Testing the interest parity condition with Irving Fisher's example of Indian rupee and sterling bonds in the London financial market (1869-1906)

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Abstract

This paper assesses the uncovered interest parity (UIP) condition by means of Indian government bonds during the 1869 to 1906 period. As emphasised by Irving Fisher, interest and exchange rates between Britain and India from that period concur closely with the theoretical assumptions of UIP since (i.) India issued bonds in different currencies (rupees and sterling) (ii.) these bonds were simultaneously traded in the London financial market, and (iii.) subject to negligible regulation and default risks. As long as the Indian currency system was stable, a close correlation arises indeed between sterling-to-rupee interest rate differences and exchange rate changes.

JEL classification: F31, N13, N23

Keywords: India, Irving Fisher, Silver currency, Uncovered Interest Parity, UIP Puzzle

1 Introduction

With the publication of "The Appreciation and Interest" 1896, Irving Fisher presented a path-breaking analysis of the various relationships between interest rates, exchange rates, and inflation (see Dimand and Gomez Betancourt, 2012). Among other things, he postulated that forward-looking investors demand relatively higher interest rates for securities whose unit of account is expected to depreciate, whereas relatively low interest rates are acceptable for securities whose unit of account is expected to appreciate. By doing so, Fisher provided arguably the first fully fledged analysis of what is nowadays called the uncovered interest parity (UIP) condition (see e.g. Dimand, 1999; Lothian *et al.*, 2013).[1]

Although currency speculators with rational expectations should arbitrage away return differences between securities, which only differ in terms of currency denomination, a voluminous empirical literature has *not* found that exchange rate changes offset, on average, international interest rate differences (see e.g. Lewis, 1995; Engel, 2014). This so-called UIP puzzle has been attributed to various, mainly theoretical, issues (see e.g. Isard, 1995, pp.83ff). In particular, assumptions such as rational expectations or risk-neutrality, on which basic versions of interest parity rest, have been questioned (see e.g. Engel, 2014, pp.498ff). Conversely, considerably less attention has been given to data problems. However, a careful empirical analysis of the UIP condition warrants securities, which are denominated in different currencies, but in terms of default risks, liquidity, taxation, etc., completely identical.

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[1] Irving Fisher did not claim to have discovered the potentially close relationship between interest and exchange rates (Fisher, 1896, pp.4-5.). Early hints at the interest parity condition can e.g. be found in the works of Henry Thornton (1760-1815), or John Stuart Mill (1806-1873) (see Dimand and Gomez Betancourt, 2012, p.191).

In reality, barely any international pair of securities meets these criteria perfectly. Rather, the empirical UIP literature has often compared interest rates between various government bonds, which are typically only traded in national financial markets, cover relatively long terms to maturity, and are subject to different levels of sovereign risk (see e.g. Chinn, 2006; Lothian and Wu, 2011; Lothian, 2016). As an alternative, money market interest, especially those quoted by the same banks in the same financial market but for different currencies, can be compared. The most prominent example is the London interbank offered rate (LIBOR), which features e.g. in Flood and Rose (1996), Huisman *et al.* (1998), Sarantis (2006), Chinn (2006), or Herger (2016). Yet, rather than being based on actual financial transactions, the LIBOR is merely an subjective assessment for the likely price large banks would have to pay for borrowing short-term money in different currencies and has, hence, been prone to manipulations (see Duffie and Stein, 2015, pp.196ff). To avoid the corresponding vagaries, Chaboud and Wright (2005) have tested the UIP condition with overnight interest rates reflecting actual financial transactions. Then again, owing to incongruent settlement rules or public holidays, a number of problems arise when matching domestic with foreign overnight interest rates.

Irving Fisher seems to have been aware of the special requirements securities must have to empirically uncover how interest rates react to international changes in the underlying unit of account. Given the dominance of metallic currency systems at the end of the 19^{th} century, in the "Appreciation and Interest", he observes that "the comparison must be between gold and silver contracts in the same market and with the same security" (Fisher, 1896, p.388).[2] He then claims to have found the the following example, where this was arguably the case:

> "Such contracts are fortunately available in the London market of government securities. The loans of India have been raised partly in gold and partly in silver, and both forms of securities are bought and sold in London. The interest on the silver bonds is paid by draft on India. The sums actually received in English money depend on the state of the exchanges." (Fisher, 1896, p.388).

From the 1870s onward, the choice between gold and silver as monetary metal became the subject of fierce political controversies in a large number of countries around the world. These debates arose amid the establishment of the gold standard as international currency system, which implied that leading economies demonetised silver and, thereby, initiated an unprecedented decline of the silver price (see Laughlin, 1885, ch.12; Eichengreen, 2008, pp.10ff.). For the few countries retaining a silver currency, including India, the decline in the monetary demand for silver manifested itself in an ongoing depreciation of their exchange rate relative to their major trading partners. From today's perspective, these developments may seem innocuous, but at the time the choice between a gold, silver, or mixed (bimetallic) currency standard was thought to have far-reaching effects on the exchange rate, the level of interest rates, and ultimately the distribution of wealth between debtors and creditors. By drawing attention to the distinction between expected and unexpected changes in the unit of account, the "Appreciation and Interest" put forward a more nuanced view. In particular, employing a mix between theory and data, Irving Fisher argued that only the expected part of appreciations and depreciations will be reflected by, respectively, lower and higher interest rates (see Niehans, 1990, 273-274; Dimand and Gomez Betancourt, 2013). However, without having access to modern time-series techniques, let alone electronic calculators, his empirical work encompassed not more than a descriptive table with around 30 annual observations of Indian bond yields and the sterling-to-rupee exchange rate. Although rudimentary from today's perspective, this was pretty much the first systematic confrontation of the UIP condition with economic data (see Lothian *et al.*, 2013, p.6).

[2] A comparison between interest rates of gold and paper currencies would also have been possible. Fisher (1896, ch.8) discusses indeed another example comparing government bond yields in the United States after the Civil war, when a gold currency and an inconvertible paper currency circulated in parallel (see also Friedman and Schwarz, 1964, ch.2).

Against this background, this paper endeavours to introduce modern financial time-series techniques to Fisher's historical example of an UIP condition encapsulated in Indian gold (sterling) and silver (rupee) bonds. In particular, a new data set with Indian interest and exchange rates at the monthly frequency has been collected to conduct a state-of-the-art econometric analysis of the interest parity condition as regards the loans raised by India in the London market for government securities. From this, the results do find a close correlation between the rupee-to-sterling interest rate differences and exchange rate changes. However, the relationship is far from perfect, and large deviations from the UIP condition seem to arise during the 1890s, when India witnessed pervasive levels of uncertainty about the future of its silver-based currency system.

The paper is organised as follows. The next section contains a selective review of the empirical UIP literature. Section 3 provides the historical background by looking at India's currency system, the market for its government bonds, and the resulting UIP condition around the year 1900. Section 4 presents and discusses the econometric results. Section 5 concludes.

2 Selected review of the empirical UIP literature

Since the beginning of the floating exchange rate era in the 1970s, the empirical analysis of exchange rates has become a major topic in international finance. Puzzlingly, it is far from evident that high interest-rate currencies tend to depreciate, which would blatantly contradict the UIP condition. A vast body of empirical research summarised in e.g. Lewis (1995) or Engel (2014) has even found the opposite result, e.g. international interest rate differences are reinforced, and not offset, by exchange rate changes. In a world with globally integrated financial markets, it is unclear why this alleged UIP-puzzle can persist without inducing "speculators" to borrow in low interest rate currencies and keep investing in high interest rate currencies. In practice, these so-called carry-trade strategies have, arguably, indeed been highly profitable (for a recent study see e.g. Doskov and Swinkels, 2015). Time-varying currency risk is typically mentioned as the main culprit (Fama, 1984). Then again, although currency risk is not directly observable, several contributions have tried to account for such risk by means of conventional financial time-series models of the GARCH family, without being able to resolve the UIP-puzzle (compare Sarantis, 2006). Examples include Berk and Knot (2001), Li *et al.* (2012, p.170), and Aysun and Lee (2014, p.86), where the UIP regressions have often found a negative, rather than the expected perfectly positive, statistical correlation between exchange rates changes and international interest rates differences.

