \equiv E\omega_{ai} - \alpha_i\sigma_{\omega ai}^2, \tag{2}$$

where $E\omega_{ai}$ and $\sigma_{\omega ai}^2$ are the mean and variance of ω_{ai}, respectively, and α_i i is the degree of risk-averse of the speculator i and a larger α_i indicates the speculator is more risk-averse.

The expected profit of the speculator i is given as:

$$E\omega_{ai} = a_i\left[(1-t)-(\overline{s}_{ai}/s)(1+t)\right] \tag{3}$$

and the variance of the profit is given as:

$$\sigma_{\omega ai}^2 = a_i^2\sigma_{sai}^2(1+t)^2/s^2 \tag{4}$$

Strictly speaking, only speculators with expected non-negative profits will trade. This implies that the *actual* number of speculators $N_a' \le N_a$. If the expected profits of the speculators are all negative, then there is no trade among speculators.

From the first order condition $\partial Eu_{ai}/\partial a_i = 0$, the optimal speculation fund $a_i(s)$ can be solved to maximize the expected utility Eu_{ai}:

$$a_i(s) = \frac{(1-t)-(\overline{s}_{ai}/s)(1+t)}{\alpha_i\sigma_{sai}^2(1+t)^2/s^2} \tag{5}$$

The four key properties of the speculation fund $a_i(s)$ are as follows:

(1) The higher the transaction cost (t) is, the less speculation funds are spent.

(2) The larger deviation of s from the perceived parity or fundamental value $\overline{s}_{ai}$ is, the more speculation activities are, *i.e.*

$$\frac{\partial a_i(s)}{\partial s}=\frac{2s(1-t)-\overline{s}_{ai}(1+t)}{\alpha_i\sigma_{sai}^2(1+t)^2}\geq\frac{2s(1-t)-s(1+t)}{\alpha_i\sigma_{sai}^2(1+t)^2}\geq\frac{s(1-3t)}{\alpha_i\sigma_{sai}^2(1+t)^2}>0 \quad (6)$$

if $t < 1/3$. That is, the speculation fund $a_i(s)$ is an upward sloping curve with s.

(3) The less uncertainty about the official intervention level or fundamental value of spot rate (σ_{sai}^2) is, the more speculation activities are. In the limit, if $\sigma_{sai}^2 = 0$, the speculator will use up *all* her available resources to engage in speculation. In this case, *the speculator becomes an arbitrageur*. That is, $\partial a_i(s)/\partial\sigma_{sai}^2 < 0$, and $\lim_{\sigma_{sai}^2\to 0} a_i(s)=\overline{a}_i$.

(4) The more risk-averse the speculator (α_i) is, the less speculation activities are.

In this study, it is focused on a devaluation game. This implies that the speculator group a is the potential arbitrageur group. However, if it is a revaluation game, then the potential arbitrageur group will be the group b.

2.2. Speculators of Group *b*

The speculators of group b will do exactly the opposite of what the speculators of group a are doing at the foreign exchange spot market. They believe the HKD is overvalued compared with their perceived value, *i.e.*, $s < s_{bj}$. Therefore, they decide to make a speculative profit to short domestic currency HKD and long foreign currency USD. This is illustrated in Panel B of Table 1. It is a "sell high then buy low" strategy with risk.

Suppose the speculation fund utilized by the speculator, j ($j = N_a + 1, N_a + 2, \cdots, K$), to short domestic currency HKD is b_j (see column 1 in Panel B of Table 1). As the spot rate is s, the amount he longs foreign currency USD is b_j/s (column 1). To close his position, the speculator j is expected to reverse his transaction when the market spot rate moves to his perceived level of s_{bj}. The reverse transaction is to long domestic currency HKD in the amount of $b_j s_{bj}/s$ and to short foreign currency USD in the amount of b_j/s (column 3). As s_{bj} is a random variable, the reverse transaction is associated with uncertainty. Subject to the transaction cost associated with each transaction, the speculators' profit is given as (column 5):

$$\omega_{bj} = b_j\left[\left(s_{bj}/s\right)(1-t)-(1+t)\right],\ \ j = N_a + 1, N_a + 2, \cdots, K \quad (7)$$

The speculator is assumed to maximize his expected utility, Eu_{bj}, defined as:

$$Eu_{bj} \equiv E\omega_{bj} - \beta_j\sigma_{\omega bj}^2 \quad (8)$$

where β_j is the degree of risk-averse of the speculator j.

The expected profit is:

$$E\omega_{bj} = b_j\left[\left(\overline{s}_{bj}/s\right)(1-t)-(1+t)\right] \quad (9)$$

and the variance of the profit is:

$$\sigma_{\omega bj}^2 = b_j^2\sigma_{sbj}^2(1-t)^2/s^2 \quad (10)$$

Similar to the previous discussion related to speculator group a, only speculators with expected non-negative profits will trade. This implies that the actual number of speculators $N_b' \le N_b$. If the expected profits of the speculators are all negative, then there is no trade among speculators.

To maximize expected utility Eu_{bj}, the optimal speculation fund $b_j(s)$ is:

$$b_j(s) = \frac{(\bar{s}_{bj}/s)(1-t)-(1+t)}{\beta_j \sigma_{sbj}^2 (1-t)^2 / s^2} \tag{11}$$

The properties of speculation fund $b_j(s)$ are similar to that of speculator group *a*, except that:

$$\frac{\partial b_j(s)}{\partial s} = \frac{\bar{s}_{bj}(1-t)-2s(1+t)}{\beta_j \sigma_{sbj}^2 (1-t)^2} \le \frac{2s(1-t)-2s(1+t)}{\beta_j \sigma_{sbj}^2 (1-t)^2} \le \frac{-4st}{\beta_j \sigma_{sbj}^2 (1-t)^2} < 0 \tag{12}$$

if $\bar{s}_{bj} \le 2s$. That is, the speculation fund $b_j(s)$ is a downward sloping curve with *s*.

2.3. Liquidity Traders and Government Intervention

Liquidity traders such as exporters/importers, consumers, and international investors may also engage foreign currency transactions at the foreign exchange market. These transactions are not of a speculative nature, *i.e.*, they are not supposed to be profit-seeking in the foreign exchange spot market *per se*. Suppose that the net demand for USD is c_h and the net supply of HKD is sc_h for the liquidity traders, where c_h is assumed, for simplicity, to be independent of the observed spot rate *s*. And assume that the exogenous demand for HKD due to the government intervention is sq, where $q = 0$ means no intervention, and $q > 0$ and $q < 0$ indicate a revaluation and devaluation intervention, respectively.

