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CONDITIONS OF PURE ARBITRAGE APPLICATIONS: EVIDENCE FROM THREE CURRENCIES

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ABSTRACT. This study analyzes the pure arbitrage conditions across three of the "Anglo-Saxon capitalism" currencies: Australian dollar, British pound, and US dollar. We examine the relationship between spot-forward exchange rates and domestic-foreign interest rates in financial markets. We find that the most important determinants that contribute to the occurrence of pure arbitrage conditions are domestic spot currency rate and domestic interest rate. Daily data is collected from the DataStream/Thomson Reuters database and analyzed in probit regression models. The predicting accuracy check is conducted through in-sample and out-of-sample tests. Our results indicate that the level of significance for factor coefficients and prediction accuracy decrease with the time lag: the longer the time lag, the lower the prediction power.
JEL codes: F31; G15

Keywords: foreign exchange; interest rate; currency risk; pure arbitrage; prediction power; probit model

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1. Introduction

The "arbitrage paradox," initially identified by Grossman and Stiglitz (1976, 1980), argues that the windows for pure arbitrage appear only when they become the most unanticipated by the currency- and/or credit markets. That is, the general expectations of non-existence for riskless pure arbitrage opportunities, especially when transaction costs are involved, will lead to the investing public's observational negligence and thus the actual occurrence of arbitrage (Akram et al., 2008). Such pure arbitrage opportunities may be rare and short-lived in real financial markets, yet their actual existences are far from negligible for practitioners.

One of the well-discussed pure arbitrage examples is "covered interest arbitrage" (e.g., Madura, 2007), which involves coinstantaneous transactions across the domestic and foreign spot currency markets, the domestic and foreign forward/futures currency markets, in addition to the domestic and foreign credit markets. Presumably, if there are sufficient numbers of arbitrageurs in perfectly competitive cross-country financial markets, the covered interest arbitrage profits, if any, will be quickly eliminated by adjustment of one or more of these exchange and interest rate variables. However, in the actual global financial markets which may be non-perfectly-competitive (with heterogeneous expectations) and/or not strongly efficient in reflecting information (due to various policy regulations and interventions across countries), the potential profits from such arbitrages could still be available with some momentums, which can be identified at least ex-post.

By examining the spot-forward relationship in some specific currency markets and domestic-foreign relationship in corresponding credit markets, the main objectives of this research work are a) to find out the frequency of pure arbitrage conditions; b) to indentify the underlying factors that may lead to the occurrence of pure arbitrage conditions; c) to test the accuracy of the model that we build for predicting the pure arbitrage conditions; and d) to summarize the rules regarding how the changes in exchange rates and interest rates can affect the timings on which the pure arbitrage opportunities occur and end. We focus on analyzing those time series of exchange rate and associated interest rate cross banding over the three currencies (Australian dollar, US dollar and British pound) during the "January 1, 1999–December 31, 2012" periods, and investigate the periods when the pure arbitrage conditions exist with the highest frequencies.

Pure arbitrage aims at achieving profits as much "risk-free" and "frictionless" as possible; therefore its application effectiveness depends on some important market conditions, such as the similarity in economic risk environments across involved countries, and the low level of restrictions in currency- and credit markets. The recent findings vary on the significance of CIRP deviations and the associated arbitrage opportunities across developed coun-

tries (e.g., Batten and Szilagyi, 2010) or emerging economies (e.g., Hague, 2010; Skinner and Mason, 2011). However, our empirical research is so far the first known attempt focusing on the currency- and credit-market interactions across three particular countries (Australia, the UK, and the US). They share the same language, largely similar cultures and comparable financial market freedoms, thus they are presumably the most "ideal" for riskless and frictionless pure arbitrage implementations. How effectively the pure arbitrage opportunities, if any, can be identified and captured across these three "Anglo-Saxon Capitalism" economies, should arouse particular interest of research. Such a study can provide updated practical advice to investors and traders who are participating in the international currency and credit markets, especially for the purpose of rebalancing arbitrage model factor weights.

2. Literature Review

Our literature reviews focus on some key areas regarding exchange and credit market conditions, with their influences contributing to the setup process of our research framework:

Covered Interest Rate Parity

Under the covered interest rate parity (CIRP), the relationship between interest rates and the spot and forward currency values of two countries are in equilibrium, with virtually no pure arbitrage opportunities (Madura, 2007). Taylor (1987), by testing arbitrage conditions in various foreign exchange markets, argues that previously recorded deviations from CIRP could be dubious from practitioners' view points, as they are not based on real-time quotes of comparable domestic-foreign interest rates and spot-forward exchange rates. However, Taylor still finds that covered interest rate arbitrages could be profitable during some periods, particularly when the exchange rates were managed by governments. Akram et al. (2008) also discover that a) covered interest arbitrage gains are more likely to occur in periods of high volatility or in illiquid markets; and b) the deviations from CIRP conditions (i.e., the arising of pure arbitrage opportunities) in those major global currency and capital markets tend to be short-lived.

Transaction Costs

The transaction costs can play an influential role in the equilibrium relationship between spot-forward exchange rates and domestic-foreign interest rates. Most of the existing empirical evidence is consistent with the CIRP theorem after adjusting for transaction cost, showing no identifiable profiting opportunities in the covered interest arbitrage (Frenkel and Levich, 1975, 1977; Callier, 1981; Levi, 1992). However, the role of transaction costs has

been found diminishing in explaining deviations of the actual forward rate from the forward parity rate (Bahmani-Oskooee and Das, 1985).