However, there are some notable exceptions to the view that the UIP-condition does not work empirically. According to Chaboud and Wright (2005), international interest rate differences are, by and large, offset by exchange rate changes during the very short term, that is for overnight transactions. Chinn (2006) has suggested that the evidence against the UIP-condition is weaker when considering yields on government bonds with a five or ten year term to maturity. Lothian and Wu (2011) and Lothian (2016) could not always reject the UIP-condition when the sample covers two centuries worth of interest and exchange rate data. Herger (2016) could not reject the UIP condition when employing panel data techniques and specifying the time-specific unobserved component as fixed effect. By studying exchange rates confined by the target bands of the European Monetary System, Flood and Rose (1996) have found that substantial deviations from the interest parity relationship are absent.

A small number of contributions has looked at the connections between exchange and interest rates with 19^{th} century data. Thereby, the focus has been on currencies forming the inner circle of the international gold standard and the years after 1870, including the dollar-to-sterling exchange rate (Goodhart, 1969; Coleman, 2012), but also the exchange rate between the pound sterling, the French franc, the German mark, and the Dutch guilder (Herger, 2017). Concurring with the already-mentioned finding that the UIP condition works better within fixed exchange rate regimes, the corresponding results give typically rise to a positive, though not per se perfectly proportional, coincidence between high interest rates and currency depreciations. Conversely, the floating exchange rates between gold and silver currencies have received less attention. With the Indian rupee being one of the most important silver exchanges at the time (see Clare, 1895, p.139), as mentioned at the outset, Fisher (1896, p.389) provided a rudimentary comparison between Indian bond yields and the sterling-to-rupee exchange rate. His later book "The Theory of Interest" contains a similar discussion, but adds the years until 1906 (see Fisher, 1930, p.404). Based on these annual observations, Lothian *et al.* (2013) have estimated a basic UIP regression, which resulted in a negative slope coefficient for the effect of interest rate differences on Indian bonds upon the rupee exchange rate. However, the standard deviations of this regression is too large to reject neither the hypothesis that the slope coefficient equals 0 (e.g. there is no connection between interest rate differences and exchange rate changes) nor 1 (e.g. there is a proportional connections as postulated by the UIP condition). Finally, Flandreau and Oosterlinck (2012) have gauged the credibility of bimetallic currency systems from the interest-rate spread between Indian gold and silver bonds with quarterly data before the 1890s. However, in their approach, this interest-rate spread is by definition attributed to currency risk, meaning that a possible effect of expected exchange rate changes, as inherent in the UIP-condition, is ignored.

3 Historical background

3.1 Indian rupee during the classical gold standard

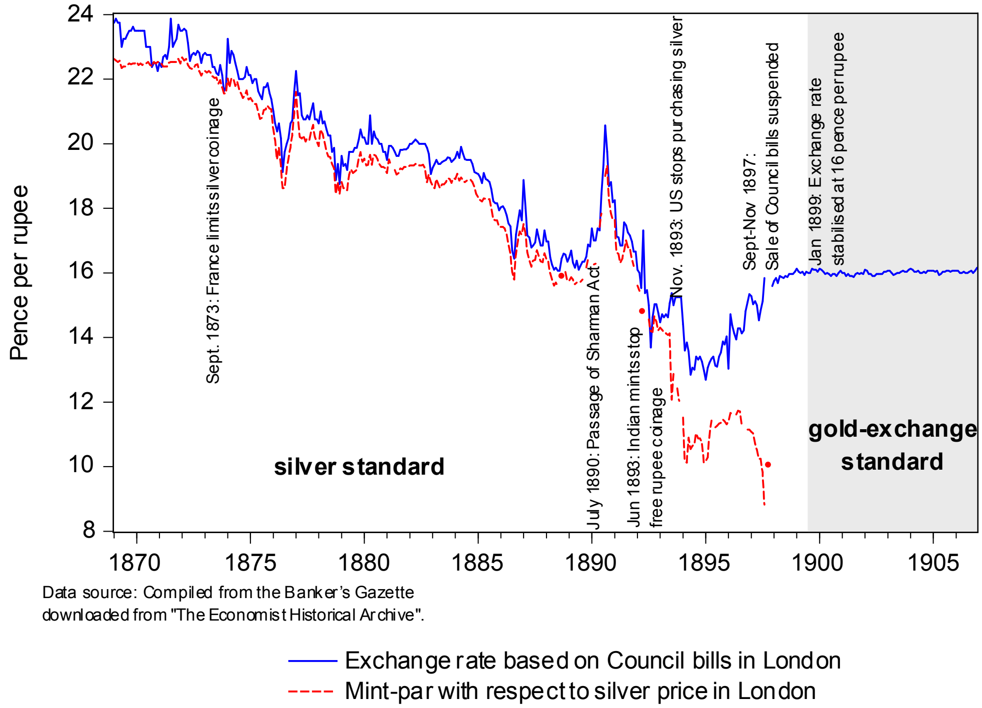
Until the 19^{th} century, numerous gold and silver-based coins circulated, without a fixed parity, in different areas of the vast Indian subcontinent (Dadachanji, 1931, ch.1; Sarkar, 1907, pp.284ff., Wadia and Joshi, 1926, ch. 19). It was only after the establishment of British colonial rule when, in 1835, the rupee[3] silver coin became legal tender, whereas gold coins were relegated to mere tokens (Clare, 1985, p.139; Dadachanji, 1931, p.5). Before the 1870s, there was nothing exceptional about the Indian currency system. Silver coins used to be a popular form of money in medieval Europe and bimetallic systems, where silver provided one metal of a pair into which a currency was convertible at an official rate, were still common during most of the 19^{th} century (see Eichengreen, 2008, pp.7ff.). However, the years after 1870 witnessed the globalisation of the British monetary system, which had been based on gold since at least the early 19^{th} century. When Germany, France, and somewhat later the United States, adopted the gold standard, the international currency system became distinctively monometallic, which gave rise to officially fixed exchange rates among the leading economies around the world (see Eichengreen, 2008, pp.15ff.). Conversely, by retaining silver as monetary metal, the Indian currency system became more and more exceptional (Clare, 1895, ch. 24; Van der Eng, 1999).

Having a silver-based currency amid an international monetary architecture, which was increasingly dominated by gold, had major economic implications. Above all, the official rupee exchange rate, in terms of the mint-par, fluctuated relative to internationally important currencies such as the pound sterling (see Clare, 1895, ch.5). One Indian rupee was officially worth $\frac{165}{444}$ of an ounce (oz.) of standard silver, whose market value in terms of pound sterling (or gold) could change daily (see Clare, 1895, p.140). For example, with the silver price standing at $52\frac{9}{16}$ pence per oz. standard on the 31^{st} of January 1880, the mint-par equaled $52\frac{9}{16} * \frac{165}{444} \approx 50.53$ pence per rupee.[4] For monthly data, the dashed line of Figure 1 depicts

[3] By being derived from the Sanskrit word "*rūpya*", which means coined silver, the very name of the rupee bears witness to the most common monetary metal on the Indian subcontinent.