2.4. Market Equilibrium

Equilibrium of the spot market is attained when the aggregate demand for domestic currency HKD by speculators of group *a* and the government intervention (s q) is equal to the aggregate supply of domestic currency by speculators of group *b* plus the net supply of liquidity traders (sc_h), *i.e.*,

$$\sum_{i=1}^{N_a} a_i(s) + sq = \sum_{j=N_a+1}^{K} b_j(s) + sc_h \tag{13}$$

Substituting Equations (5) and (11) into Equation (13), it has:

$$\sum_{i=1}^{N_a} \frac{(1-t)-(\bar{s}_{ai}/s)(1+t)}{\alpha_i \sigma_{sai}^2 (1+t)^2 / s^2} + sq = \sum_{j=N_a+1}^{K} \frac{(\bar{s}_{bj}/s)(1-t)-(1+t)}{\beta_j \sigma_{sbj}^2 (1-t)^2 / s^2} + sc_h \tag{14}$$

Hence,

$$\begin{aligned} &\frac{1}{s}\left[(1+t)\sum_{i=1}^{N_a} \frac{\bar{s}_{ai}}{\alpha_i \sigma_{sai}^2} + \frac{(1+t)^2}{1-t} \sum_{j=N_a+1}^{K} \frac{\bar{s}_{bj}}{\beta_j \sigma_{sbj}^2} + (1+t)^2 (c_h - q)\right] \\ &= (1-t)\sum_{i=1}^{N_a} \frac{1}{\alpha_i \sigma_{sai}^2} + \frac{(1+t)^3}{(1-t)^2} \sum_{j=N_a+1}^{K} \frac{1}{\beta_j \sigma_{sbj}^2} \end{aligned} \tag{15}$$

Solving for the equilibrium spot rate s^*:

$$s^* = \frac{(1+t)\sum_{i=1}^{N_a}\frac{\bar{s}_{ai}}{\alpha_i\sigma_{sai}^2} + \frac{(1+t)^2}{1-t}\sum_{j=N_a+1}^{K}\frac{\bar{s}_{bj}}{\beta_j\sigma_{sbj}^2} + (1+t)^2(c_h - q)}{(1-t)\sum_{i=1}^{N_a}\frac{1}{\alpha_i\sigma_{sai}^2} + \frac{(1+t)^3}{(1-t)^2}\sum_{j=N_a+1}^{K}\frac{1}{\beta_j\sigma_{sbj}^2}} \tag{16}$$

This suggests that an increase in government intervention—specifically, injecting USD into the market ($q > 0$) to boost demand for HKD—will lead to an appreciation of HKD and the equilibrium spot rate s^* fall.

To establish the spot exchange rate market equilibrium, rewrite equation (13) without government intervention ($q = 0$) as follows:

$$\sum_{i=1}^{N_a} a_i(s) = \sum_{j=N_a+1}^{K} b_j(s) + sc_h \tag{17}$$

where $a_i(s)$ and $b_j(s)$ are defined in Equations (5) and (11) respectively, c_h is the net supply of HKD by liquidity traders.

Since speculators in group a anticipate that the HKD would revalue to their perceived level, they take long positions in HKD, becoming demanders of HKD in the spot market. Define their revaluation fund as their transaction volume in the left-hand-side of Equation (17):

$$R(s) \equiv \sum_{i=1}^{N_a} a_i(s) \tag{18}$$

Since $\partial a_i/\partial s > 0$ from Equation (6), $R(s)$ is an upward sloping curve in s as depicted in Figure 1.

In contrast, since speculators in group b anticipate that the HKD may devalue to their perceived levels, they take short positions in HKD, becoming HKD suppliers in the spot market. Define their devaluation fund as their transaction volume, together with the net supply of the HKD of liquidity traders sc_h, in the right-hand-side of Equation (17):

$$D(s) \equiv \sum_{j=N_a+1}^{K} b_j(s) + sc_h \tag{19}$$

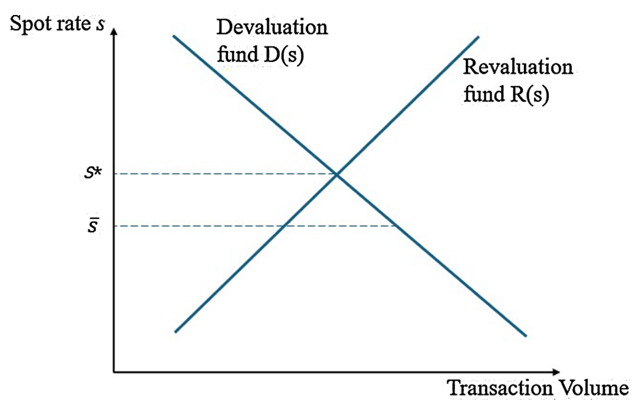


Figure 1. Equilibrium spot exchange rate s^*.

This figure shows that the equilibrium spot exchange rate s^* may, or may not, equal to the true official intervention level or the fundamental value $\bar{s}$.

If $c_h < 0$, $D(s)$ curve is depicted as downward sloping because $\partial b_j/\partial s < 0$ from Equation (12). If $c_h > 0$ and c_h is not too large, then $\partial D(s)/\partial s < 0$ still may hold and $D(s)$ curve remains downward sloping. If c_h is excessively large and $\partial D(s)/\partial s > 0$, then $D(s)$ curve will slope upward; however, this does not alter the qualitative nature of the analysis. For simplicity, this paper focuses its analysis on cases where the $D(s)$ curve slopes downward. The market equilibrium spot rate s^* is defined at the level at which $R(s^*) = D(s^*)$, as depicted in **Figure 1**.

Figure 1 shows an example that the market equilibrium rate s^* is above the official parity or the fundamental value $\bar{s}$, indicating the market value of HKD is devalued at the spot market. This is a typical example that the market equilibrium may not be settled at its fundamental value if there are speculative activities betting on devaluation (Ma [8]) or revaluation (Sun and Ma [32]) of a domestic currency.

2.5. Theoretical Implications: Why s* May Not be Fixed to $\bar{s}$

Figure 1 illustrates that in the absence of government intervention ($q = 0$), there is no guarantee that Equation (16) will set $s^* = \bar{s}$. The equilibrium spot rate s^* may or may not be align with the true official intervention level or the fundamental value, $\bar{s}$. This section further demonstrates that, even with government intervention (*i.e.*, $q \neq 0$), $s^* = \bar{s}$ is still not guaranteed.

Rewrite the equilibrium spot rate s^* Equation (16) as follows:

$$s^* = \theta_0 + \theta_1 q \tag{20}$$

where

$$\theta_0 = \frac{(1+t)\sum_{i=1}^{N_a} \frac{\bar{s}_{ai}}{\alpha_i \sigma_{sai}^2} + \frac{(1+t)^2}{1-t}\sum_{j=N_a+1}^{K} \frac{\bar{s}_{bj}}{\beta_j \sigma_{sbj}^2} + (1+t)^2 c_h}{(1-t)\sum_{i=1}^{N_a} \frac{1}{\alpha_i \sigma_{sai}^2} + \frac{(1+t)^3}{(1-t)^2}\sum_{j=N_a+1}^{K} \frac{1}{\beta_j \sigma_{sbj}^2}}$$

$$\theta_1 = \frac{-(1+t)^2}{(1-t)\sum_{i=1}^{N_a} \frac{1}{\alpha_i \sigma_{sai}^2} + \frac{(1+t)^3}{(1-t)^2}\sum_{j=N_a+1}^{K} \frac{1}{\beta_j \sigma_{sbj}^2}}$$

Both θ_0 and θ_1 are true parameter values of private information undisclosed to the government. Therefore, the government may not be able to identify the exact intervention $\bar{q} = (\bar{s} - \theta_0)/\theta_1$ such that $s^* = \bar{s} = \theta_0 + \theta_1 \bar{q}$. However, the government may estimate θ_0 and θ_1 and derive q based on the estimated $\hat{\theta}_0$ and $\hat{\theta}_1$, *i.e.*, $\hat{q} = (\bar{s} - \hat{\theta}_0)/\hat{\theta}_1$ such that

$$\bar{s} = \hat{\theta}_0 + \hat{\theta}_1 \hat{q} \tag{21}$$

Substituting $\hat{q}$ into Equation (20):

$$\hat{s}^* = \theta_0 + \theta_1 \hat{q} \tag{22}$$

Subtracting Equation (22) by Equation (21), it has:

$$E\left(\hat{s}^* - \overline{s} \mid \hat{q}\right) = E\left(\theta_0 - \hat{\theta}_0\right) + \hat{q}E\left(\theta_1 - \hat{\theta}_1 \mid \hat{q}\right) \tag{23}$$