Bid-Ask Form

In this study, all data and models are described in the bid-ask form, and all market conditions are calculated by using both bid and ask rates. Rhee and Chang (1992) and Blenman and Thatcher (1997) have both, by determining arbitrage conditions in bid-ask forms, empirically tested the profitability of arbitrage opportunities. They conclude that there is statistically little chance to either earn profit under covered interest rate arbitrage or reach market equilibrium (in terms of non-reversed trades). More specifically, according to Blenman and Chen (2001), profitable arbitrage opportunities are especially rare when one-month and three-month forward rates are employed, but the occurrence of such profitable conditions grows to statistically non-trivial when the maturity of forward rate is extended to six months or beyond. Blenman (2000) also documents that if non-reversed traders set the arbitrage boundaries, there can be no other form, except for bid-ask, of profitable one-way arbitrage.

Pure and Quasi Arbitrage Conditions

Compared with "pure arbitrage" in which the identical asset is traded across different markets, "quasi arbitrage" occurs when replacing of one asset with another that has equivalent risk and higher expected return. To minimize the cost of exchanging currencies across markets, traders would choose one-way arbitrage if such is preferable to a direct transaction, and choose quasi arbitrage if such is preferable to pure arbitrage (Deardorff, 1979). Blenman (2000) and Blenman & Chen (2005), in their empirical analysis of currency market equilibrium conditions, find that non-reversed trading conditions are tighter than any other types of one-way arbitrage condition. They suggest that shall such type of trading actively set the arbitrage boundaries, the other types of profitable one-way arbitrage activities would be phased out.

Arbitrage Prediction

Luckner (2008) finds that there exist virtually few substantial pure arbitrage opportunities regarding market predictions; and the achieving the forecast accuracy highly depends on the selection of appropriate measures. Out-of-sample tests can be used to avoid data mining and to improve prediction effectiveness, as Fildes and Makridakis (1995) claim that a model, when running on data outside those used in the model construction process, remains the touchstone for its utility in all applications. Thus in general, for making their predictions more robust, forecasters are willing to employ out-of-sample tests over in-sample tests.

Current Debates about CIRP Validity and Arbitrage Effectiveness

Batten and Szilagyi (2010) employ the daily time series that cover years 1983–2005, and find that the "US Dollar vs. Japanese Yen" CIRP deviations have substantially lost their statistical significance since 2000, which implies the diminishing of covered interest arbitrage opportunities between the US and Japan. Fong et al. (2010) employ the tick-by-tick intraday data that covers 05/17/2005–12/31/2005, and find that the "US Dollar vs. Hong Kong Dollar" CIRP arbitrage profits do exist, yet they are mostly composed of liquidity- and credit-risk premiums. In addition, Liu and Witte (2013) and Csavas (2014) both use privately placed credit- and currency-swap rates (instead of open-market price quotes) of developed countries, and their sample periods cover from 2008 to 2011. However, out of these two research works, the former provides evidence of significant CIRP arbitrage profits, whereas the latter finds such CIRP arbitrage opportunities hardly exist.

As for the less developed financial markets, Bhargava et al. (2011) test the CIRP validity for BRIC nations, showing that profitable arbitrage opportunities do exist in those emerging economies during the early 2000s, but remain very limited due to transaction costs and regulative policies in their currency and capital markets. Furthermore, Haque (2010) indicates that the CIRP validity holds (i.e., no arbitrage windows exist) in the long run between the US and various emerging Asian economies, while Skinner and Mason (2011) suggest that the CIRP for emerging markets (e.g., Brazil, Chile, Russia and South Korea) only holds for the short term (e.g, up to 3-month maturity).

Such mixed findings by various previous researchers leave much room for further investigations in this field. Our study thus examines pure arbitrage conditions by emphasizing on three of the "Anglo-Saxon Capitalism" developed countries over the period of 01/01/1999–12/31/2012. Not only we consider these three countries are among the most ideal for "riskless" and "frictionless" pure arbitrages, but also our sample period covers both before and after the late-2000s international financial meltdown.

3. Data and Methodology

Our sample dataset consists of bid and ask quotes for both spot and forward exchange rates of three currencies: Australian dollar, British pound, and US dollar. It also includes the interest rates of bid and asks quotes in these three countries. Daily data series are downloaded from DataStream and Thomson Reuters database, with the test period covering from January 1, 1999 till December 31, 2012. The total numbers of observations are 3,652 for each variable of exchange rate or interest rate.

The two types of transaction costs are implicit or explicit. The former is implied in the bid-ask spread, while the latter is in terms of direct commission

as a percentage of the traded value or a fixed value. We only consider the first type of transaction cost for our study, as all involved data series and models are described in bid and ask form and all conditions are calculated by using both bid and ask rates.

The fundamental theorem of our study is based on Blenman and Chen's (2005) framework, in which equilibrium conditions of forward exchange market are expressed in a simple geometric structure. Accordingly, pure arbitrage opportunities can be identified when:

$$F_a < S_b (1+ r_b) (1+ r_a^*)^{-1} \quad (1)$$

$$F_b > S_a (1+ r_a) (1+ r_b^*)^{-1} \quad (2)$$

where F_b and F_a respectively represent the forward bid and ask exchange rates, S_b and S_a respectively denote spot bid and ask exchange rates. Currency market participants sell a currency at the bid price and buy it at the ask price; and all such prices are quoted in terms of dollar amount per unit of foreign currency. On the other hand, domestic interest rates are quoted as r_b for the bid rate and r_a for the ask rate, the corresponding foreign interest rates are bid rate r_b^* and ask rate r_a^*, at which credit market participants can lend and borrow, respectively. The major descriptive statistics of exchange and interest rates are summarized in Table I. In addition are the statistics of pure arbitrage condition dummy variable. The total numbers of pure arbitrage conditions are thus be calculated and presented in Table II. The transaction order of such pure arbitrage conditions is described in Figure A, as elaborated by Taylor (1987) and Madura (2007).