[4] The British currency system was not on a decimal basis at the time. Rather, one pound sterling (£) was worth 20 shillings (s.) and one shilling (s.) was worth 12 pence (d.).

Figure 1: Sterling-to-rupee exchange rate and mint-par (1869-1906)



the floating mint-par between the rupee and sterling between 1869 and 1897, based on the silver prices published in the “Banker’s Gazette”—which was a supplement to the newspaper “The Economist” reporting financial news and data. However, despite the metallic origin of 19^{th} century currency systems, most international transactions were actually settled via financial instruments such as bills of exchange, rather than a costly shipping of coins or bullion (Eichengreen, 2008, pp.24ff.). Bills (or drafts) issued by the India Council—the colonial government of India residing in London—-in sterling, but payable in rupees after 60 days, provided the key financial instrument to carry out payments to India (see Sarkar, 1909, pp.283ff.; Laughlin, 1885, pp.126ff.). According to demand and supply, the market exchange rate for these “Council bills” could deviate, to some extent, from the mint-par (see Clare, 1895, p.141). The solid line of Figure 1 depicts the monthly sterling-to-rupee exchange rate on the foreign exchange market as published in the “Banker’s Gazette”.[5] Because India typically recorded a trade surplus with Britain (mainly thanks to large cotton exports), the countervailing net capital flow to India gave rise to an excess demand for Council bills, which pushed the exchange rate slightly above the silver mint-par (see Laughlin, 1885, pp.130ff.; Clare, 1985, p.140). However, as long as sterling and the rupee were, more or less, freely convertible into their underlying monetary metal, gold and silver arbitrage tied the Council bills exchange rate closely to the floating mint-par.

Having a floating silver mint-pars did not cause much concern until the middle of the 1870s. Until then, the relative price between silver and gold had been quite stable for decades (Laughlin, 1885, pp.161ff.). It was only after France, which used to be the champion of bimetallism, imposed limits on the coinage of silver in September 1873, when the demise of silver as monetary metal began. The global shift towards gold-based money manifested itself in a unprecedented reduction of the silver price (Eichengreen, 2008, p.17; Laughlin, 1886,

[5]There were also sterling-to-rupee exchange rates quoted for bills issued in Bombay, Calcutta, and Madras on London. These rates followed the one quoted in London quite closely.

ch.12; Clare, 1895, p.141). For countries such as India holding onto a silver-based currency, this lead to a substantial depreciation of the exchange rate with e.g. the rupee being worth around 22 pence in 1875, but only around 17 pence in 1889 (see Figure 1). This downward trend was only briefly reversed when, in July 1890, the United States responded to the political agitation to remonetise silver with the passage of the Sherman Act, which included a clause instructing the Treasury to purchase $4\frac{1}{2}$ million ounces of silver per month (see Fisher, 1896, p.48). Thanks to this, the Treasury was able to put notes in addition to the existing gold as well as silver-backed dollar coins and banknotes into circulation. However, the uncertainty about which currency system and means of payment would eventually prevail in the United States, lead almost immediately to considerable monetary disturbances, wherefore the purchase clause in the Sherman Act was repealed as soon as November 1893 (see Friedman and Schwarz, 1960, pp.104ff.). For the rupee exchange rate, these events manifested themselves in a marked, but short-lived, re-appreciation during the early 1890s.

As noted by Keynes (1913, ch.1)—who after 1906 spent a brief part of his career as civil servant for the India Office in London (see Niehans, 1990, p.346)—the ongoing rupee depreciation was widely perceived as a major impediment to trade and investment (see also Dadachanji, 1931, pp.14ff. 28ff.; Wadia and Joshi, 1926, pp.187). Therefore, India eventually began to follow the global trend by gradually demonetising silver. In particular, in 1893, Indian mints stopped the free coinage of rupees for private persons (Sarkar, 1909, p.290; Wadia and Joshi, 1926, pp.191ff.; Dadachanji, 1931, pp.23ff.), which lead to an immediate decoupling of the market exchange rate from the silver mint-par (see Figure 1). Furthermore, between September and November 1897, due to a shortage of currency reserves in India, the sale of Council bills was suspended during ten weeks (New York Times, 1897). Thereafter, the silver link of the rupee was soon completely severed. More specifically, in 1898, an Indian Currency Committee, whose report was published in July 1898, recommended to fix the rupee value in terms of gold (Dadachanji, 1931, pp.50ff). However, instead of backing the rupee directly by gold, which would have required to reopen an official mint, it was decided to put the Indian currency system on a gold-exchange standard. By making the rupee convertible into sterling, which was in turn convertible into gold, the exchange rate was stabilised around a value of 1 shilling and 4d., or 16 pence during the year 1899 (Dadachanji, 1931, pp.69ff; Wadia and Joshi, 1926, pp.196ff.). After around a decade of pervasive uncertainty as regards the future organisation of the Indian currency system, this marked the replacement of the floating rupee based on silver, to a fixed exchange rate regime during the first part of the 20^{th} century (Keynes, 1913, p.33; Wadia and Joshi, 1926, ch.24).

3.2 India bonds in the London market for government securities

During the second part of the 19^{th} century, India's government debt was raised by bonds denominated in rupees, but partly also in sterling (Fisher, 1897, p.388). What is even more remarkable, some tranches of these rupee and sterling bonds circulated simultaneously with the same coupon between 3 and 5 per cent (see Flandreau and Oosterlinck, 2012, p.659). The top panel of Figure 2 illustrates this by means of a price list taken from the May 1877 edition of the "Investor's Monthly Manual", which was published by the newspaper "The Economist" to provide a comprehensive overview of British financial data including a large section on domestic, colonial, and foreign government securities traded in the London Stock Exchange.[6] As shown by the last column, some of the payments on Indian bonds were made in sterling by warrant at the Bank of England, e.g. in a currency convertible into gold, whereas others were payable in rupees, e.g. in a currency convertible into silver. Furthermore, between 20 and 25 per cent of the rupee bonds were "enfaced for payment in London", e.g. in form of the above-mentioned Council bills (Flandreau and Oosterlinck, 2012, p.656; Fisher, 1896, p.388). Taken together, this meant that silver-based rupee-bonds

[6] At the time, government securities appeared under the heading "stock" and a coupon payments were called "dividends", even though these were actually fixed-interest securities.

and gold-based sterling-bonds, backed by the same credible government, traded in the same financial market in London, were literally quoted side-by-side in the financial press.

For the 1869 to 1906 period, Table 2 provides a list of Indian bonds with frequent price quotations in London.[7] The corresponding end of the month prices, depicted in the middle panel of Figure 2, provide the basis for calculating comparable internal interest rates for gold and silver-based currency. Even when coupon payments are identical, for several reasons, this calculation is far from trivial. Firstly, since the Investor's Monthly Manual reports all data in pounds sterling, the silver bond prices need converting into rupees to obtain a genuine silver-currency yield. Following Fisher (1896, p.389), the corresponding conversion employs the market exchange rate for Indian Council bills, rather than the floating mint-par. Secondly, the various bonds matured on different dates. Thirdly, interest payments on most bonds were paid semi-annually, whereas some of the sterling bonds had quarterly interest payments. Fisher (1896, 1930) essentially ignored these details by treating each bond as a perpetuity and calculating a corresponding yield given by

$$i = \frac{p_{par} C}{p_t}, \tag{1}$$

where p_{par} denotes the par-value, C the annual coupon payment, and p_t the current bond price.[8]

Fisher (1896, p.389; 1930, pp.404-405) looked at several tranches of Indian bonds to compile his annual interest-rate data. In particular, for sterling (or gold currency) until 1880, he uses the 4%'s, between 1880 and 1884 the $3\frac{1}{2}$%'s, and thereafter the 3%'s. For the rupee (or silver currency), between 1869 and 1894, he uses the 4%'s, and thereafter the $3\frac{1}{2}$'s to calculate interest rates. However, in particular between the 4 and the $3\frac{1}{2}$ sterling-bonds, the different coupon payments seem to give rise to an apparent structural break (see Figure 2). Conversely, at the end of 1894, the 4% rupee paper could be converted into $3\frac{1}{2}$'s (Fisher, 1896, p.389), which might be the reason why the corresponding price transition was much smoother. To mitigate against structural breaks, wherever possible, the results of Section 4 employ bonds with identical coupon payments. In particular, until October 1888, the 4%'s are used. After October 1895, the $3\frac{1}{2}$'s are used. Between those dates, yields are derived from the 4%'s for silver (rupee), and from the $3\frac{1}{2}$'s for gold currency (sterling).