If both $\hat{\theta}_0$ and $\hat{\theta}_1$ are unbiased estimation of θ_0 and θ_1, respectively, then it has:

$$E\left(\hat{s}^* - \overline{s} \mid \hat{q}\right) = 0$$

i.e.,

$$E\left(\hat{s}^* \mid \hat{q}\right) = \overline{s} \tag{24}$$

This shows that the government may be able to lock the spot rate s to $\overline{s}$ on average (provided that the government has sufficient foreign reserve), but not always. Indeed, from the spot exchange rate equilibrium Equation (16), it shows that there are so many factors that may affect the level of spot rate, rendering any government intervention a very difficult task to accomplish. For example, Taylor [33] highlights that central banks from Canada, France, Germany, Italy, Japan, Spain, Switzerland, the United Kingdom, and the United States incurred substantial losses, estimated at around \$12 billion, while attempting to stabilize exchange markets during the 1970s. Furthermore, Naranjo and Nimalendran [34] find that bid-ask spreads diverged with government foreign exchange rate intervention during the period 1976-1994, which increased estimated \$27.5 billion transaction costs on an annualized basis.

3. Arbitrage Mechanism to Fix Spot Exchange Rate

Based on the general framework established in Section 2, this section aims to establish a market arbitrage mechanism to fix the spot rate to its official parity. However, as argued by Shleifer and Vishny [35], there are limits to the market arbitrage. This paper therefore purposes to identify the sufficient conditions that can ensure the market arbitrage mechanism to lock the spot rate to the official rate.

Specifically, it is shown that if all the following three conditions are satisfied, it is sufficient for $s^* = \overline{s}$, even without government direct intervention in the spot market, *i.e.*, $q = 0$. That is, it becomes a "buy low and sell high" profit-making strategy without risk. However, it will also illustrate that a violation of any one of the conditions may fail to lock s^* to $\overline{s}$. Without loss of generality, assume that the spot market HKD is devalued against its official parity, *i.e.*, the observed spot exchange rate $s > \overline{s}$. Define this as a devaluation game. A revaluation game where $s < \overline{s}$ can be analyzed in a parallel way.

Condition (i). There must be a committed official convertibility undertaking (CU) rate $\overline{s}$ which convinces a group of arbitrageurs, $\mathrm{G} \subset \{i \mid i = 1, 2, \cdots, N_a\}$, that their perceived spot rate s_{ai} has no uncertainty and is not a random variable anymore, *i.e.*, $\sigma_{sai}^2 = 0$, $\forall i \in \mathrm{G}$, such that

$$s_{ai} = \overline{s}_{ai} = \overline{s}\,. \tag{25}$$

Condition (i) permits agents in group G to conduct risk-free arbitrage between the official convertibility undertaking rate $\overline{s}$ and the spot market rate s.

This is illustrated in **Table 2** in a devaluation game. To start with, suppose the observed market spot rat s is devalued against the official convertibility undertaking (CU) rate $\bar{s}$, with $s > \bar{s}$. Upon identifying an arbitrage opportunity between the market spot rate and official convertibility undertaking (CU) rate $\bar{s}$, the arbitrageur i immediately deploys her arbitrage fund a_i to go long on the domestic currency HKD while shorting foreign currency USD in the amount of a_i/s (as shown in column 1 of **Table 2**). Simultaneously, the arbitrageur executes a reverse transaction, going long on USD in the same amount of a_i/s by paying $a_i\bar{s}/s$ worth of HKD through the monetary authority's trading window, thereby activating the official convertibility undertaking (see column 3). The profit, after deducting the transaction costs, made by the arbitrageur, $a_i\left[(1-t)-(1+t)\bar{s}/s\right]$, is risk-free without any uncertainty (column 5).

Table 2. Transaction record of the arbitrageur.

	At current spot open market		At the monetary authority's trading window		Profits (ω) (5) (=(1) + (2) + (3) + (4))
	Trade volume (1)	Transaction cost (2)	Trade volume (3)	Transaction cost (4)	
HKD	$+a_i$	$-a_i t$	$-a_i\bar{s}/s$	$-ta_i\bar{s}/s$	$a_i\left[(1-t)-(1+t)\bar{s}/s\right]$
USD	$-a_i/s$		$+a_i/s$		0

This table shows the transaction records of an arbitrageur i in a devaluation game with $\bar{s} < s$. That is, the arbitrageur i seizes the arbitrage opportunity between the spot rate s and the official convertibility undertaking (CU) rate $\bar{s}$. "+" indicates a purchase and "−" indicates a sale or a payment. t is the unit transaction cost, which is assumed to be paid in HKD. All profits are denominated in HKD for simplicity.

Next, the spot market equilibrium is derived by incorporating the full impact of the market arbitrage mechanism. Define

$$\lambda = \sum_{i\in G}\frac{1}{\alpha_i\sigma_{sai}^2} \tag{26}$$

and insert λ into Equation (16):

$$\begin{aligned} s^* &= \frac{\bar{s}\sum_{i\in G}\frac{1+t}{\alpha_i\sigma_{sai}^2}+\sum_{i\notin G}\frac{(1+t)\bar{s}_{ai}}{\alpha_i\sigma_{sai}^2}+\frac{(1+t)^2}{1-t}\sum_{j=N_a+1}^{K}\left(\frac{\bar{s}_{bj}}{\beta_j\sigma_{sbj}^2}\right)+(1+t)^2 c_h}{\sum_{i\in G}\frac{1-t}{\alpha_i\sigma_{sai}^2}+\sum_{i\notin G}\frac{1-t}{\alpha_i\sigma_{sai}^2}+\frac{(1+t)^3}{(1-t)^2}\sum_{j=N_a+1}^{K}\frac{1}{\beta_j\sigma_{sbj}^2}} \\ &= \frac{\frac{\bar{s}(1+t)}{\lambda}+\sum_{i\notin G}\frac{(1+t)\bar{s}_{ai}}{\alpha_i\sigma_{sai}^2}+\frac{(1+t)^2}{1-t}\sum_{j=N_a+1}^{K}\left(\frac{\bar{s}_{bj}}{\beta_j\sigma_{sbj}^2}\right)+(1+t)^2 c_h}{\frac{1-t}{\lambda}+\sum_{i\notin G}\frac{1-t}{\alpha_i\sigma_{sai}^2}+\frac{(1+t)^3}{(1-t)^2}\sum_{j=N_a+1}^{K}\frac{1}{\beta_j\sigma_{sbj}^2}} \\ &= \frac{\bar{s}(1+t)+\lambda\left[\sum_{i\notin G}\frac{(1+t)\bar{s}_{ai}}{\alpha_i\sigma_{sai}^2}+\frac{(1+t)^2}{1-t}\sum_{j=N_a+1}^{K}\left(\frac{\bar{s}_{bj}}{\beta_j\sigma_{sbj}^2}\right)+(1+t)^2 c_h\right]}{(1-t)+\lambda\left[\sum_{i\notin G}\frac{1-t}{\alpha_i\sigma_{sai}^2}+\frac{(1+t)^3}{(1-t)^2}\sum_{j=N_a+1}^{K}\frac{1}{\beta_j\sigma_{sbj}^2}\right]} \end{aligned} \tag{27}$$

Hence, $\forall i \in G$, it has:

$$\lim_{\sigma_{sai}^2 \to 0} s^* = \lim_{\lambda \to 0} s^* = \bar{s}(1+t)/(1-t). \tag{28}$$

This implies the spot rate is locked to $\bar{s}$ subject to the transaction cost.