Figure A Transaction Order of Pure Arbitrage Conditions

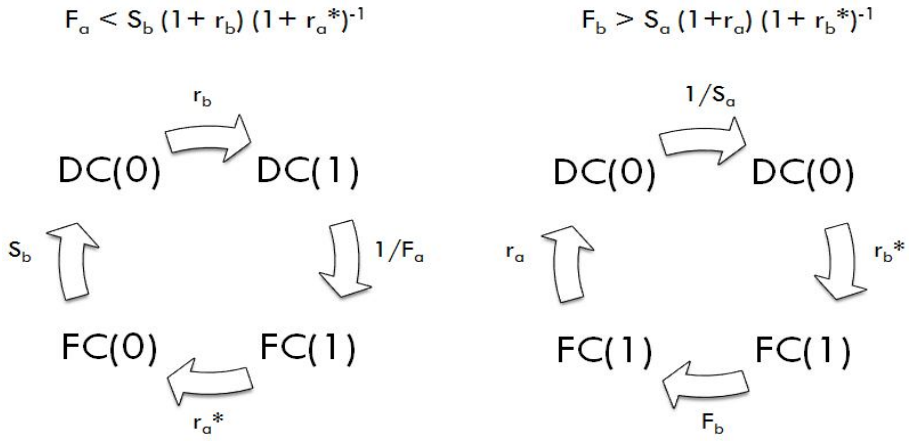


Figure A illustrates the transaction order of first and second pure arbitrage conditions. Based on Equations 1 and 2 of pure arbitrage conditions, shall the ratio of the trading circle exceed 1, pure arbitrage opportunities exist. DC(0): domestic currency spot rate, DC(1): foreign currency forward rate, FC(0): foreign currency spot rate, FC(1): foreign currency forward rate.

Table I Descriptive Statistics of Sample Data

Australian Dollars exchange to US Dollars	**Mean**	**Std.Dev.**	**Min**	**Max**
Dependent Variables				
First Pure Arbitrage Conditions Dummy	0.037	0.188	0	1
Second Pure Arbitrage Conditions Dummy	0.040	0.195	0	1
Independent Variables				
$\mathbf{F_a}$	1.408	0.301	0.949	2.092
$\mathbf{S_b}$	1.377	0.306	0.906	2.064
$\mathbf{r_b}$	0.055	0.010	0.029	0.087
$\mathbf{r_a^*}$	0.032	0.019	0.005	0.076
$\mathbf{F_b}$	1.407	0.301	0.948	2.091
$\mathbf{S_a}$	1.378	0.306	0.907	2.066
$\mathbf{r_a}$	0.057	0.010	0.036	0.088
$\mathbf{r_b^*}$	0.031	0.020	0.005	0.074
Australian Dollars exchange to UK Pounds	**Mean**	**Std.Dev.**	**Min**	**Max**
Dependent Variables				
First Pure Arbitrage Conditions Dummy	0.011	0.103	0	1
Second Pure Arbitrage Conditions Dummy	0.058	0.234	0	1
Independent Variables				
$\mathbf{F_a}$	2.305	0.399	1.516	3.026
$\mathbf{S_b}$	2.273	0.417	1.463	3.028
$\mathbf{r_b}$	0.055	0.010	0.029	0.087
$\mathbf{r_a^*}$	0.042	0.017	0.009	0.069
$\mathbf{F_b}$	2.301	0.398	1.514	3.022
$\mathbf{S_a}$	2.275	0.418	1.464	3.030
$\mathbf{r_a}$	0.057	0.010	0.036	0.088
$\mathbf{r_b^*}$	0.040	0.018	0.007	0.068
US Dollars exchange to UK Pounds	**Mean**	**Std.Dev.**	**Min**	**Max**
Dependent Variables				
First Pure Arbitrage Conditions Dummy	0.007	0.086	0	1
Second Pure Arbitrage Conditions Dummy	0.159	0.366	0	1
Independent Variables				
$\mathbf{F_a}$	1.655	0.171	1.356	2.082
$\mathbf{S_b}$	1.668	0.177	1.367	2.108
$\mathbf{r_b}$	0.031	0.020	0.005	0.074
$\mathbf{r_a^*}$	0.042	0.017	0.009	0.069
$\mathbf{F_b}$	1.654	0.172	1.356	2.082
$\mathbf{S_a}$	1.669	0.177	1.367	2.108
$\mathbf{r_a}$	0.032	0.019	0.005	0.076
$\mathbf{r_b^*}$	0.040	0.018	0.007	0.068

There are an overall total 3,652 observations over the period Jan/01/1999–Dec/31/2012. Dependent variables are censored at 0 with no pure arbitrage condition and at 1 with pure arbitrage condition. Variable are defined in Section 3.