Reflecting the periods between 1869 and 1906 during which the various bonds of Table 1 were actively traded in the London financial markets for government securities, the bottom panel of Figure 2 depicts the resulting yields calculated from (1). Whereas the sterling-bond yields were closely tied to their coupon rate, the rupee-bond yields fluctuated heavily. More precisely, they were typically traded at a, more or less large, discount relative to the sterling-bonds. To explain such differences, in the "Appreciation of Interest", Irving Fisher suggested that for securities denominated in different currency standards, expectations about future

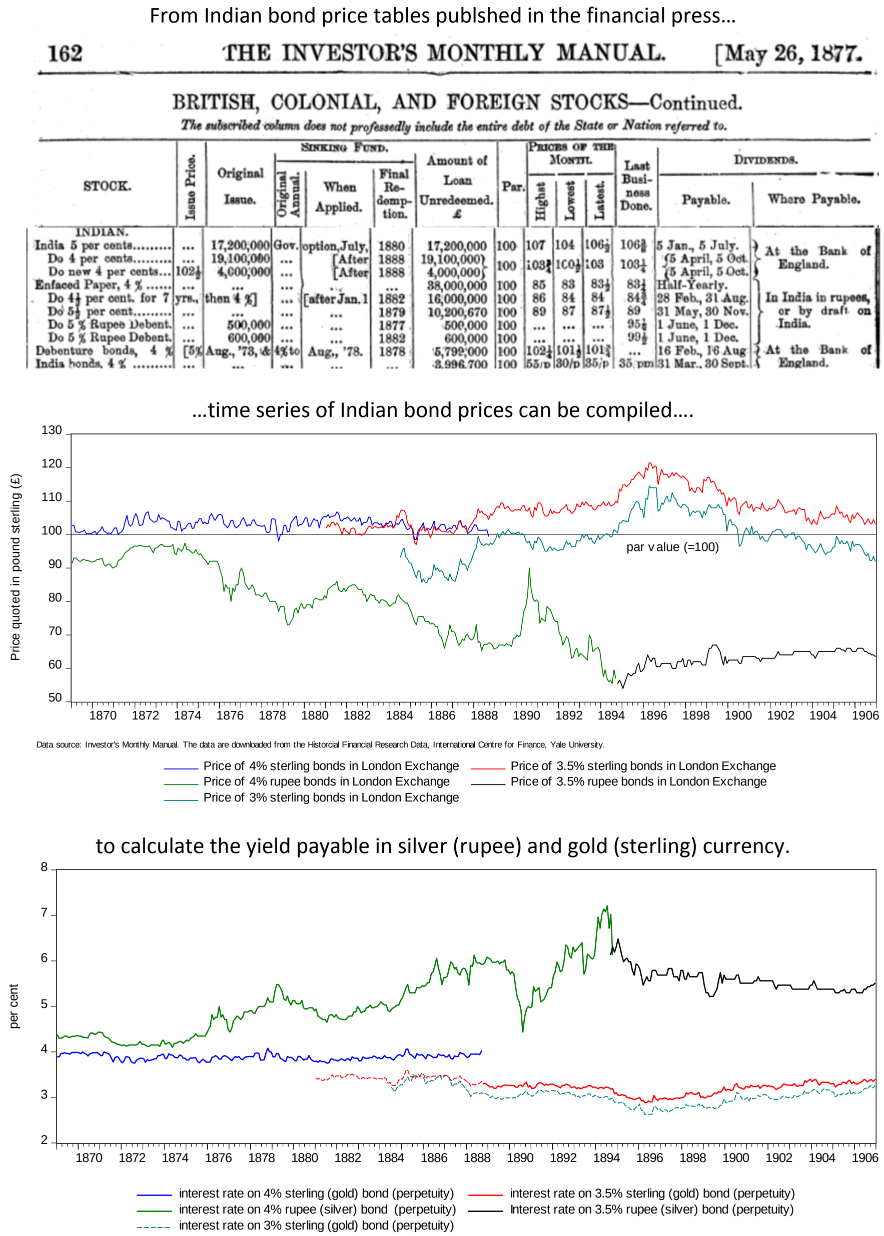
[7]For a more complete list, see Flandreau and Oosterlinck (2012, p.659).

[8]The yield of a perpetual bond depends only on the coupon rate and the current bond price and, hence, ignores the effect from different terms to maturity. To account for these, modern finance commonly uses yields to maturity (see also Flandreau and Oosterlinck, 2012, p.658). For the case with semi-annual coupon payments, the annualised yield to maturity is approximately is given by

$$i \approx 2 \frac{c + \frac{p_{par} - p_t}{n}}{\frac{p_{par} + p_t}{2}}$$

where n denotes the number of semi-annual periods left to maturity. For the case of the 4% rupee paper, another complications arises from an in build (call) option value, since the bond could be redeemed somewhen after October 1888 on a three-months notice. According to Flandreau and Oosterlinck (2012, p.665), it is even nowadays hard to value such a "Bermudian call option", which can be exercised at several dates. As the corresponding theory has only recently been developed, and without the help of electronic computers, it is probably safe to say that this task would have been impossible to solve for a 19^{th} century investor. Nevertheless, when employing the yield to maturity as defined by the formula above, the essence of the results reported in Section 4 did not change.

Figure 2: Derivation of interest rates on Indian government bonds



From Indian bond price tables publshed in the financial press…

162 THE INVESTOR'S MONTHLY MANUAL. [May 26, 1877.

BRITISH, COLONIAL, AND FOREIGN STOCKS—Continued.

The subscribed column does not professedly include the entire debt of the State or Nation referred to.

STOCK.	Issue Price.	Original Issue.	Sinking Fund. Original Annual.	Sinking Fund. When Applied.	Sinking Fund. Final Redemption.	Amount of Loan Unredeemed. £	Par.	Prices of the Month. Highst	Prices of the Month. Lowest	Prices of the Month. Latest.	Last Business Done.	Dividends. Payable.	Dividends. Where Payable.
INDIAN.													
India 5 per cents.........	...	17,200,000	Gov.	option, July,	1880	17,200,000	100	107	104	106½	106⅜	5 Jan., 5 July.	At the Bank of England.
Do 4 per cents.........	...	19,100,000	...	[After	1888	19,100,000	100	103¾	100½	103	103¼	5 April, 5 Oct.	
Do new 4 per cents...	102½	4,000,000	...	[After	1888	4,000,000						5 April, 5 Oct.	
Enfaced Paper, 4 %	...	...	...	...	...	38,000,000	100	85	83	83½	83¼	Half-Yearly.	In India in rupees, or by draft on India.
Do 4½ per cent. for 7	yrs.,	then 4 %]	...	[after Jan. 1	1882	16,000,000	100	86	84	84	84¾	28 Feb., 31 Aug.	
Do 5½ per cent.........	...	...	...	...	1879	10,200,670	100	89	87	87½	89	31 May, 30 Nov.	
Do 5 % Rupee Debent.	...	500,000	...	...	1877	500,000	100	...	...	...	95⅛	1 June, 1 Dec.	
Do 5 % Rupee Debent.	...	600,000	...	...	1882	600,000	100	...	...	...	99½	1 June, 1 Dec.	
Debenture bonds, 4 %	[5%	Aug., '73, &	4% to	Aug., '78.	1878	5,799,000	100	102¼	101½	101¾	...	16 Feb., 16 Aug	At the Bank of England.
India bonds, 4 %	...	...	...	...	...	3,996,700	100	55/p	30/p	35/p	35 pm	31 Mar., 30 Sept.	

