



## Arbitrage in the foreign exchange market: Turning on the microscope

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### ARTICLE INFO

**Article history:**

Received 27 February 2007

Received in revised form 12 June 2008

Accepted 24 July 2008

**Keywords:**

Exchange rates

Arbitrage

Covered interest rate parity

Foreign exchange microstructure

**JEL classification:**

F31

F41

G14

G15

### ABSTRACT

This paper provides real-time evidence on the frequency, size, duration and economic significance of arbitrage opportunities in the foreign exchange market. We investigate deviations from the covered interest rate parity (CIP) condition using a unique data set for three major capital and foreign exchange markets that covers a period of more than seven months at tick frequency. The analysis unveils that: i) short-lived violations of CIP arise; ii) the size of CIP violations can be economically significant; iii) their duration is, on average, high enough to allow agents to exploit them, but low enough to explain why such opportunities have gone undetected in much previous research using data at lower frequency.

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### 1. Introduction

Arbitrage is one of the fundamental pillars of financial economics. It seems generally accepted that financial markets do not offer risk-free arbitrage opportunities, at least when allowance is made for transaction costs. While the assumption of no arbitrage is likely to be reasonably mild or valid in several contexts in finance, its violations can be rationalized on several grounds. In general terms, the absence of arbitrage opportunities gives rise to the so-called ‘arbitrage paradox’, first pointed out by Grossman and Stiglitz (1976, 1980). That is, if arbitrage is never observed, market participants may not have sufficient incentives to watch the market, in which case arbitrage opportunities could arise. A possible resolution of this paradox is for very short-term arbitrage opportunities to arise, inviting traders to exploit them, and hence be quickly eliminated. Also, microstructure theory shows how price differences may occur for identical assets in markets that are less than fully centralized, segmented or with an imperfect degree of transparency (O’Hara, 1995; Lyons, 2001).<sup>1</sup>

Empirical studies have been unable to detect short-term arbitrage opportunities in a variety of financial markets. Given the high activity level in major financial markets, such short-term arbitrage opportunities can only be adequately studied using real-time quotations on all asset prices involved. Such data are, however, notoriously difficult to obtain. Furthermore, one must take into account all relevant aspects of the microstructure of the markets in order to capture the opportunities and transaction costs that market participants face.

This paper investigates empirically the existence of arbitrage and the properties of potential departures from no-arbitrage conditions using a microstructure perspective. Specifically, we study the foreign exchange (FX) market, for which the no-arbitrage condition is well known and relatively easy to test. This condition is covered interest rate parity (CIP), which states that net returns

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<sup>1</sup> See also the theories related to limits to arbitrage (e.g. Shleifer and Vishny, 1997).

on an investment that borrows at home and lends abroad (or vice versa) in similar interest-bearing assets will be zero when exchange rate risk is hedged through forward or swap contracts. The CIP condition is the cornerstone riskless no-arbitrage condition in the FX market. The relevant literature suggests that CIP arbitrage opportunities do not generally arise in the FX market and mispricing is negligible when one accounts for estimated transaction costs.<sup>2</sup>

The key advantages of this study relative to all previous empirical analyses of arbitrage are our data set, and a precise account of transaction costs as well as pricing and trading conventions. A rigorous empirical examination of no-arbitrage interest rate conditions in the FX market places stringent requirements on the data used. Contemporaneous, tradable (firm) quotes of comparable domestic and foreign interest rates and spot and forward exchange rates are needed in order to establish whether an apparent deviation from no-arbitrage conditions actually represented a profitable opportunity to agents at a given time or not. Moreover, the high level of activity in FX and international capital markets demands use of high-frequency, real-time quotes to characterize the properties of arbitrage opportunities, especially their duration. Finally, it is also important to have a sufficiently long sample to draw general conclusions. Our data set is the first in this literature that possesses these characteristics to a large extent, mainly because such data have been unavailable to researchers until recently. The move to electronic trading platforms in the 1990s has made it possible to obtain long data samples of real-time quotations for rigorous empirical work. The move itself provides a motivation for a fresh analysis of arbitrage opportunities because of changes in trading practices and market characteristics induced by electronic platforms.<sup>3</sup>

Our data set includes contemporaneous tick quotes of exchange rates and interest rates that pertain to the most liquid segments of the FX and capital markets. The sample includes ask and bid quotes for three major US dollar spot exchange rates: euro, UK sterling and Japanese yen. It also includes ask and bid quotes for exchange rate swaps and for interest rates on deposits in quoting and base currencies. The tick quotes cover a period of more than seven months spanning from February 13 to September 30, 2004, and is the longest and highest-frequency data set ever used for examining FX arbitrage. The data have been collected through Reuters trading system on special order.