Table II Frequency of Pure Arbitrage Conditions

	First Pure Arbitrage Condition	Mean	Percentage
AUS-US	134	0.037	3.7%
AUS-UK	39	0.011	1.1%
US-UK	27	0.007	0.7%

	Second Pure Arbitrage Condition	Mean	Percentage
AUS-US	145	0.040	4.0%
AUS-UK	212	0.058	5.8%
US-UK	582	0.159	15.9%

4. Results and Analysis

Variable Movements leading to the Pure Arbitrage Conditions

According to Equation 1, $F_a < S_b (1+ r_b) (1+r^*_a)^{-1}$, for the occurrence of a pure arbitrage condition, the domestic forward ask exchange rate F_a and the foreign interest ask rate r_a* are expected to drop, while the domestic spot bid rate S_b and domestic interest bid rate r_b are expected to rise. For the ending of such a pure arbitrage condition, these four rates shall reverse their movement directions with the same momentum. Such movements in financial market rates are measured by regression analyses, with the dummy of the first pure arbitrage condition serving as dependent variable and F_a, S_b, r_b and r_a* as independent variables. The upper part of Table III reports the results for the first pure arbitrage condition.

Table III Regression Results for Principle Movements lead the Pure Arbitrage Conditions

Dependent Variable = First Pure Arbitrage Conditions Dummy

	AUS-US		AUS-UK		US-UK	
Variable	**Parameter Estimate**	**t-Value**	**Parameter Estimate**	**t-Value**	**Parameter Estimate**	**t-Value**
F_a	-15.56	-25.49***	-2.98	-12.82***	-3.07	-9.45***
S_b	15.79	25.23***	2.98	12.71***	3.05	9.52***
r_b	15.70	19.21***	5.36	10.78***	5.20	9.64***
r_a*	-21.35	-24.97***	-5.78	-11.76***	-6.01	-10.52***

Dependent Variable = Second Pure Arbitrage Conditions Dummy

	AUS-US		AUS-UK		US-UK	
Variable	**Parameter Estimate**	**t-Value**	**Parameter Estimate**	**t-Value**	**Parameter Estimate**	**t-Value**
F_b	6.48	11.70***	15.44	24.39***	51.85	36.46***
S_a	-6.68	-11.74***	-15.96	-24.77***	-51.00	-36.23***
r_a	-10.54	-12.41***	-35.86	-23.87***	-79.18	-34.6***
r_b*	8.18	10.32***	35.23	25.82***	74.47	33.37***

Table III reports the regression results for principle movements lead the pure arbitrage conditions. Variable are defined along with Equations (1) and (2).

The estimated parameter of domestic forward ask exchange rate F_a is negative, indicating that the decrease of domestic forward ask rate leads to the occurrence of pure arbitrage conditions. The estimated parameter of domestic spot bid exchange rate S_b is positive, suggesting that the increase of S_b leads to the occurrence of pure arbitrage conditions. Moreover, the signs of the estimated parameters of domestic interest bid rate r_b and foreign interest ask rate r_a* are positive and negative respectively. Thus, the increase of domestic interest bid rate and the decrease of foreign interest ask rate result in the occurrence of pure arbitrage conditions. All such findings are significant at the 0.01 level.

According to the second pure arbitrage condition, $F_b > S_a (1+r_a) (1+r^*_b)^{-1}$, if the pure arbitrage condition occurs, the domestic forward bid exchange rate F_b and the foreign interest bid rate r_b* shall rise increase, whereas the domestic spot ask rate S_a and the domestic interest ask rate r_a shall fall. The reversal movements of these four rates under market forces will cause the ending of the pure arbitrage condition. The associated regression results for second pure arbitrage condition are described in lower part of Table III. Once again, all those findings are consistent with the second pure arbitrage condition at the 0.01 level. (Throughout the article, ***, **, * denotes the statistical significance at 0.01, 0.05, 0.10 level, respectively.) Next, the results of principle movements of each variable are described in Table IV. These results, which will be elaborated in the following Table V, identify the weight structure of each market rate variable that could contribute to the happening and ending of pure arbitrage conditions.

Table IV Results of Variable Movements leading to Pure Arbitrage Conditions

First Pure Arbitrage Conditions		
Variable	**Occurrence**	**End**
$\mathbf{F_a}$	Decrease	Increase
$\mathbf{S_b}$	Increase	Decrease
$\mathbf{r_b}$	Increase	Decrease
$\mathbf{r_a}$*	Decrease	Increase

Second Pure Arbitrage Conditions		
Variable	**Occurrence**	**End**
$\mathbf{F_b}$	Increase	Decrease
$\mathbf{S_a}$	Decrease	Increase
$\mathbf{r_a}$	Decrease	Increase
$\mathbf{r_b}$*	Increase	Decrease

Determinants of the Occurrence and End of Pure Arbitrage Conditions

Table V presents the results regarding the specific contribution weights of financial market rate variables to the occurrence and end of pure arbitrage conditions. We conclude that the spot exchange rates and domestic interest rates are playing the most important roles in the process of determining such conditions.

