



## Does the law of one price hold in international financial markets? Evidence from tick data

Q. Farooq Akram<sup>a</sup>, Dagfinn Rime<sup>a,b,\*</sup>, Lucio Sarno<sup>c,d</sup>

<sup>a</sup> Norges Bank, Research Department, P.O. Box 1179, Sentrum, 0107 Oslo, Norway

<sup>b</sup> Norwegian University of Science and Technology, Department of Economics, Dragvoll, N-7491 Trondheim, Norway

<sup>c</sup> Cass Business School, Finance Faculty, 106 Bunhill Row, London EC1Y 8TZ, United Kingdom

<sup>d</sup> Centre for Economic Policy Research (CEPR), 53–56 Great Sutton Street, London EC1V 0DG, United Kingdom

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### ABSTRACT

This paper investigates the validity of the law of one price (LOP) in international financial markets by examining the frequency, size and duration of inter-market price differentials for borrowing and lending services ('one-way arbitrage'). 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, we find that the LOP holds on average, but numerous economically significant violations of the LOP arise. The duration of these violations is high enough to make it worthwhile searching for one-way arbitrage opportunities in order to minimize borrowing costs and/or maximize earnings on given funds. We also document that such opportunities decline with the pace of the market and increase with market volatility.

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### 1. Introduction

Textbook finance theory is based on the law of one price (LOP), which postulates that in efficient financial markets two assets with identical cash flows must trade at the same price. Specifically, in international financial markets, the LOP for lending and borrowing services requires that the domestic lending (borrowing) interest rate should be the same as the foreign lending (borrowing) interest rate when the latter is adjusted to fully hedge for exchange rate risk. Violations of the LOP imply that the same need – desire to lend (owner arbitrage) or desire to borrow (borrower arbitrage) – can be met at two different prices at a point in time. Following the seminal work by Deardorff (1979), a number of studies refer to the LOP to describe the absence of 'one-way arbitrage', which may be stated in the form of 'owner arbitrage' and 'borrower arbitrage'.

Since Deardorff (1979) introduced the concept of one-way arbitrage, researchers often interpreted this concept as closely related to pure, round-trip arbitrage associated with deviation from the covered interest rate parity (CIP) condition. CIP states that net re-

turns 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. However, CIP is conceptually very different from the LOP for lending and borrowing services studied in this paper. In particular, violation of CIP is a sufficient but not a necessary condition for violation of the LOP. More importantly, violations of the LOP do not imply riskless profits since they refer to differences in the prices of the same financial service (borrowing or lending) which do not allow for a self-financing transaction (borrow and lend).<sup>1</sup> It seems therefore more appropriate to consider violations of the LOP as a form of 'mispricing' rather than pure arbitrage opportunities such as CIP violations, which do not require any initial endowment or borrowing need and imply riskless profits (e.g. see Deardorff, 1979; Akram et al., 2008).

This paper investigates whether the LOP holds for borrowing and lending services and examines the frequency, size and duration of LOP deviations. A rigorous empirical examination of the

\* Corresponding author. Address: Norges Bank, Research Department, P.O. Box 1179, Sentrum, 0107 Oslo, Norway. Tel.: +47 22316757; fax: +47 22424062.

E-mail addresses: [farooq.akram@norges-bank.no](mailto:farooq.akram@norges-bank.no) (Q.F. Akram), [dagfinn.rime@norges-bank.no](mailto:dagfinn.rime@norges-bank.no) (D. Rime), [l.sarno@city.ac.uk](mailto:l.sarno@city.ac.uk) (L. Sarno).

<sup>1</sup> In other words, the violations of the LOP considered here are related either to borrowing capital at the lowest possible rate or lending at the highest possible rate offered by financial markets at a point in time. The violations do not generate a riskless return since agents will not be allowed to borrow at the cheaper rate and lend at the higher rate.

LOP 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 to establish whether an apparent deviation from no-arbitrage conditions actually represented a one-way arbitrage opportunity to agents at a given time. Moreover, the high level of activity in the foreign exchange (FX) and international capital markets demands use of high-frequency, real-time quotes to characterize the properties of possible arbitrage opportunities, especially their duration. For example, Taylor (2001) shows that large biases are generated in studies of the persistence of LOP violations when researchers employ data at a lower frequency than the frequency at which convergence to the LOP occurs. The direction of these biases is upward, meaning that using data that are not in real time is likely to give illusory evidence of more persistent deviations of the LOP than the true deviations. Finally, it is also important to have a sufficiently long sample to draw general conclusions.