Condition (ii). $t = 0$ (no transaction cost).

It implies that:

$$\lim_{t \to 0} s^* = \bar{s}. \tag{29}$$

Condition (iii). Abundant arbitrage funds and official foreign reserves.

This proves that the three conditions (i), (ii), and (iii) together provide a market environment for the "buy low and sell high" profit-making strategy without risk. To see the importance of condition (iii), rewrite Equation (13) without government intervention ($q = 0$) as follows:

$$\sum_{i \in G} a_i(s) + \sum_{i \notin G} a_i(s) = \sum_{j=N_a+1}^{K} b_j(s) + sc_h$$

or,

$$\sum_{i \in G} a_i(s) = \sum_{j=N_a+1}^{K} b_j(s) - \sum_{i \notin G} a_i(s) + sc_h \tag{30}$$

Let the non-arbitrage fund as the right-hand-side of Equation (30):

$$B(s) \equiv \sum_{j=N_a+1}^{K} b_j(s) - \sum_{i \notin G} a_i(s) + sc_h \tag{31}$$

where $a_i(s)$ and $b_j(s)$ are defined in Equations (5) and (11) respectively, and c_h is the net supply of HKD by liquidity traders.

If $c_h < 0$, the $B(s)$ curve of non-arbitrage fund is depicted in Figure 2 as downward sloping because $\partial b_j/\partial s < 0$ from Equation (11) and $-\partial a_i/\partial s < 0$ from equation (6). If $c_h > 0$ and c_h is not excessively large, then $\partial B(s)/\partial s < 0$ still may hold and $B(s)$ curve remains downward sloping. If c_h is excessively large that leads to $\partial B(s)/\partial s > 0$, then $B(s)$ curve will be upward sloping; however, this does not

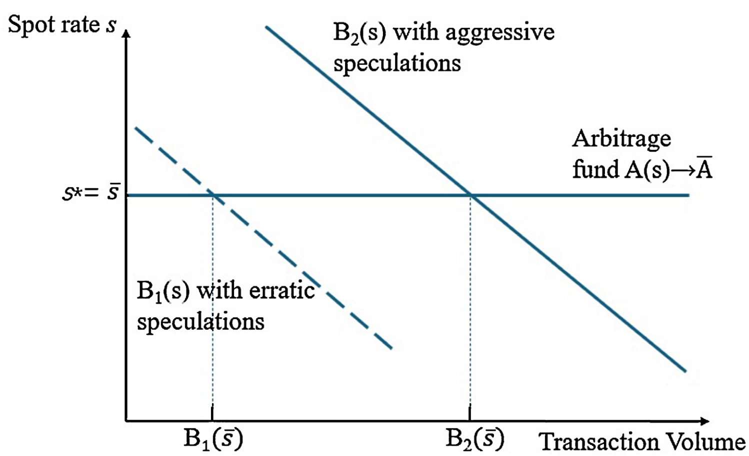


Figure 2. Fixed exchange rate regime with arbitrage mechanism and sufficient arbitrage fund.

change the qualitative results of this analysis. For simplicity, this study focuses on cases where the $B(s)$ is a downward sloping curve. In **Figure 2**, it shows two non-arbitrage funds' curves. $B_1(s)$ is the fund with small erratic speculation activities. $B_2(s)$ is the fund with large aggressive speculation activities.

Let the arbitrage fund as the transaction volume of the left-hand-side of equation (30):

$$A(s) \equiv \sum_{i \in G} a_i(s) \tag{32}$$

If $\sigma_{sai}^2 \to 0$, then $A(s)$ approaches to its upper limit. It can also be understood why $A(s) \to \bar{A}$ by looking at **Table 2**, which shows the transaction record of an arbitrageur i. The profit made by the arbitrageur, $a_i\left[(1-t)-(1+t)\bar{s}/s\right]$ (see column 5), is risk-free without any uncertainty. The arbitrageur will put up all her arbitrage fund to engage in the arbitrage, leading to $A(s) \to \bar{A}$. In **Figure 2**, the arbitrage fund $A(s)$ is depicted as a horizontal line at the official parity $s^* = \bar{s}$, assuming zero transaction cost $t = 0$.

Figure 2 illustrates the effect of the establishment of the arbitrage mechanism on the spot market equilibrium solution. It shows that the horizontal arbitrage fund schedule at $\bar{s}$ has abundant amount of $A(s)$. The spot rate is fully locked at the official parity $\bar{s}$, no matter there is a small erratic speculation attack $B_1(s)$, or a large aggressive speculative attack $B_2(s)$ on the HKD, since the upper limit of the arbitrageur fund $\bar{A} > B_2(\bar{s}) > B_1(\bar{s})$.

A crucial question is what would happen if arbitrage fund is not sufficient, e.g.,

$$B_2(\bar{s}) > \bar{A} > B_1(\bar{s}) \tag{33}$$

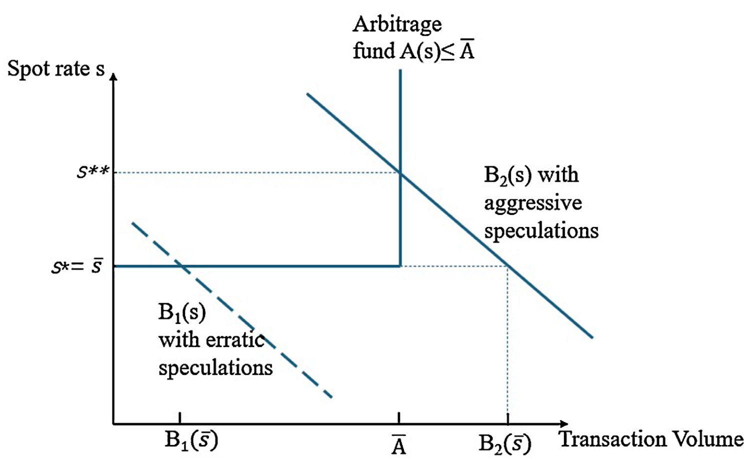


Figure 3. Fixed exchange rate regime with an arbitrage mechanism but insufficient arbitrage fund.

A simple case is that both conditions (i) and (ii) are satisfied but condition (iii) is not met. **Figure 3** depicted an example of such a situation. When there is a small erratic speculation attack on the domestic currency HKD, the arbitrage fund is just enough to defeat the speculation attack and the spot rate is still locked at the official parity $\bar{s}$ (see the $B_1(s)$ curve in **Figure 3**). However, when a large aggressive attack occurs (see the $B_2(s)$ curve in **Figure 3**), because of insufficient arbitrage fund ($\bar{A} < B_2(\bar{s})$), there is an excess supply of domestic currency by speculators that results in a devaluation of the market spot rate s^{**}, *i.e.*, $s^{**} > \bar{s}$. The shortage of arbitrage fund is given as $B_2(\bar{s}) - \bar{A}$.