Table V The Weights of Driving Force for Pure Arbitrage Conditions

First Pure Arbitrage Conditions						
	AUS-US		AUS-UK		US-UK	
Variable	**Occur**	**End**	**Occur**	**End**	**Occur**	**End**
$\mathbf{F_a}$	36.13%	21.05%	16.92%	21.74%	25.00%	28.57%
$\mathbf{S_b}$	41.29%	36.84%	32.31%	23.19%	18.33%	18.37%
$\mathbf{r_b}$	9.68%	26.32%	32.31%	33.33%	30.00%	26.53%
$\mathbf{r_a}$*	12.90%	15.79%	18.46%	21.74%	26.67%	26.53%

Second Pure Arbitrage Conditions						
	AUS-US		AUS-UK		US-UK	
Variable	**Occur**	**End**	**Occur**	**End**	**Occur**	**End**
$\mathbf{F_b}$	22.44%	17.43%	35.69%	25.49%	30.16%	21.62%
$\mathbf{S_a}$	30.71%	26.15%	37.10%	23.53%	38.60%	25.83%
$\mathbf{r_a}$	28.35%	32.11%	20.14%	33.99%	16.77%	28.53%
$\mathbf{r_b}$*	18.50%	24.31%	7.07%	16.99%	14.48%	24.02%

Table V presents the results of the proportion of each exchange- or credit-market rate variable that leads to the occurrence and end of the pure arbitrage conditions. Variable are defined along with Equations (1) and (2).

The statistical outcomes related to "Australian dollar vs. US dollar" transactions, reported in the second and third column of Table V (AUS-US), show that when the first pure arbitrage conditions occur, domestic spot bid rate S_b becomes the most dominant (with 41.29% contribution in driving force), followed by domestic forward ask rate F_a (with 36.13% contribution). When the first pure arbitrage conditions end, domestic spot bid rate S_b dominates once again, followed by domestic interest bid rate r_b (with 36.84% and 26.32% of driving force proportions, respectively). Furthermore, when the second pure arbitrage conditions occur, domestic spot ask rate S_a becomes the most dominant, followed by domestic interest ask rate r_a. When the second pure arbitrage conditions end, the domestic interest asks rate r_a dominates by the most, followed by domestic spot ask rate S_a.

Similarly, when "Australian dollar vs. British pound" transactions are involved, the results presented in the fourth and fifth column of Table V (AUS-UK) indicate that a) domestic spot bid rate S_b and domestic interest bid rate r_b play the leading roles in the occurrence of those first pure arbitrage conditions; b) domestic interest bid rate r_b and domestic spot bid S_b rate provide the dominant effects towards the ending of a first pure arbitrage condition; c) domestic spot ask rate S_a and domestic forward bid rate F_b are the most influential determinants of the occurrence of the second pure arbitrage conditions; and d) domestic interest ask rate r_a and domestic forward bid rate F_b are the key driving force factors towards the ending of the second pure arbitrage conditions.

As reported in the last two columns of Table V (US-UK), the occurrence of a first pure arbitrage condition for "US dollar vs. British pound" is mostly

driven by domestic interest bid rate r_b and foreign interest ask rate r_a*, as its end is dominated by the movements in domestic forward ask rate F_a, domestic interest bid rate r_b and foreign interest ask rate r_a* (with effect weights of 28.57%, 26.53% and 26.53%, respectively). For a second pure arbitrage condition, its occurrence is mainly influenced by domestic spot ask rate S_a (38.60% contribution weight) and domestic forward bid rate F_b (30.16% contribution weight) whereas its end is mostly determined by domestic interest ask rate r_a and domestic spot ask rate S_a.

Such findings have noteworthy practical implications for international arbitragers. For example, if market participants trade between Australian and US markets, they shall initially put their focus on Australian spot (particularly the bid rate) and forward market (particularly the ask rate) before the pure arbitrage conditions occur. Once the pure arbitrage opportunities are identified, traders need to still focus on the Australian spot exchange market (particularly the bid rate) but also need to then extend their radar scopes to Australian interest market (particularly the bid rate), in order to predict when these pure arbitrage opportunities will end. Moreover, under those second pure arbitrage conditions, the Australian spot bid rate and Australian interest ask rate are the most important rate which needs to be watched by market participants before a pure arbitrage condition occurs, whereas the Australian interest ask rate and Australian spot ask rate are the most crucial variables to monitor when a pure arbitrage condition is getting close to its end. Arbitragers shall accordingly adjust the weights of their underlying model factors.

Probit Model Results

We employ the probit model, with both in-sample and out-of-sample tests, to investigate whether our results have predicting power of statistical significance. The probit regression is conducted on concurrent, one-day-lagged and two-day-lagged return data samples, respectively. In-sample test uses full samples and runs the regression with probit procedure. The resulting maximum likelihood parameter estimates for three aforementioned time series are presented in Table VI, Table VII and Table VIII, respectively.

Table VI Probit Model Maximum Likelihood
Parameter Estimates for Concurrent Sample Dataset

Dependent Variable = First Pure Arbitrage Conditions Dummy						
	AUS-US		**AUS-UK**		**US-UK**	
Variable	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**
F_a	439.41	168.16***	411.10	72.99***	1044.78	39.63***
S_b	-445.23	168.26***	-417.75	72.75***	-1029.12	39.92***
r_b	-475.49	142.62***	-821.89	71.78***	-1641.02	41.61***
r_a*	548.51	168.23***	879.79	67.61***	1707.83	42.52***

Dependent Variable = Second Pure Arbitrage Conditions Dummy						
	AUS-US		**AUS-UK**		**US-UK**	
Variable	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**
F_b	-276.82	147.17***	-327.52	316.63***	-367.38	518.03***
S_a	286.39	147.25***	335.32	320.76***	362.23	513.43***
r_a	353.03	159.41***	651.82	310.53***	588.85	474.26***
r_b*	-332.08	134.12***	-644.80	328.04***	-566.68	447.8***

Table VII Probit Model Maximum Likelihood
Parameter Estimates for One-Day Lagged Dataset