To anticipate our key results, we find that trading aimed at exploiting no-arbitrage conditions is, on average, not profit-making. However, we document numerous short-lived profitable deviations from CIP. The size of the profitable deviations can be economically significant and is comparable across different maturities of the interest rates examined. Their duration is, on average, high enough to allow agents to exploit these opportunities, but low enough to explain why such CIP violations have gone undetected in much previous research using data at lower frequencies. We find little evidence in favor of the view that prices for spot and forward rates and for money market instruments are set directly from the formulas of no-arbitrage conditions in real time. Finally, our results suggest that frequency, size and duration of apparent arbitrage opportunities decline with the pace of markets and increase with market volatility.

Overall, the evidence is consistent with the Grossman–Stiglitz view of financial markets, where efficiency is not interpreted as a statement about prices being correct at each point in time but the notion that in efficiently-functioning financial markets very short-term arbitrage opportunities can arise and invite traders to exploit them, which makes it worthwhile to watch the relevant markets. This is the arbitrage mechanism that restores the arbitrage-free prices we observe on average. Nevertheless, the lack of predictability of arbitrage and the fast speed at which arbitrage opportunities are exploited and eliminated imply that a typical researcher in international macro-finance using data at the daily or lower frequency can safely assume that CIP holds.

The paper is organized as follows. Section 2 presents the concept of CIP and a brief review of the literature. Section 3 discusses quoting conventions, transaction costs and their implications for calculations of gains and losses from arbitrage. This section also describes the data set. Section 4 presents the main empirical findings, relating to frequency, size, duration and economic significance of returns from arbitrage opportunities. Section 5 reports the results from the sensitivity analysis of the core results, and an analysis of whether and how characteristics of profitable arbitrage opportunities vary with market pace and market volatility. Section 6 briefly summarizes and concludes. Finally, the Appendix presents further details on a variety of relevant FX microstructure details and on the construction of the limit order book used in part of our empirical work.

## 2. Arbitrage in the FX market

CIP postulates that it is not possible to earn positive returns by borrowing domestic assets for lending, in a similar asset, abroad (or vice versa) while covering the exchange rate risk through a forward contract of equal maturity. Domestic and foreign interest-bearing assets can be considered similar if they are of equal maturity and share the same characteristics, such as liquidity and political and default risk. Commonly, CIP is expressed as

$$(1 + r_d) = \frac{F}{S} (1 + r_f) \quad (1)$$

where  $r_d$  and  $r_f$  denote domestic and foreign (nominal) interest rates on similar assets, respectively;  $S$  is the spot nominal exchange rate, expressed in units of domestic currency per unit of foreign currency; and  $F$  is the forward exchange rate of maturity equal to that of the interest-bearing assets.

<sup>2</sup> Studies of FX arbitrage include Branson (1969), Frenkel (1973), Frenkel and Levich (1975, 1977), Taylor (1987, 1989), Clinton (1988), Rhee and Chang (1992), Fletcher and Taylor (1996), Aliber et al. (2003) and Juhl et al. (2006). We briefly review this literature in the next section.

<sup>3</sup> The growing literature on high-frequency exchange rate behavior and FX market microstructure has not-to the best of our knowledge-studied arbitrage, focusing instead on a variety of other issues relating to international currency patterns, trading behavior, and the role of order flow in explaining exchange rate movements (e.g. Lyons, 1995, 2001; Osler, 2000, 2003, 2005; Covrig and Melvin, 2002; Evans, 2002; Evans and Lyons, 2002, 2005; Payne, 2003; Bjønnes and Rime, 2005; Lyons and Moore, 2005).

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