Table 1: Actively traded tranches of Indian bonds in the London Stock Exchange

Security	Par	Issue and redemption date	Payment profile
Silver (rupee) bonds			
4% rupee bond	100	Issued in 1865. Maturing after October 1888. Thereafter callable on a three-month notice. This notice was given in 1894. The bonds were redeemed or converted into $3\frac{1}{2}$ rupee bonds before the end of 1894.	Semi-annual interest rates (April and October). Payments are made by draft on India.
$3\frac{1}{2}$% rupee bond	100	Issued in 1895. Maturing in 1926.	Semi-annual interest rates (various dates). Payments are made in India or by draft on India.
Gold (sterling) bonds			
4% sterling bond	100	Issued in 1869. Maturing after October 1888.	Semi-annual interest rates (April and October). Payments are made by warrant at the Bank of England
$3\frac{1}{2}$% sterling bond	100	Issued in January 1881, redemption not before January 1931.	Quarterly interest rates (January, April, June, and October). Payments are made at the Bank of England.
3% sterling bond	100	Issued in January 1884. Final redemption not before October 1948.	Quarterly interest rates (January, April, June and October). Payments are made at the Bank of England.

Notes: Compiled from Flandreau and Oosterlinck (2012) and "Investor's Monthly Manual". There were also 5% sterling and rupee bonds issued in 1859 and 1867 and redeemed in 1880 and 1882, respectively. However, the 5% rupee paper was rather illiquid in the sense that prices were only sporadically quoted.

exchange rate changes matter. Concretely, the upsurges of the price for rupee paper reflect the prospect of future silver depreciations, at least as far as they were widely anticipated. According to this interpretation, the development of the rupee bond yields at the time is a reflection of time-varying "silver risk", meaning the uncertainty resulting from a decreasing silver mint-par. Up until the mid 1870s, the interest rates derived from sterling and rupee bonds moved in close parallel, but began to diverge thereafter, suggesting that concerns about investing in silver bonds increased in times of an ongoing rupee depreciation. In terms of monetary history, the two decades after 1873 were indeed characterised by the emergence of the international gold standard, which was associated with a great deal of uncertainty about the future of silver-based currencies. According to the rupee bond yields, this uncertainty culminated around the unsuccessful attempt of the United States to remonetise silver in the early 1890s. In any case, the parallel movement between the interest rate on sterling and rupee bonds returns only towards the end of the 1890s, when India made the transition from a silver to a gold-exchange standard. However, compared with the 4%'s during the period of stability in the early 1870s, the more or less stable spread between the $3\frac{1}{2}$%'s silver and gold bonds after 1900 is considerably larger.

3.3 Interest-parity condition between silver and gold currency

When applying the conventional logarithmic approximation, the interest-parity condition between Indian gold and silver bonds is given by

$$i_t^{£} \approx i_t^{rs} + s_{t+h}^e - s_t + \alpha + \sigma_t, \tag{2}$$

where $i_t^{£}$ is the yield on sterling bonds, i_t^{rs} the yield on rupee bonds, s_t the exchange rate from Indian Council bills (transformed into logarithms), and s_{t+h}^e the corresponding expected value at the future horizon h. Furthermore, α is a term absorbing constant factors and σ_t reflects time-varying currency risk. Equation (2) is similar to other UIP conditions equating the exchange rate adjusted return between domestic and foreign securities and accounting for currency (or exchange rate) risk (see e.g. Isard, 1995, pp.83ff.; Chinn, 2006, pp.8-9; Sarantis, 2006, p.1173; or Li *et al.*, 2012, pp.168-169).

In several regards, the data employed in empirical UIP studies are imperfect. Firstly, rather than only changes in the currency value, interest rate differences could also reflect differences in a large number of country characteristics, which impact upon such things as default risks (see e.g. Frankel, 1992). Conversely, the bonds from which $i_{£}$ and i_{rs} are derived were both issued by the Indian government and, hence, subject to the same sovereign risk which, thanks to the backing of the British Empire, was arguably negligible (Flandreau and Oosterlinck, 2012, p.654-655). Secondly, assets denominated in different currencies are often traded in different financial markets with disparate financial regulations, taxes, or transaction costs. Such things as capital controls, which were commonplace before the 1970s (see e.g. Dooley and Isard, 1980), and recently more stringent capital requirements (Rime *et al.*, 2016), can indeed drive a wedge into interest-parity relationships. Conversely, all interest and exchange rates appearing in (2) are derived from securities traded in the London financial market, which was the world's pre-eminent financial centre at the time (Cassis, 2010, pp.83ff). Furthermore, the era of the international gold standard was characterised by extremely free capital movements, quite low taxes, and a laisser-faire attitude towards financial regulation (Obstfeld and Taylor, 2005, ch.3.1). Thirdly, for both historical and modern examples, exchange rate expectations s^e_{t+h} are unobserved. In empirical work, usually, rational expectations are invoked such that $s^e_{t+h} = s_{t+h}$ (see e.g. Li *et al.*, 2012, p.168). Although this is, perhaps, a strong behavioural assumption, any alternative postulating some form of "irrational expectations" would imply that speculators could make potentially huge profits by borrowing in the low-interest-rate currency and investing in the currency offering a high interest rate. If $s^e_{t+h} \neq s_{t+h}$, the corresponding difference would, even on average, not be offset by exchange rate changes. Interestingly, as regards the valuation of Indian gold and silver bonds during the year 1890, a contemporaneous pamphlet written by an experienced foreign exchange trader, called Ottomar Haupt, employs this argument. In particular, Haupt (1890) observed that an ongoing appreciation of the rupee caused by the United States' silver purchases and constantly higher interest rates on Indian silver bonds cannot be sustained without inviting arbitrage transactions (see also Flandreau and Oosterlinck, 2012, pp.656-657).

When converting the UIP condition into an empirical equation, coefficients β and γ are introduced, a statistical error term ϵ_t accounts for the stochastic nature of econometric relationships, and (2) is rearranged such that interest rate differences are regressed onto exchange rate changes. Taken together, the UIP-regression is given by

$$s_{t+h} - s_t = \alpha + \beta(i_{£} - i_{rs}) + \gamma\sigma_t + \epsilon_t. \tag{3}$$

A one-to-one relationship between interest rate differences and exchange rate changes maps into the null-hypothesis of $\beta = 1$. Furthermore, in case $\gamma \neq 0$, time-varying currency risk affects the fluctuations of the sterling-to-rupee exchange rate in excess to the volatility originating from interest rates.