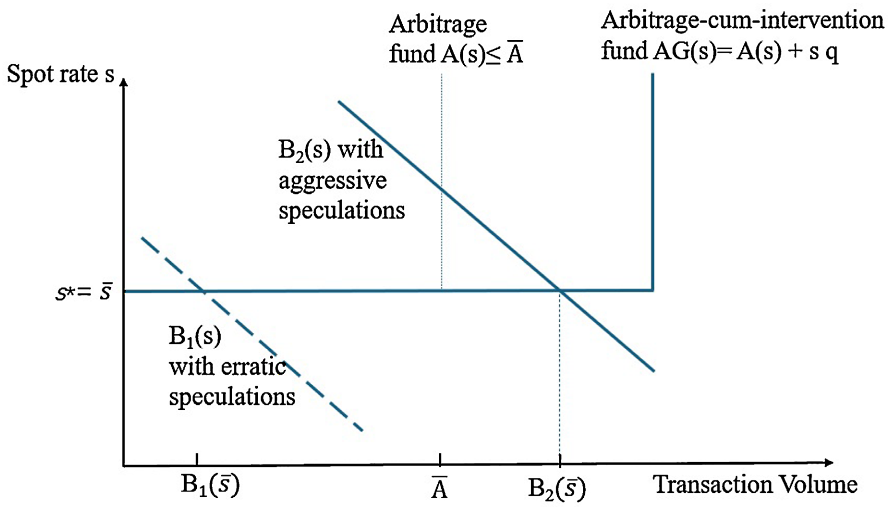


Figure 4. Fixed exchange rate regime with arbitrage mechanism and government intervention.

In this circumstance, government intervention (*i.e.*, $q > 0$) may have to be called upon to help restore s^* to $\bar{s}$. **Figure 4** illustrates such a situation. For example, the arbitrage-cum-intervention fund is defined as

$$AG(s) = A(s) + sq \tag{34}$$

If this combined fund $AG(s)$ is abundant, e.g., $AG(\bar{s}) = \bar{A} + \bar{s}q > B_2(\bar{s})$, then it extends the horizontal line of the arbitrage fund further to the right. It can effectively defeat the aggressive speculative attacks to restore $s^* = \bar{s}$ again. However, if the government lacks foreign reserves such that $AG(\bar{s}) = \bar{A} + \bar{s}q < B_2(\bar{s})$, then even the government intervention is helpless to fend off the aggressive speculation attacks. Although this study focuses on a devaluation attack game, a *revaluation* game can be analyzed in a parallel way.

4. Institutional and Empirical Relevance

This section explores the institutional and empirical relevance of the theoretical arbitrage-speculation model of spot exchange rate determination. It will discuss the main issues with regards to the following three exchange rate regimes: floating rate, fixed rate without arbitrage mechanism, and fixed rate based on the market forces of arbitrage.

4.1. Floating Exchange Rate Regime

In the case of floating exchange rates where the fundamental value $\bar{s}$ is not easily observable. Hence, the perceived fundamental mean value of the spot rate $\bar{s}_k$ of agent k may be inconsistent with $\bar{s}$ and the perceived variance σ_k^2 may be non-zero. As a result, the equilibrium spot exchange rate may not be equal to $\bar{s}$, as Figure 1 illustrates. Over time, $\bar{s}$ may still not be observable and that may generate persistent deviations of the equilibrium spot exchange rate from $\bar{s}$. The lack of informational certainty about $\bar{s}$ may further create difficulties for arbitrage and may actually encourage speculations. As a result, the spot rate may drift further away from $\bar{s}$ because of noise.

4.2. Fixed and Semi-Fixed Exchange Rate Systems without Arbitrage Mechanism

In this case, the government establishes an official parity in a fully fixed exchange rate regime. Alternatively, the government sets up a central parity in a semi-fixed exchange rate regime. Examples of the former type include the situations in most developing countries with fixed exchange rate arrangements. As to the latter, the best example is Exchange Rate Mechanism (ERM) in Europe during 1980s and 1990s. Suppose $\bar{s}$ is the government-set central parity in such a case. This central parity may or may not equal the fundamental value of the exchange rate. As there is a clear target, the perceived mean value of the spot rate, $\bar{s}_k$, may be consistent with $\bar{s}$, at least for some agents *k*.

However, the historical evidence showed that the government interventions in these fixed rate regimes have not been transparent. Bhattacharya and Weller [36] and Fernholz [37]), for example, argue that the "policy secrecy" or "constructive ambiguity" about the scale and the target of intervention might have advantage for the central bank as they have deterrent effects on the speculators. This result is consistent with the prediction of the model of this study. The non-transparency of policy generates uncertainty to speculators and the perceived variance σ_k^2 is non-zero. A higher degree of policy non-transparency will increase σ_k^2 and that will reduce speculative activities.

This should mean that spot rate stability would be enhanced. For example, Krugman's [9] target-zone model shows that there should be an automatic stabilizing effect on the exchange rate. However, an evident empirical puzzle is that this has not been the case. The spot exchange rates in most of these regimes have never been fully locked as the authorities expected. Nor did they pass the empirical stability tests on target zones (Svensson [10]).

The behavioral model of this paper may be useful to shed some light on this empirical puzzle. The above "constructive ambiguity" argument is only half of the story. In fact, non-transparency of policy generates uncertainty to both speculators and arbitrageurs. As a result, the perceived variance σ_k^2 for both arbitrageurs and speculators is non-zero and would rise if policy becomes less transparent. This deters both arbitrage as well as speculation activities. Overall, policy uncertainty violates the sufficient conditions to lock the spot rate to $\bar{s}$. In other words, in the absence of a market arbitrage mechanism, this type of fixed exchange rate regimes has not provided a firm anchor for arbitrageurs to restore the official parity of the exchange rate.

4.3. The Gold Standard: Fixed Exchange Rate Regime with Gold Arbitrage Mechanism

A gold standard requires the central bank to undertake two-way convertibility, *i.e.*, from domestic to foreign currency and vice versa, at the fixed gold point to their fiat money. If two countries both adopt a gold standard, their bilateral exchange rate is effectively fixed via the gold points (Tsang [5]). In a hypothetical case, if the Hong Kong Monetary Authority (HKMA) fixes one HKD to p_{HK} ounces of gold and the US Monetary Authority (USMA) fixes one USD to p_{US} ounces of gold. The bilateral exchange rate between HKD and USD is effectively fixed at

$$\bar{s} = p_{US} / p_{HK} \quad \text{(HKD per USD)} \tag{35}$$

Any deviation of the spot rate from this fixed rate will generate a profitable opportunity for arbitrageurs via gold arbitrage, subject to transaction costs. As long as there is an adequate supply of gold, with the potential for recycling to support arbitrage activities, the need for government intervention in the foreign exchange market is reduced under the gold standard. This serves as a good example of a transparent and market-driven fixed exchange rate system.

To illustrate the arbitrage mechanism in the gold standard, suppose there is a group of gold arbitrageurs, G, who take the view that $s_{ai} = \bar{s}_{ai} = \bar{s}$ without uncertainty, *i.e.*, $\sigma_{sai}^2 = 0$, $\forall i \in \mathrm{G}$. Table 3 presents the gold arbitrage mechanism in a devaluation game for the HKD with $\bar{s} < s$. In this example, the market spot rat s deviates from the official parity $\bar{s}$, indicating the HKD being devalued against the USD. The gold arbitrageur i seizes this arbitrage opportunity. She will short foreign currency USD in the amount of a_i/s and long domestic currency HKD in the amount of a_i at the spot exchange market (see column 1 in Table 3).

Table 3. Transaction record of the gold arbitrageur under the gold standard.