The data set used in this paper possesses, to a large extent, the desired characteristics. It 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 one-way arbitrage. The data have been collected through Reuters trading system on special order. We have also gathered precise information about transaction costs facing the agents.<sup>2</sup>

An investigation of the validity of the LOP for borrowing and lending services can shed light on the degree of capital mobility in international financial markets and their integration, as well as being informative about the ability of financial markets to efficiently price similar assets. The investigation can also shed light on the extent to which market participants have incentives to watch financial markets to exploit mispricings and thereby ensure that they remain efficient. It may thereby also contribute to resolve the so-called 'arbitrage paradox', first pointed out by Grossman and Stiglitz (1976, 1980). That is, if mispricing is never observed, market participants may not have sufficient incentives to watch the market, in which case arbitrage opportunities could arise. A possible resolution to this paradox is for very short-term arbitrage opportunities to arise, inviting traders to exploit them, and hence be quickly eliminated.

Our use of real-time quotations can also provide evidence on the validity of another proposed resolution of the arbitrage paradox, which is the anecdote that providers of interest rate and exchange rate quotes set their quotes such that they knowingly do not misprice – i.e. set prices that do not violate the LOP. For example, if quotes are always set such that no-arbitrage conditions are ensured conditional on the latest quotes of other instruments, these conditions will hold continuously without requiring trade to actually take place. However, from the microstructure literature

we know that prices can temporarily deviate from no-arbitrage values due to, for example, risk management. More generally, 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; Lamont and Thaler, 2003).<sup>3</sup>

To preview our main results, we find that the LOP holds on average. Yet, we provide evidence that there are numerous short-lived profitable deviations from the LOP for lending and borrowing services. The size of the profitable deviations is economically significant across exchange rates and 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 LOP violations can be difficult to detect using data at lower frequencies. Our results also suggest that frequency, size and duration of apparent arbitrage opportunities decline with the pace of markets, but increase with market volatility. We find scant 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. 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 mispricings can arise and invite traders to exploit them, which makes it worthwhile to watch the relevant markets. This is the mechanism that restores the LOP we observe on average.

The paper is organized as follows. Section 2 considers the two relevant cases of one-way arbitrage in the foreign exchange market. It also relates the concept of one-way arbitrage to that of round-trip arbitrage (CIP). For the sake of consistency with existing literature on arbitrage in the FX markets, we use the terms 'one-way arbitrage', 'owner arbitrage' and 'borrower arbitrage' interchangeably with (perhaps the more appropriate terms) 'LOP', 'LOP for lending services' and 'LOP for borrowing services', respectively. Section 3 briefly discusses quoting conventions, transaction costs and their implications for calculations of gains and losses from arbitrage of the different forms. This section also describes the data set. Section 4 presents the main empirical findings, relating to frequency, size and duration of returns from LOP violations. It also undertakes a sensitivity analysis to demonstrate the robustness of the results. Section 5 analyses whether and how characteristics of profitable arbitrage opportunities vary with market pace and market volatility and sheds light on the response of the different asset prices to deviations from the LOP. Section 6 briefly summarizes the main conclusions. Finally, the appendix presents further details on quoting conventions, calculations of days to maturity and transaction costs for different exchange rates and traded volumes.

## 2. The LOP from the view point of fund owners and raisers

We use the term 'owner arbitrage' (OA) to refer to the case where a trader has an endowment of funds in some currency and wants to lend the funds to obtain the highest possible net return. Such traders weigh the option of lending own funds at the market bid interest rate for the endowment currency, against the option of converting the funds to another currency at the spot exchange rate and lending them at the market bid interest rate for that currency,

<sup>2</sup> Previously, some early studies have found evidence of deviations from the LOP in FX, which appear to be small and economically insignificant (e.g. Deardorff, 1979; Callier, 1981; Taylor, 1987). However, no study has come closer than the present one to meeting the stringent data requirements discussed above and the literature has been dormant for the last two decades or so after the launch of electronic foreign exchange platforms. See also the recent research on triangular arbitrage by Lyons and Moore (2005); on convertible bond arbitrage by Hutchinson and Gallagher (2008); on the law of one price in international goods markets by Sarno et al. (2004), Sarno and Valente (2006) and Nikolaou (2008); and on closed-end fund arbitrage by Kim and Lee (2007) and Fuertes and Thomas (2006). See Sarno (2005) for an overview of recent research on international parity conditions.

<sup>3</sup> See also the theories related to limits to arbitrage (Shleifer and Vishny, 1997).

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