Dependent Variable = First Pure Arbitrage Conditions Dummy						
	AUS-US		**AUS-UK**		**US-UK**	
Variable	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**
F_a	153.97	16.36***	178.07	20.75***	251.56	5.99**
S_b	-158.70	17.36***	-181.00	21.13***	-238.82	5.65**
r_b	-134.63	30.85***	-284.92	81.35***	-369.44	38.24***
r_a*	189.06	28.05***	196.29	39.32***	167.26	22.42***

Dependent Variable = Second Pure Arbitrage Conditions Dummy						
	AUS-US		**AUS-UK**		**US-UK**	
Variable	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**
F_b	-185.76	22.25***	-101.12	20.2***	-204.83	32.09***
S_a	191.60	23.83***	103.44	21.47***	208.88	35.3***
r_a	295.20	107.49***	283.56	105.3***	140.71	28.18***
r_b*	-200.70	24.32***	-83.60	3.76*	-154.27	24.11***

Table VIII Probit Model Maximum Likelihood
Parameter Estimates for Two-Day Lagged Dataset

Dependent Variable = First Pure Arbitrage Conditions Dummy						
	AUS-US		**AUS-UK**		**US-UK**	
Variable	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**
F_a	124.79	10.83***	-40.98	0.92	112.71	1.26
S_b	-130.89	11.8***	41.28	0.95	-104.07	1.13
r_b	6.31	0.07	26.82	0.57	-118.76	2.63
r_a*	88.89	5.82**	-43.71	1.31	-84.72	4.17**

Dependent Variable = Second Pure Arbitrage Conditions Dummy						
	AUS-US		**AUS-UK**		**US-UK**	
Variable	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**	**Parameter Estimate**	**Chi-Square**
F_b	-1.37	0.00	-32.08	2.19	-130.01	14.74***
S_a	8.85	0.05	31.53	2.12	132.66	16.29***
r_a	-7.14	0.05	25.53	0.97	45.70	3.14*
r_b*	-81.82	4.72**	3.83	0.01	-21.35	0.55

For the concurrent sample dataset, all pure-arbitrage factors are significant at the 0.01 level, and the coefficient sign for each factor is similar across all three currency exchange transactions. We also find resembling results for the one-day lagged dataset, although the magnitude of significance becomes somehow weaker (in terms of Chi-square values and levels of significance). For the two-day lagged dataset, the significance of results has diminished even by more. More importantly, some of the coefficient signs have varied across conditions and/or across currencies, and some of them even carry coefficient signs which contrast with our expectations. For example, in Table VIII, when exchanging between Australian dollar and British pound ("AUS-UK"), the coefficients F_a, S_b, r_b, r_a* and r_b* have signs that are opposite to Table IV results and inconsistent with the first or second pure arbitrage condition theorem.

Next, the prediction accuracies outcomes for in-sample test are presented in Table IX, documenting the goodness of fit of probit model applications. Over the full sample period, we estimate 90.63% average accuracies when predicting arbitrage opportunities, and 86.99% accuracies when predicting no-arbitrage conditions. For one-day lagged sample period, the prediction accuracies drop to 63.41% for arbitrage opportunities and 76.25% for no-arbitrage conditions, respectively. As for two-day lagged test period, the prediction accuracies drop even lower to 49.65% and 58.14%, respectively. Such evidence implies that the predicting accuracy of the probit model decreases with time lag: the longer the time lag, the lower the prediction power.

Table IX Total Prediction Accuracies Outcomes (In-Sample Test)

	Full Sample		**Lagged One Day**		**Lagged Two Days**	
	Actual w Arbitrage	Actual w/o Arbitrage	Actual w Arbitrage	Actual w/o Arbitrage	Actual w Arbitrage	Actual w/o Arbitrage
Predicted Arbitrage	90.63%	13.01%	63.41%	23.75%	49.65%	41.86%
Predicted No Arbitrage	9.37%	86.99%	36.59%	76.25%	50.35%	58.14%

This Table IX presents the total average prediction accuracies outcomes for in-sample test, combining all three cross-currency transactions together.

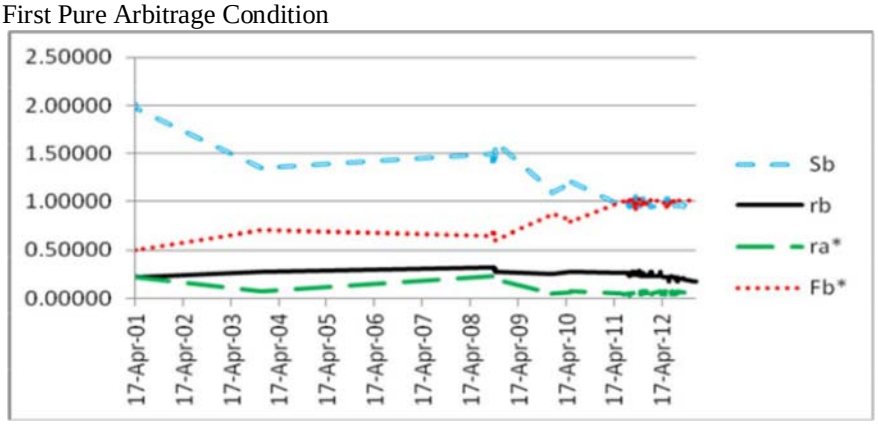
To ensure the reliability for the test results of predictability in this study, we employ not only in-sample tests but also out-of-sample tests. An out-of-sample evaluation of predicting accuracy starts with the division of the historical data series into a fit period and a test period. In this study, the first 10 years (1999–2009) and the remaining 3 years (2010–2012) are selected as the fit period and the test period, respectively. We do the out-of-sample test by using coefficients from the fit period, and then use those coefficients to predict pure arbitrage probabilities in the test period. To save space, the detailed results are not presented here but instead available upon request. In brief summary, the predicting probabilities turn out to be lower relative to in-sample test estimates, but they are still in comparable levels. Most importantly, we can still find that the prediction accuracy is decreasing with the time lag, being consistent with in-sample test outcomes.