	At current spot open market		At the monetary authority's trading window				Profits (ω) (7) (=(1) + (2) + (3) + (4) + (5) + (6))
			Hong Kong SAR		USA		
	Trade volume (1)	Transaction cost (2)	Trade volume (3)	Transaction cost (4)	Trade volume (5)	Transaction cost (6)	
	Currency transactions volume						
HKD	$+a_i$	$-a_i t_1$	$-a_i \bar{s}/s$	$-t_2 a_i \bar{s}/s$		$-a_i t_3$	$a_i\left[(1-t_1-t_3)-(1+t_2)\bar{s}/s\right]$
USD	$-a_i/s$				$+a_i/s$		0
	Gold transactions volume						
Gold			$+p_{HK} a_i \bar{s}/s$		$-p_{HK} a_i \bar{s}/s$		0

This table shows the transaction records of a gold arbitrageur i in a devaluation game with $\bar{s} < s$ under the gold standard. That is, the gold arbitrageur i seizes the arbitrage opportunity between the market spot exchange rate s and the official parity $\bar{s}$, where $\bar{s} = p_{US}/p_{HK}$ is the implicit official parity of bilateral spot exchange rate of HKD per USD, p_{HK} and p_{US} are the official gold parity per HKD and USD, respectively. "+" indicates a purchase and "−" indicates a sale or a payment. t is the unit transaction cost, which is assumed to be paid in HKD. All profits are denominated in HKD for simplicity.

To close her position, the gold arbitrageur would reverse the transaction by carrying out gold buying and selling with the HKMA and the USMA respectively. Firstly, she needs to sell the amount ($a_i\bar{s}/s$) of HKD to HKMA and get $(a_i\bar{s}/s)\,p_{HK}$ amount of bullion in return (column 3). Secondly, as shown in column 5 of **Table 3**, she has to transport this $(a_i\bar{s}/s)\,p_{HK}$ amount of bullion to the US and sell it to the USMA. In return, she will get USD $(a_i\bar{s}/s)\,p_{HK}/p_{US} = a_i/s$, which is exactly the same amount of USD she sold in column 1.

Transactions of USD in column 5 constitute the reverse transaction to column 1 of **Table 3**. While transactions of gold in column 5 constitute the reverse transaction to column 3 of **Table 3**. Effectively, gold arbitrage allows arbitrageurs to implement the reverse transactions at the fixed rate, $\bar{s}$, without uncertainty, as both HKMA and USMA fully commits to two-way convertibility undertaking at fixed gold points. Repeated arbitrage activities eventually will compete away the profits of gold arbitrageurs by appreciating the HKD against the USD, *i.e.*,

$$\omega_{ai} = a_i\left[(1-t_1-t_3)-(1+t_2)\bar{s}/s^*\right]=0 \tag{36}$$

Similar to equation (28), the arbitrage exchange rate model gives the equilibrium spot rate as follows:

$$\lim_{\sigma_{sai}^2\to 0} s^* = \bar{s}(1+t_2)/(1-t_1-t_3), \tag{37}$$

if there is sufficient gold for arbitrage.

This implies that the spot exchange rate can be effectively locked subject to the transaction costs if gold bullion is in sufficient supply in countries adopting the gold standard. The collection of works by Officer [38] provides empirical evidence to support the prediction from the new model of this paper. Officer [38] shows that the gold standard was efficient if it takes account of the transaction costs, which included those on transportation and various forms of financing schemes.

4.4. Classical Currency Board: Fixed Exchange Rate Regime with Cash Arbitrage Mechanism

Another type of fixed exchange rate regime without government intervention is the currency board system. Varieties of it were practiced mainly in former British colonies (Schwartz [39]); and now in Hong Kong SAR, Macao SAR, Bulgaria, Brunei, amongst others (IMF [14]). The classical "currency board" issues currency notes, *i.e.*, cash, with 100 per cent foreign reserve backing at a fixed exchange rate under a two-way convertibility undertaking. This represents a strong commitment to economic discipline. Any holder of paper money therefore rests assured that he can exchange it into foreign currency at the fixed rate and vice versa.

Similar to the gold standard, the *classical* currency board arrangements (CBAs) depends on cash-based arbitrage to fix the spot exchange rate. Since the exchange rate of paper money is fixed, the rate of bank deposit has to follow suit. Any rate differential gives rise to profitable activity that closes the gap. As there is no government discretion, it eliminates the uncertainty for arbitrageurs. Suppose there is a group of arbitrageurs, G, take the view that $s_{ai} = \bar{s}_{ai} = \bar{s}$ without uncertainty, *i.e.*, $\sigma_{sai}^2 = 0$, $i \in G$. It may illustrate their cash arbitrage activities by **Table 2** again. They long HKD and short USD at the spot market (see column 1 of **Table 2**). At the same time, they can also *physically* move their cash and sell it to the HKMA. They get USD in return and can sell it at spot market, reversing the transaction. This is illustrated in column 3. As HKMA fully commits to two-way convertibility at the fixed rate, these transactions face no uncertainty.

If arbitrage fund is abundant, it should be able to get the same equilibrium spot rate as that under the gold standard. In other words, the spot rate should be still be fixed subject to the transaction cost of cash arbitrage. For instance, in October 1983, the government of Hong Kong requested its Exchange Fund to have purchased US$100 million in cash, physically stored in a vault in Hong Kong, from the Federal Reserve Bank of New York (James [40], p. 194). This action took place when the government adopted Greenwood's [15] proposal to return to a classical currency board arrangements and resolved the currency crisis on 15th October 1983. At that time, the government anticipated that it would be a large shortage of USD cash arbitrage fund held by market arbitrageurs. Given the circumstances, government intervention by injecting USD cash to the market was inevitable, resembling the scenario previously discussed in **Figure 4**. The purchase of USD cash in advance represented a significant political and economic commitment. The historical records of some small British colonies operating a sterling CB show that their exchange rates are fully fixed to the pounds (Williamson [16]).

However, exceptions can also be found. For example, just before the 1997 Asian Financial Crisis, Tsang [5] [19] highlighted one of the weaknesses in Hong Kong's currency board arrangements at that time. He argued that as Hong Kong developed into a modern financial economy and achieved the status of an international financial center, cash accounted for a very small—and increasingly shrinking—portion of the total money supply. There may be simply very little cash that can be employed for arbitrage fund. This violates the sufficient condition to lock the spot rate to the official parity $\bar{s}$ fully (see **Figure 3** again for an illustration). In reality, since the inception of the currency board arrangements (CBAs) in Hong Kong in October 1983 and until September 1998, cash arbitrage had been never effectively functioned. As a result, the Hong Kong Monetary Authority (HKMA) had to depend on the management of interbank liquidity and interest rates, as well as outright intervention in the foreign exchange market to defend the Hong Kong dollar (HKMA [41]; Tsang [5]). Some would call that "conventional central banking dressed up as a currency board system" (Tsang [30]). Due to imperfect information to the HKMA, significant deviations can be found in the spot rate from its official parity, although the CBAs in Hong Kong survived from the speculative attacks (Tsang [5] [19]; Tsang and Ma [20]). This is consistent with the theoretical prediction in Section 2.5 that government intervention is not effective to fix the spot rate under a classic currency board.

4.5. Modern Currency Board: Fixed or Semi-Fixed Exchange Rate Regime with Electronic Arbitrage Mechanism

After completing a series of visits to the IMF, the World Bank, and relevant central banks to conduct his commissioned project by the Hong Kong Policy Research Institute in 1996, Tsang [5] [19] discovered that several former currency board countries, including Argentina, Estonia, and Lithuania, had adopted a modernized arrangement of convertibility undertakings by their monetary authorities, referred to as the "AEL model". Convertibility at the fixed exchange rate $\bar{s}$ is extended to the whole monetary base, not just the cash base as in the case of the classical currency board arrangements (CBAs). The monetary base includes the cash base, as well as all the reserves and balances of banks with the monetary authority. This ingenious set-up bypasses the problem of moving cash around for arbitrage.