A major econometric challenge to estimating (3) arises from time-varying currency risk, which is not directly observable. Moreover, ignoring σ_t is likely to give rise to an omitted variables bias, insofar as e.g. silver risk affects the spread between Indian bonds and is, hence, correlated with the regressors of (3) (compare Fama, 1984). In financial econometrics, risk measures such as σ_t are nowadays commonly captured via the standard deviation of the error term ϵ_t of (3), e.g. $\sigma_t = \sqrt{\epsilon_t^2}$ (see e.g. Tsay, 2005, p.123). Subsequently, the time series behaviour of this conditional-variance, which is referred to as "volatility", is thought to depend on past shocks, as represented by ϵ^2_{t-1}, as well as its own past observation, as represented by σ^2_{t-1}. This approach, where expected asset returns depend on expected asset risks, leads to a broad class of so-called "generalised autoregression conditional heteroscedasticity in mean", or GARCH-M, models. Differences arise as regards the specification of the "conditional variance equation". For the case of the UIP regression, Berk and Knot (2001) provide an early example with a simple ARCH(1) process, meaning that time-varying currency risk depends only the most recent volatility shock ϵ_{t-1}^2. In a slightly transformed version, where volatility shocks are defined in terms of deviations from unconditional volatility q, this can be written as $\sigma_t^2 = \phi_0 + \phi_1(\epsilon_{t-1}^2 - q)$, where $\phi_{(.)}$ are coefficients to be estimated. Aysun and Lee (2014, p.86) consider the more general GARCH(1,1), where the time-varying currency risk can also depend on the past conditional variance, e.g. $\sigma_t^2 = \phi_0 + \phi_1(\epsilon_{t-1}^2 - q) + \phi_2(\sigma_{t-1}^2 - q)$. Although the GARCH(1,1) is one of the most widely used models in empirical finance, it ignores, perhaps, some of the special features of the Indian currency system during the second part of the 19^{th} century. As mentioned above, the demise of bimetallism after 1870 gave rise to pervasive uncertainties about the future of the remaining currencies aligned with silver. In particular, the marked depreciation of the rupee was seen as an impediment to India's international trade and finance with contemporary observes being well aware that a depreciation as well as an increase in interest rates on silver bonds would increase the burden to service public debt (see e.g. Dadachanji, 1931, pp.24ff.). Hence, currency risks could have had asymmetric effects, which are commonly reflected via a threshold term $\phi_3 D_t$, where D_t is a dummy variable identifying unexpected rupee depreciations, e.g. $\epsilon_{t-1} < 0$. Finally, Li *et al.* (2012) have suggested that the component GARCH(1,1) model, or CGARCH(1,1), of Engle and Lee (1999) is warranted to separate transitory from permanent currency risks in the UIP regression. By doing so, even in the long term, currency risk is not necessarily constant, e.g. $q_t \neq q \; \forall \; t$, but can depend on a permanent component obeying the equation $q_t = \phi_4 + \phi_5(q_{t-1} - \phi_4) + \phi_6(\epsilon_{t-1}^2 - \sigma_t^2)$. Meanwhile, transitory (or short-term) currency risk is again modelled by means of the GARCH(1,1) process introduced above. Taken together, the fully fledged conditional variance equation, which coincides with the comprehensive CGARCH(1,1) model of Li *et al.* (2012, p.170), is given by

$$\begin{aligned} \sigma_t^2 &= q_t + \phi_1(\epsilon_{t-1}^2 - q_{t-1}) + \phi_2(\sigma_{t-1}^2 - q_{t-1}) + \phi_3 D_t(\epsilon_t^2 - q_{t-1}) \\ q_t &= \phi_0 + \phi_4(q_{t-1} - \phi_4) + \phi_5(\epsilon_{t-1}^2 - \sigma_{t-1}^2), \end{aligned} \tag{4}$$

The coefficients of (4) are subject to the following restrictions. The transitory and the permanent component are stationary and the conditional variance σ_t^2 is non-negative if $|\phi_1 + \phi_2| < 1$ and $|\phi_5| < 1$ (see Engle and Lee, 1999?). This property implies that currency risks arise in a concentrated, or clustered, manner, whereby transitory volatility σ_{t+1}^2 converges to q_t with speed $\phi_1 + \phi_2$, and permanent volatility converges to ϕ_4 with speed ϕ_5. Compared with the transitory component, the permanent component is typically highly persistent, e.g. ϕ_5 is close to 1 and $\phi_1 + \phi_2 < \phi_5$. Otherwise, the model would converge faster in the long-term than in the short-term and, hence, be unstable (see Li *et al.*, 2014, p.170). Finally, for unexpected rupee depreciations causing relatively more uncertainty, the coefficient ϕ_3 has to be positive.

The vagaries about the nature of unobserved currency risk map into uncertainties about the appropriate specification of the conditional variance equation (Sarantis, 2006, p.1170). Therefore, during the next section, more or less parsimonious versions of (4) will be considered. In principle, it would be possible to try out a huge number of permutations. However, to concur with the empirical UIP literature, the choice will be restricted to conditional volatility equation specified as ARCH(1) model as in Berk and Knot (2001) where $\phi_2 = \phi_3 = \phi_4 = \phi_5 = 0$, as GARCH(1,1) as in Aysun and Lee (2014) where $\phi_3 = \phi_4 = \phi_5 = 0$, and the comprehensive CGARCH(1,1) including a threshold effect (e.g. $\phi_3 \neq 0$) as in Li *et al.* (2014).[9]

[9]Several further specifications have been tried, which typically gave rise to similar results than those reported in Section 4.

4 Results

Table 2 reports estimates of the conditional mean equation (3) ignoring, for the moment, the effect of currency risk, e.g. imposing the restriction $\gamma = 0$. To first replicate the result of Lothian *et al.* (2013, p.11), column 1 employs Fisher's (1930) annual data, which cover the 1869 to 1906 period, which yields an incorrectly-signed coefficient of -1.78 for β.[10] However, the standard deviations are large, and no coefficient is significantly different from 0.[11] However, Fisher's (1930) annual data cover only 36 years. To obtain a larger number of observations, the remaining columns of Table 2 turn to the monthly data depicted in Figures 1 and 2. With a forecast horizon h of 1 year (or 12 months) the 1869 to 1906 period would in principle provide 36 years $\times$ 12 months=432 observations. However, as mentioned in Section 3.1, between September and November 1897 the sale of Indian Council bills was suspended. Hence, the common sample covers only 429 observations. From these, similar to the annual data, a negative slope coefficient of -1.26 arises in column 2. However, with a larger number of observations, the coefficient standard deviations are smaller, wherefore the hypothesis of $\beta = 1$ can now be rejected at any conventionally-used level. Recall from the discussion of Section 3 that Indian currency history was severely disrupted by such events as the passage of the Sherman Act or the transition from a silver to a gold-exchange standard during the 1890s. To account for these, column 3 restricts the sample to the months between 1869 and August 1897, when the rupee was on a silver standard. Then again, the results are qualitatively similar to those of the full sample. Column 4 restricts the sample even further to observations before October 1888 to ignore the uncertainties about the long-term trend of the silver price around the year 1890, as well as to avoid a comparison between bonds with incongruent coupons. By doing so, the estimated coefficient for β becomes positive and is no longer statistically different from the hypothesised value of the UIP condition. Conversely, column 5 looks at months between January 1889 and September 1997, which were characterised by large swings in the rupee exchange rate. With a slope coefficient of -7.39, which reflects a massive deviation from the UIP condition, the underlying uncertainties about the future of silver-based currency systems like the Indian rupee were apparently pervasive. Column 6 focuses on the end of the sample, e.g. the months after 1898, which gives again rise to a significantly negative coefficient despite the fact that all interest rates are derived from $3\frac{1}{2}\%$ bonds. However, when restricting the sample to the months after January 1899, when the rupee exchange rate had been stabilised at 16 pence, in column 7, an estimated slope coefficient of 0.66 arises that is quite close to 1. Taken together, at least during periods with stable and established currency regimes and when comparing bonds with identical coupons, a proportional movement between Indian interest rate differences and exchange rate changes cannot be rejected.