Patterns and Rules of Pure Arbitrage Conditions

This section discusses the trends of each variable during the "life cycle" of pure arbitrage conditions, and also attempts to identify relevant rules under such conditions. In Figures B, C, and D, the dynamics of each variable during the period of pure arbitrage are exhibited. The trends jointly exhibit that the domestic forward and spot rates move in opposite directions with foreign spot and forward rate, respectively. As we have found, forward and spot exchange rates are ever-changing; however, interest rates might remain relatively fixed for a period of time.

Figure B Pure Arbitrage Conditions Trends for AUS-US

First Pure Arbitrage Condition



Second Pure Arbitrage Condition

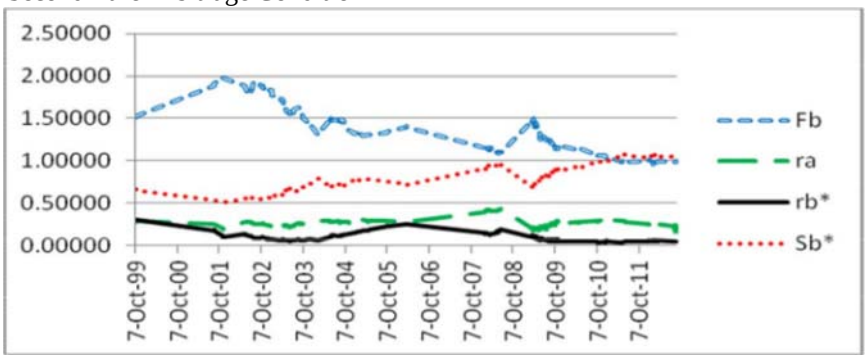
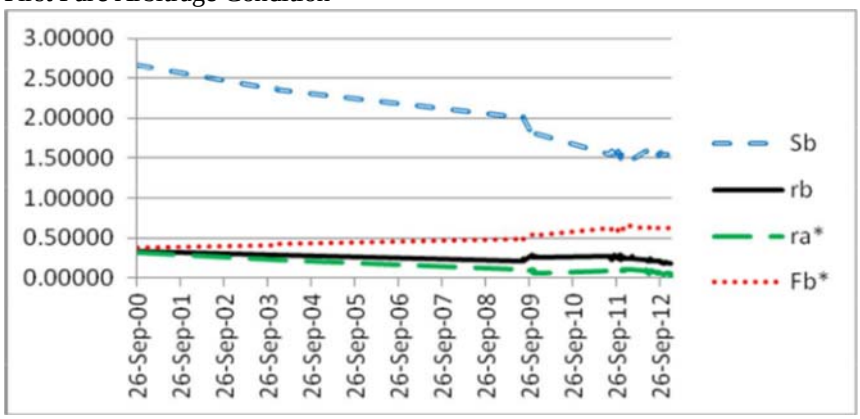


Figure C Pure Arbitrage Conditions Trends for AUS-UK

First Pure Arbitrage Condition



Second Pure Arbitrage Condition

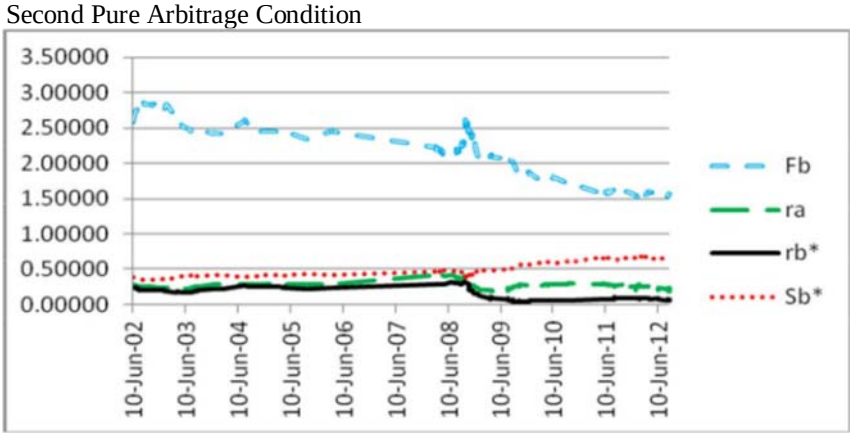
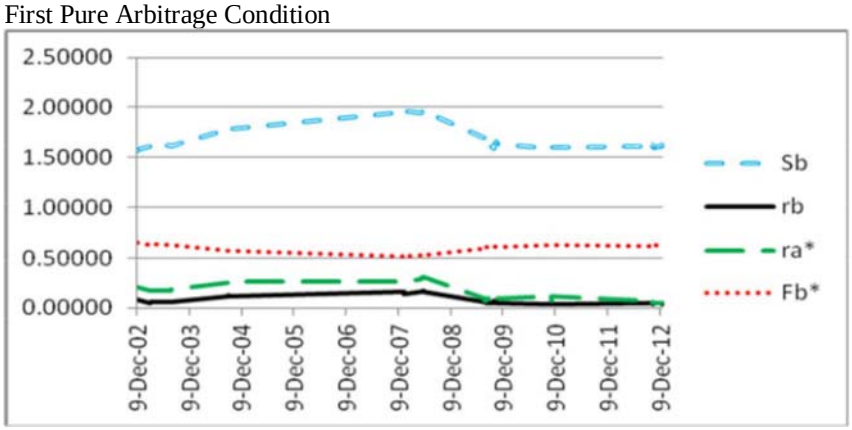
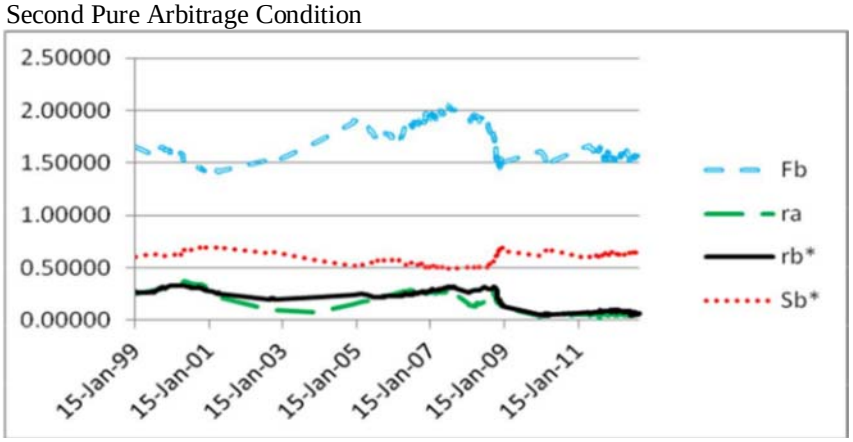