Under this "convertible reserves" system, arbitrage can be carried out by banks against each other and settled electronically through the inter-bank clearing system hosted by the monetary authority. That is, all transactions in **Table 2** are carried out electronically and simultaneously, thereby reducing the transaction cost and risk to the minimal. A real-time gross settlement system (RTGS) hosted by the monetary authority, like what Hong Kong implemented in late 1996, provides such a kind of efficient arbitrage facility (Tsang [42]).

This represents a breakthrough in arbitrage efficiency, surpassing that of both the old gold standard and the classical CBAs. Furthermore, "electronic arbitrage" should also increase substantially the available arbitrage fund, subject to the speed and cost of the settlement system. The mobilized arbitrage fund may never hit its upper limit $\bar{A}$. The mechanism of electronic settlement (that minimizes the transaction cost of arbitrage), the monetary authority's two-way convertibility undertaking, and sufficient arbitrage fund fulfill the three sufficient conditions (i) to (iii) laid out in the theoretical model in Section 3 of this paper. A modern currency board system meeting these conditions can lock the spot rate firmly at the official parity $\bar{s}$.

This recommendation was initially put forward to the Hong Kong government and the Hong Kong Monetary Authority (HKMA) in 1996 (Tsang [5] [19]; Law [43]). Its objective was to tackle vulnerabilities in Hong Kong's Linked Exchange Rate System and prepare for any potential speculative attacks on Hong Kong dollar during Hong Kong's political transition in 1997. During and after the 1997 Asian Financial Crisis, this recommendation was revisited and debated again at the HKMA and the Legislative Council of Hong Kong (Legislative Council [44]; Tsang [42] [45]).

Subsequent institutional development in Hong Kong further supports this theoretical finding and Tsang's [5] recommendations. In September 1998, the Hong Kong Monetary Authority (HKMA [46]) adopted the seven technical measures to partially strengthen the Linked Exchange Rate System, the official term for the currency board arrangements. The HKMA introduced a weak-side Convertibility

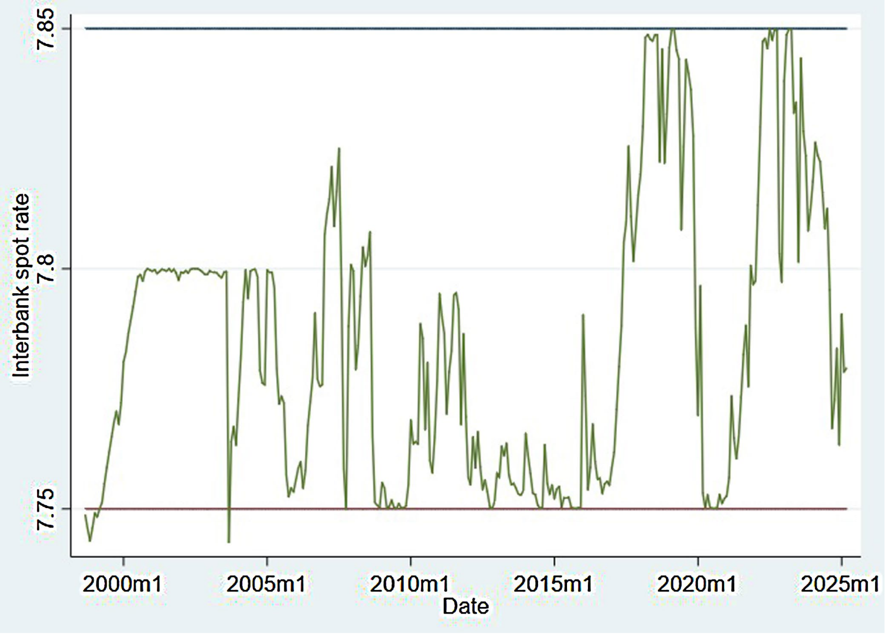
Undertaking to sell US dollars to licensed banks via an electronic system, without establishing a strong-side commitment. Consequently, from 1998 to 2003, the implicit strong-side threshold of HK$7.75 per US$ was breached on multiple occasions, although the weak-side edge remained intact throughout the period. In May 2005, the HKMA [47] further implemented a two-side Convertibility Undertaking to buy and sell US dollars with licensed banks at exchange rates of 7.75 and 7.85, respectively. This eliminated the uncertainty regarding the Hong Kong dollar's appreciation or depreciation beyond the specified band and achieved symmetry around the Linked Exchange Rate of HK$7.8 per US dollar.

This is a big political and economic commitment. It marked the full implementation of modern currency board arrangements recommended by Tsang [5] [19] and satisfied the three sufficient conditions outlined in Section 3 of this paper, albeit the new measures have introduced a hybrid exchange rate system in Hong Kong. On the strong- and weak-side of the band, the banks may trigger convertibility undertakings with the HKMA. Within the band, the Hong Kong dollar is a managed floating rate arrangement with limited arbitrage uncertainty, as the HKMA [47] may choose to conduct market operations to smooth the operation of the exchange rate system.

Nevertheless, following these strengthening measures, the Hong Kong dollar has remained firmly pegged to the US dollar within the official committed band. Furthermore, the Hong Kong's modern currency board system has withstood numerous crises, including the 9/11 terrorist attacks in 2001, the SARS outbreak in 2002, the global financial crisis of 2008, the Brexit event in 2016, Hong Kong's social unrest in 2019, and the COVID-19 pandemic from 2019 to 2022. It has continued to function effectively during the ongoing tariff war that began in 2018.

To provide empirical data to substantiate the predictions of this paper's new model, **Figure 5** presents the monthly time series of the Hong Kong dollar's interbank spot exchange rate against the US dollar over the period of September 1998 to March 2025. **Figure 5** clearly shows that the Hong Kong dollar has been stayed within the official Convertibility Undertaking band of 7.75 to 7.85 per US dollar. This provides direct evidence to support the prediction of the newly developed behavioral model incorporating an arbitrage mechanism and Tsang's [5] [19] foresight.

However, there are seven times before 2005 when the interbank spot rates appreciated against the US dollar that breached the 7.75 official band. It happened because the Hong Kong Monetary Authority had not yet implemented the strong-side Convertibility Undertaking to buy US dollars from licensed banks. As predicted by the behavioral model developed in this paper, when arbitrageurs encounter uncertainty regarding their arbitrage transactions, they are unable to fully commit to engaging in arbitrage. Consequently, the spot rate cannot be anchored within the official band. Only after May 2005, when the HKMA [47] implemented a two-sided Convertibility Undertaking, has the Hong Kong dollar spot rate been maintained within the official band, consistent with the predictions of the behavioral model.



This figure shows the monthly time series of the Hong Kong dollar interbank spot exchange rate (HK$ per US$) over the period of September 1998 to March 2025. A high value of the spot rate indicates a week Hong Kong dollar against the US dollar. In September 1998, the Hong Kong Monetary Authority (HKMA [46]) introduced a weak-side Convertibility Undertaking at 7.85 HK$ per US$, without the strong-side commitment. As a result, the spot rates breached the implicit strong-side official band of 7.75 HK$ per US$ seven times before 2005. In May 2005, the HKMA [47] finally implemented a two-side Convertibility Undertaking to buy and sell US dollars with licensed banks at exchange rates of 7.75 and 7.85, respectively. Since then, the interbank spot rate has remained within the official band without any breaches.

Figure 5. Hong Kong dollar interbank spot exchange rate (HK$ per US$).