Currency risk is a widely invoked culprit for deviations from the UIP condition. To test whether this manifests itself in ARCH effects, the bottom of Table 2 reports standard Lagrange multiplier (LM) tests from regressing the squared residual e_t^2 on a constant and its own past value (see Tsay, 2005, pp.101-102). Whereas for monthly data, it cannot be rejected that the residuals are conditionally homoscedastic during the gold-exchange period, the null hypothesis of having no ARCH effect is clearly rejected when the value of the rupee was more or less closely aligned to the fluctuating silver mint-par and, hence, subject to considerable uncertainty as regards the future exchange rate.[12] To account for the corresponding risks, Table turns to the GARCH-M model, which encompasses the conditional mean equation (3) with $\gamma \neq 0$ and several specifications of the conditional variance equation (4). Estimation

[10]For the year 1890, Fisher (1930) reports an observation for the first and the second half of the year. As in Lothain *et al.* (2012), the corresponding semi-annual observations are averaged.

[11]Lothian *et al.* (2012,) report conventional coefficient standard deviations. However, to account for potential autocorrelation, the current results always estimate coefficient standard deviations that are robust to heteroscedasticity and autocorrelation (HAC).

[12]It is also possible to test for higher order ARCH effects by including p past observations of the squared residuals in the ARCH-LM test. With monthly data, it is sensible to also consider 12 lags (e.g. p=12). However, this does not change the essence of the results reported in Table 2.

Table 2: Interest parity regressions with Indian gold (sterling) and silver (rupee) bonds ignoring currency risk

Frequency:	Annual		Monthly				
Sample:	1869-1906		1869-1897	1869-1888	1889-1897	1898-1906	1899-1906
	(1)	(2)	(3)	(4)	(5)	(6)	(7)
			Conditional mean equation				
Intercept ($\widehat{\alpha}$)	-0.22	-3.18***	-3.01**	-1.54***	-21.0***	-1.74	1.45*
	(1.25)	(0.87)	(0.44)	(0.83)	(3.42)	(0.84)	(0.73)
$i_t^{£}$-i_t^{rs} ($\widehat{\beta}$)	-1.78	-1.26**	-0.97***	0.38	-7.39***	-0.83**	0.66*
	(2.73)	(0.61)	(0.39)	(0.88)	(1.31)	(0.39)	(0.34)
Reject ($\beta = 1$)		***	***		***	***	
R^2	0.09	0.05	0.02	0.003	0.18	0.09	0.06
N	36	438	332	225	92	96	84
ARCH-LM test	0.14	471.5***	317.9***	51.5***	76.8***	11.0*	2.86

Notes: This table reports estimates of equation (3) with dependent variable $s_{t+h} - s_t^*$ and restriction $\gamma = 0$. Estimation is by OLS. Heteroscedasticity and autocorrelation robust (Newey-West) coefficient standard errors are reported in parentheses. Significant coefficients at the 10% level are marked by a *; at the 5% level by **, and at the 1% level by ***. The null hypothesis that the interest parity (via long-bill transactions) holds implies that $\beta = 1$. Significant deviations from this are indicated by * at the 10% level; ** at the 5% level, and *** at the 1% level. R^2 denotes the fit of the regression and N the number of observations. ARCH-LM test refers to the Lagrange multiplier test for ARCH effects according to the test statistic, $e_t^2 = \theta_0 + \theta_1 e_{t-1}^2 + \zeta_t$, where e_t denotes the residual and ζ_t is an error term. The null-hypothesis is $\theta_1 = 0$.

of GARCH-M models occurs by maximum likelihood assuming, typically, that ϵ_t follows a normal distribution with mean 0 and unconditional variance σ^2.[13] Since the corresponding routines are recursive, a continuous sample of time-series observations is warranted (see e.g. Tsay, 2005, ch.3).

For the sake of comparison with Lothian *et al.* (2012), column 1 of Table 3 reports estimates of the widely used GARCH(1,1) model with annual data. From this, a positive coefficient of 1.04 on interest rate differences arises, which concurs almost exactly with the hypothesised value of $\beta = 1$. Furthermore, the coefficient estimates of the conditional variance equation are, as expected, positive, which indicates the presence of volatility clustering, and satisfy the stationarity condition $|\phi_1+\phi_2| < 1$. However, with only 36 observations, these results are at most indicative. Indeed, none of the coefficient estimates is statistically significant from 0. Furthermore, the Jarque-Berra test statistic rejects the hypothesis that the standardised residuals $\widetilde{e}_t = e/\sigma_t$ follow a normal distribution (compare Tsay, 2005, p.109).

The remaining columns of Table 3 turn again to monthly data. Since the estimation of GARCH models warrants a continuous sample, and owing to the suspension of Council bill sales at the end of the year 1897, the results cannot be estimated across the 1869 to 1906 period. By and large, the years 1897 mark the transition of the Indian currency system from a silver to the gold-exchange standard, which is likely to exhibit lower degrees of currency risk. Hence, it is necessary, and seems sensible, to contemplate the silver period separately in columns 2 to 4, which report the UIP regression with the specifications of the conditional volatility equation that have hitherto been considered in the literature. It turns out that the introduction of a GARCH-M model does not overturn the results mentioned above. Above all, the UIP puzzle does not disappear. Furthermore, currency risk gives only rise to a significant effect in the ARCH(1) specification of column 2 and the stationarity condition $|\phi_1 + \phi_2| < 1$ is violated in the GARCH(1,1) specification of column 3. Although the transitory and permanent components satisfy the stationarity conditions of, respectively, $|\phi_1 + \phi_2| < 1$ and $|\phi_4| < 1$, the comprehensive CGARCH(1,1) specification of column 4 violates the stability and conditions $|\phi_1 + \phi_2| < |\phi_4|$, e.g. the transitory component does not converge faster than the permanent component.

Columns 2 to 4 of Table 3 cover different regimes in the foreign exchange market. As mentioned in Section 3.1, the first part of the 1890s was characterised by idiosyncratic

[13] Alternatively, ϵ_t can also be assumed to follow a t-distribution with v degrees of freedom, which has heavier tails than the standard normal distribution (see e.g Tsay, 2005, p.108). However, using the t-distribution did not change the essence of the results reported below.

Table 3: M-GARCH Interest parity regressions with Indian gold (sterling) and silver (rupee) bonds