Figure D Pure Arbitrage Conditions Trends for US-UK

First Pure Arbitrage Condition



Second Pure Arbitrage Condition



We also identify some specific rules about the dynamics of variables during the pure arbitrage periods, with two of them being the most typical. The first identified rule is shown in Table X. Australian dollar and U.S. dollar are exchanged in an adjacent time period from June 2nd to August 4th of 2009. "O" symbolizes the case in which the changes in interest and currency rates cause the happening of first pure arbitrage conditions, whereas "E" denotes the case in which the changes in rates cause the ending of such conditions. In this adjacent period, the pure arbitrage conditions occur and end almost in a similar pattern.

Table X First Rule about Variables Dynamics during Pure Arbitrage Periods

Date	S_b	r_b	r_a*	F_a*
2-Jun-09		O		O
3-Jun-09		E	E	E
11-Jun-09				
12-Jun-09	O	O		
15-Jun-09		E	E	E
23-Jun-09				
24-Jun-09		O		O
25-Jun-09		E		E
27-Jul-09				
28-Jul-09		O		O
29-Jul-09		E		E
31-Jul-09				
3-Aug-09		O		O
4-Aug-09		E		E

The second rule (the table of detailed results is not presented in this paper, instead available upon request) is identified within the time series from May 14th to June 11th, 2012, in which the pure arbitrage conditions continue to occur. Forward and spot rates alternatively lead to the occurrence in a series of pure arbitrage conditions, while the interest rates hardly alter during the period. However, interest rates start to get involved in the dynamics when the series of pure arbitrage ends.

There are also some other rules that we have found (once again, to save page space, we do not present details here). In many occasions when an arbitrage condition ends, if forward or spot exchange rates are not influential on this movement, the other three rate variables change together to lead the ending of this pure arbitrage condition. Moreover, as always, pure arbitrage conditions end when any three of those four rates change together. Lastly, for most cases, no matter pure arbitrage conditions occur or end, both forward and spot exchange rates are involved as determinants in the process.

5. Conclusions

Our empirical research focuses on the three "Anglo-Saxon Capitalism" countries (Australia, the UK, and the US), which presumably provide some of the most ideal international environments for risk-free and frictionless pure

arbitrage applications. By examining the percentage weights of each variable that could contribute to the occurrence and end of pure arbitrage conditions, we find that the most important initiative change occurs in the domestic spot currency market, while the domestic interest rate market plays the most leading role in the end phrase ("exit") of pure arbitrage conditions. The probit regression analysis reaffirms such findings.

On the other hand, the respective influence of market rate variables in the arbitrage process may also be flexible. Although this paper concludes that the domestic spot exchange rates and domestic interest rates are the most important determinants throughout the life cycle of pure arbitrage conditions, arbitragers should pay attention to the limitation of time lags on the accuracy of predicting when those pure arbitrage conditions may occur or end. Specifically, the coefficients of those arbitrage driving factors typically have very high magnitudes with great levels of statistical significance for concurrent and one-day lagged sample datasets, suggesting that the pure arbitrage conditions can be predicted with relatively satisfactory accuracies for those two types of time horizons. For two-day lagged datasets, however, the insignificance of estimates and even sign change for some coefficients indicate that the prediction power becomes relatively much lower for such a time horizon. The signs and level of significance of parameter estimates start to become mixed rather than clear-cut, as the time lag of prediction is extended to two days. Such findings would help researchers and practitioners to reaffirm the time-sensitivity on a) the predictive power and b) the effectiveness of pure arbitrage strategy under cross-market currency and/or interest rate risks. The extended understanding of the formations and shifts of each market rate variable' role, especially the time sensitivity in such dynamics, shall help to improve hedging effectiveness.

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