To demonstrate that the Hong Kong dollar has endured multiple crises throughout the abovementioned sample period, **Table 4** presents the results of OLS regressions using the Hong Kong dollar interbank spot exchange rate (HK$ per US$) as the dependent variable, incorporating dummy variables for six major historical events as explanatory variables. The sample period is from September 1998 to March 2025, a total of 319 monthly observations. The *9/11 Attacks* dummy equals one for terrorist attacks in September 2001 and zero otherwise. The *SARS2002* dummy equals one for the period of SARS outbreak from November 2002 to May 2004 and zero otherwise. The *Crisis2008* dummy equals one over the period of global financial crisis from August 2007 to June 2009 and zero otherwise. The *Brexit2016* dummy variable is assigned a value of one in June 2016 to represent the Brexit event—the UK-wide referendum held on 23 June 2016, in which 52% of voters supported leaving the EU—and zero in the remaining month-years. The *Social unrest* dummy equals one for the period of Hong Kong SAR's social unrest during June 2019 to June 2020 and zero otherwise. The *COVID-19* dummy equals one over the pandemic period of January 2020 to May 2023.

In **Table 4**, columns 1 to 6 introduce each major event dummy variable

Table 4. Impact of historical events on the Hong Kong currency board system.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
9/11 Attacks	0.0039						0.0036
	(0.7898)						(0.8044)
SARS2002		−0.0009					−0.0006
		(0.8910)					(0.9252)
Crisis2008			−0.0168***				−0.0168***
			(0.0031)				(0.0031)
Brexit2016				−0.0046			−0.0052
				(0.7559)			(0.7178)
Social unrest					−0.0061		−0.0062
					(0.2879)		(0.2727)
COVID-19						0.0190**	0.0189**
						(0.0213)	(0.0206)
Month fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year fixed effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Number of Observations	319	319	319	319	319	319	319
Adjusted R^2	0.7830	0.7829	0.7897	0.7830	0.7838	0.7870	0.7910

This table presents OLS regression results on the impact of six historical events on the Hong Kong dollar interbank spot exchange rate. The sample period is from September 1998 to March 2025. The dependent variable is the Kong dollar interbank spot rate HK$ per US$. A positive (negative) coefficient indicates a depreciation (appreciation) impact on the Kong dollar against the US dollar. P-values are reported in parentheses. ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively. The monthly time series of the interbank spot rate is downloaded from the Hong Kong Monetary Authority website: https://www.hkma.gov.hk/eng/data-publications-and-research/data-and-statistics/economic-financial-data-for-hong-kong.

individually in the regression, while column 7 incorporates all six event dummies within the same regression model. Additionally, each regression includes 11 month dummy variables (*i.e.*, February to December) to account for seasonal effects, with January omitted as the reference month. Year fixed effects are also included in capturing the annual macroeconomic developments such as trade balance, GDP per capita, inflation, and employment.

Columns 1, 2, 4 and 5 of **Table 4** show that these four historical events did not generate statistically significant impact on the Hong Kong dollar interbank spot exchange rate at the 10% level. But column 6 and 7 both show that the COVID-19 pandemic from 2019 to 2023 has a persistent devaluation impact on the Hong Kong dollar that is significant at the 5% level. Interestingly, the global financial crisis dummy shows an appreciation impact on Hong Kong dollar that is statistically significant at the 1% level. This was a result of the subprime crisis originating in the United States, which had spillover effects on Europe. These effects triggered capital flows into Hong Kong's financial market, positioning it as a relatively safe international financial center in Asia. In conclusion, despite the series of events impacting the Linked Exchange Rate System, **Figure 5** demonstrates that Hong Kong's currency board remains robust, with the interbank spot rate consistently maintained inside the official band up to March 2025, which provides strong evidence to support the prediction of the behavioral model and Tsang's [5] [19] foresight.

Parenthetically, while this study employs a simple dummy variable approach to test the stability of the Hong Kong dollar, it may oversimplify its complex dynamics. For example, Krugman's [9] target zone model does not assume government interventions within the band (Flood and Garber [48]). However, under the current currency board arrangements in Hong Kong, the HKMA [47] may choose to intervene in foreign exchange markets when the Hong Kong dollar exchange rate is within the band, if it deemed necessary. Future research could benefit from more sophisticated empirical designs, such as structural equation modeling or time-series analysis, to capture the intricate interplay of factors influencing the credibility and stability of the hybrid exchange rate system in Hong Kong.

One final note is in order. It is important to emphasize that modern currency board arrangements, like the gold standard, are technical mechanisms designed to stabilize exchange rates. They cannot be substitutes for sound policies to address broader economic or financial challenges (Tsang [30]). For instance, it has been widely recognized that the gold standard cannot serve as a remedy for inflation, if the political economy cannot commit to constrain inflation (Flood and Garber [49]). The gold standard also cannot be served as instruments to cure excessive public debt, if the government cannot discipline its fiscal deficits (Cochrane [50]).

Similarly, Argentina adopted a solid modern currency board in 1991 but was forced to abandon it in early 2002 due to poor economic fundamentals. By contrast, Hong Kong's currency board has thrived, thanks to its vibrant and adaptable economy, as well as its determined political-economic commitment, which has successfully navigated the evolving global landscape over the past four decades. Likewise, Fernández-Villaverde and Sanches [13] present a successful gold standard with full commitment to price stability and fiscal discipline in their theoretical analysis. In conclusion, a stable exchange rate regime is underpinned by a resilient economy with sound macroeconomic policies, and vice versa. The two are inherently complementary.

5. Conclusions

This paper develops a behavioral spot exchange rate model from an explicitly micro-market perspective. The equilibrium spot exchange rate is determined by the balance between arbitrage and speculation, given the exogenous position of liquidity traders. It provides plausible explanations for the apparent puzzle of flexible exchange rate models based on macroeconomic approaches, and the problems in fixed exchange rate regimes supposedly underpinned by discretionary government intervention. The model of this study sheds some light on the reasons behind the success of certain fixed exchange rate regimes, especially those based on market-driven arbitrage mechanisms such as the old gold standard and modern currency board arrangements. This study argues that a transparent exchange rate system with a credible convertibility undertaking, augmented by an effective arbitrage mechanism, can lock the spot rate at the official parity through the market force with sufficient arbitrage fund.

On the other hand, under a floating exchange rate regime, uncertainty of various forms may result in the spot rate drifting away from the fundamental value, even persistently. A non-transparent, semi-fixed exchange rate system, such as the European Exchange Rate Mechanism (ERM) or a target zone, may generate unsettling noise regarding both the scale and the level of policy interventions. The result would be a dampening effect on both speculation and arbitrage, and the lack of stabilization of the spot exchange rate around the fundamental value or the official parity.

Among the existing fixed exchange rate regimes in the world today, this study shows that the modern currency board is an effective market-driven system that harnesses market forces with an efficiency that is even higher than that in the old gold standard. In theory, an ideal currency board should provide (i) electronic interbank settlement; (ii) an official two-way convertibility undertaking covering the monetary base at the fixed exchange rate; and (iii) sufficient arbitrage funds (Tsang [5] [19]). These would satisfy the three sufficient conditions laid out in the theoretical model of this paper to lock the spot rate firmly. In practice, Hong Kong's strengthened modern currency board arrangements after the 1997 Asian Financial Crisis provided a successful empirical showcase to support the prediction of the theoretical findings of this paper and the foresight of Tsang [5] [19].

Finally, the behavioral model developed in this paper may also help identify potential strategies for stabilizing the exchange rates of digital and crypto currencies against official currencies, such as the US dollar, provided there is sufficient political and economic will to implement such measures. Given the decentralized nature of cryptocurrency markets, their equilibrium exchange rates rely solely on market behaviors. With appropriate modifications, the analytical framework of this study could be potentially adapted to explore cryptocurrency markets in depth in future research.

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Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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