Frequency:	Annual	Monthly										
Sample:	1869-1906	January 1869 until August 1897			January 1869 until October 1888			Jan.1889-Dec.1894			1898-1906	1899-1906
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)
					Conditional mean equation							
Intercept ($\widehat{\alpha}$)	-2.60	-3.10***	-3.04***	-2.91***	-2.19***	-3.13***	-2.99***	-28.4***	-21.0	-23.4***	-0.31	1.47
	(2.49)	(0.65)	(0.61)	(0.33)	(0.46)	(0.476)	(0.27)	(2.74)	(21.5)	(3.62)	(2.10)	(1.30)
$i_t^{\pounds}$-i_t^{rs} ($\widehat{\beta}$)	1.04	-2.39***	-1.65***	-1.58***	1.38***	0.09	0.97***	-11.6***	-7.39*	-10.0***	-0.17	0.41
	(2.78)	(0.70)	(0.65)	(0.24)	(0.39)	(0.70)	(0.30)	(1.10)	(4.35)	(1.31)	(0.27)	(0.36)
ρ ($\widehat{\gamma}$)	0.41	-0.16*	-0.06	-0.001	0.15***	0.30**	0.46***	-0.23	0.003	-0.26	-0.05	-1.51
	(0.62)	(0.10)	(0.13)	(0.11)	(0.06)	(0.14)	(0.10)	(0.22)	(0.47)	(0.24)	(1.01)	(2.35)
Reject ($\beta = 1$)		***	***	***				***	*	***	***	
					Conditional variance equation							
Specification:	GARCH	ARCH	GARCH	CGARCH	ARCH	GARCH	CGARCH	ARCH	GARCH	CGARCH	ARCH	ARCH
$\widehat{\phi}_0$	2.59	5.61***	1.87**	27.7	2.42***	0.76*	13.8***	10.1**	49.7	111.6	0.11***	0.12***
	(3.27)	(1.38)	(0.95)	(17.3)	(0.77)	(0.46)	(0.90)	(4.44)	(146.3)	(178.3)	(0.04)	(0.02)
$\widehat{\phi}_1$	0.29	0.96***	0.82***	0.26***	1.16***	0.72***	0.20**	1.02***	0.15	0.62	0.50**	0.12
	(0.33)	(0.13)	(0.16)	(0.12)	(0.22)	(0.20)	(0.09)	(0.32)	(0.39)	(0.61)	(0.24)	(0.11)
$\widehat{\phi}_2$	0.59		0.28***	0.66***		0.40***	0.09		0.60	0.32		
	(0.40)		(0.09)	(0.09)		(0.10)	(0.17)		(1.06)	(0.50)		
$\widehat{\phi}_3$				0.11			0.37***			-0.09		
				(0.09)			(0.13)			(0.27)		
$\widehat{\phi}_4$				0.77***		0.40***	0.96***			0.87**		
				(0.02)		(0.10)	(0.04)			(0.36)		
$\widehat{\phi}_5$				0.34***			0.35***			0.32		
				(0.09)			(0.10)			(0.59)		
Log-likelihood	-99.1	-959.6	-949.5	-943.1	-579.6	-508.7	-571.1	-306.4	-336.0	-284.7	-57.7	-35.2
N	36	332	332	332	225	225	225	92	92	92	96	84
ARCH-LM test	0.01	1.41	0.69	0.01	1.74	0.01	0.18	0.15	39.8***	0.001	0.41	3.92*
Jarque Berra	12.25***	3.80	3.64	2.70	0.33	1.01	0.67	1.18	1.43	1.88	1.34	3.02

Notes: This table reports estimates of the GRACH-M model consisting of the conditional mean equation (3) with dependent variable $s_{t+h} - s_t^*$ and the conditional variance equation (4). Estimation is by maximum likelihood assuming that ϵ_t follows a normal distribution with mean 0 and (unconditional) variance σ^2. Starting values are taken from the unconditional variance estimate $\sigma^2 = \sum_{t=1}^{T} e_t^2/T$, where e denotes the OLS-residual and T the total number of observations. Heteroscedasticity and autocorrelation robust (Newey-West) coefficient standard errors are reported in parentheses. Significant coefficients at the 10% level are marked by a *; at the 5% level by **, and at the 1% level by ***. The null hypothesis that the interest parity (via long-bill transactions) holds implies that $\beta = 1$. Significant deviations from this are indicated by * at the 10% level; ** at the 5% level, and *** at the 1% level. Log-likelihood reports the maximised value of the log-likelihood function and N denotes the number of observations. ARCH-LM test refers to the Lagrange multiplier test for ARCH effects according to the test statistic, $e_t^2 = \theta_0 + \theta_1 e_{t-1}^2 + \zeta_t$, where e_t denotes the residual and ζ_t is an error term. The null-hypothesis is $\theta_1 = 0$. Jarque-Berra refers to the test on the null-hypothesis that the standardised residuals $\widetilde{e}_t = e/\sigma_t$ follow a normal distribution.

events in US monetary history. To avoid the distortions associated with these, similar to the results of Table 2, in columns 5 to 7 of Table 3, the GARCH-M regressions are estimated including only the months before October 1888. Then again, when contemplating a period when the rupee was an established silver currency, the UIP-puzzle disappears. However, to obtain stationary coefficients in the conditional variance equation, the fully fledged CGARCH(1,1) model is warranted, which now satisfies the stationarity and stability condition $|\phi_1 + \phi_2| < |\phi_4| < 1$. Furthermore, the coefficient ϕ_3 from asymmetric currency risk is now significant, which is perhaps not surprising given the endemic silver risks during the period under consideration.

The counterpart to the period with an entrenched silver depreciation are the months between January 1889 and August 1897, when the rupee witnessed substantial swings in its exchange rate reflecting the political controversies about the future of silver-based currency systems (see Sec. 3.1). Regardless the specification of the conditional variance equation, similar to the results of Table 2, columns 8 to 10 of Table 3 uncover massive deviations from a proportional movement between interest rate differences and exchange rate changes during that period.

Finally, the remaining columns of Table 3 turn to the gold-exchange period of the Indian rupee. For the sake of brevity, columns 11 and 12 only report the results of a simple ARCH(1) specification, which reflects that such things as asymmetric currency risks or differences between transitory and permanent components are, probably, of minor importance in a regime with an officially fixed exchange rate.[14] In particular, with a significant ARCH(1) effect, an UIP puzzle arises in column 11, which includes the year 1898. Conversely, for a sample covering only the years from 1899 onwards, in column 12, the ARCH effect is no longer significant, currency risk has no significant effect on the conditional mean equation, and the coefficient for β is positive. Similar to the results of Table 2, as soon as the rupee-to-sterling had been stabilised, and it became clear that the Indian currency system had finally been re-organised around a gold exchange standard, the UIP-puzzle vanishes.

Taken together, when comparing the return on Indian rupee and silver bonds with the corresponding exchange rate changes between 1869 and 1906, the UIP-puzzle seems only to be present during the 1890s. Aside from ordinary currency risks, these years were characterised by extraordinary uncertainties about the future of silver-based currencies, including the Indian rupee. Apparently, a lack of confidence about the future setup of the domestic currency regime can be associated with large deviations from the interest-parity condition, which are left unexploited by currency speculators. Indeed, spotting the abnormal behaviour of exchange and interest rates in his annual data during the 1890s, Fisher (1930, p.) reached the conclusion ...

> "...until the par was proved actually stable by two or three years' experience, the public refused to have confidence that gold and the rupee were once more to run parallel. Their lack of confidence was shown in the difference in the rates of interest in the gold and rupee securities during the transition period 1893 - 1898."

5 Conclusion

This paper has provided an empirical assessment of the uncovered interest parity (UIP) condition by means of historical interest rates derived from Indian gold (sterling) and silver (rupee) bonds and the corresponding rupee-to-sterling exchange rate during the 1869 to 1906 period. These Indian financial, which were already discussed in Irving Fisher's seminal

[14] When contemplating more comprehensive models, almost all coefficients of the conditional variance equation were insignificant, meanwhile the essence of the results did not change.

appreciation of interest rates, provide a much better case to study in how far expected depreciations of a unit of account are priced into interest rates than most modern data. In particular, the Indian government used to raise its debt in sterling and rupee bonds, which were simultaneously traded in the most liquid government bond market in London, suffered only from negligible default risks, and were subject to relatively light-touch financial rules and regulations. Underscoring the importance of having data reflecting the theoretical assumptions of the UIP condition as closely as possible, across a large number of time periods and econometric specifications, the historical sterling-to-rupee exchange rate changes and interest rates differences tend to be positively correlated. Above all, a proportional relationship between interest rate differences exchange rate changes as postulated by the UIP condition not only arise during the gold-exchange-standard period, when the value of the rupee was highly stable, but also in the 1870s and 1880s, when the rupee value followed a floating silver mint-par. Conversely, an UIP puzzle is still present during the 1890s, when the future of silver-based currencies, including the Indian rupee, was extremely uncertain.

6 References

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