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Limits to arbitrage during the crisis: funding liquidity constraints and covered interest parity*

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Abstract

Arbitrage normally ensures that covered interest parity (CIP) holds. Until recently, excess profits, if any, were documented to last merely seconds and reach a few pips. Instead, this paper finds that following the Lehman bankruptcy, these were large, persisted for months and involved strategies short in dollars. Profits are estimated by specifying the arbitrage strategy as a speculator would actually implement it, considering both unsecured and secured funding. Either way, it seems that dollar funding constraints kept traders from arbitraging away excess profits. The claim finds support in an empirical analysis drawing on several novel high frequency datasets of synchronous quotes across securities, including transaction costs.

JEL classification: F31, G01, G14

Keywords: arbitrage limits, covered interest parity, funding liquidity, financial crisis

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A system's dynamics often stand out more clearly when observed under some strain. Connections too faint to be noticed are amplified and relations too complex to be grasped are untangled. In this sense, the recent financial crisis has opened new fields of research and turned attention to questions formerly overlooked. Such is the case for the covered interest parity condition (CIP) which, until the Lehman bankruptcy, was assumed to hold without reservations and used widely to price forward exchange rate contracts. The CIP condition was perceived to be solidly anchored in riskless arbitrage, a notion essential and ubiquitous in finance for asset pricing.

But even such fundamental conditions have their limits. Keynes, already in 1923, expressed the intuition that the CIP condition may be violated if "speculation is exceptionally active and is all one way. It must be remembered that the floating capital normally available... for the purpose of taking advantage of moderate arbitrage... is by no means unlimited in amount" and thus excess profits, when they arise, persist until "fresh capital [is drawn] into the arbitrage business" (Keynes, 1923). Today, in our modern, highly efficient markets, it seems that Keynes' intuition still applies: in the months following the Lehman bankruptcy, the CIP condition broke down and arbitrage opportunities were left unexploited, a situation exacerbated first and foremost by the lack of funding liquidity in dollars.

This paper has two goals: first of documenting CIP deviations during the crisis and second of explaining them. Documentation begins with an effort to specify the arbitrage strategy as a speculator would actually implement it. Two approaches are considered. The first, closer to the operations of a bank's proprietary trading desk (prop desk), involves rolling over overnight unsecured money market positions across currencies, and hedging interest rate risk using overnight index swap (OIS) contracts. The second, more symptomatic of a hedge fund, suggests borrowing and lending against collateral, using repo contracts. We call the first unsecured arbitrage and the second secured. Data, relative to each strategy, come from novel datasets offering multiple daily snapshots of interbank quotes, synchronous across securities and, in most cases, inclusive of transaction costs. Deviations from the CIP condition of up to 360 bps annualized appear incontestably after the Lehman bankruptcy, and last until year-end. They are somewhat smaller and less persistent, though, than those found in earlier studies which use more coarse data. Furthermore, deviations from CIP are (i) currency specific and (ii) directional, in the sense that they appear on trades involving the US dollar and, specifically, in which the dollar is the funding currency.

In short, insufficient arbitrage flows failed to exert the necessary pressure on the forward forex market, leaving the forward rate "mis-priced" according to CIP. Specifically, during the post Lehman period, the dollar was too cheap on the forward market, as compared to the rate suggested by the CIP condition. While those traders who did have access to dollar funding probably made hefty profits at very low risk from CIP arbitrage at the height of the crisis, to most others this opportunity merely remained out of reach; thus, to speak of excess returns from CIP arbitrage means that potential profits were left unexploited.

But why did arbitrage break down? That is the focus of the second part of this paper. Two hypotheses are entertained, one emphasizing risk and the other liquidity factors. The distinction is useful also because secured arbitrage, as opposed to unsecured, removes many of the trading risks and therefore offers a natural experiment to test the importance of risks on excess returns. More generally, this paper's empirical analysis suggests liquidity factors dominate. Dollar funding was rationed due to deleveraging imperatives, prudential hoarding in the face of growing internal funding and liquidity needs, as well as limited capital to pledge in exchange for liquid funds. In this light, the erosion of excess profits and stabilization of the CIP condition at the end of 2008 can be explained by the return of dollar liquidity on money markets, in great part due to the generous central bank swap lines established in the wake of the Lehman bankruptcy.

Several studies precede this paper in exploring deviations from CIP, starting with Frenkel and Levich (1975, 1977). More recently, several papers have focussed on the 2007-2009 financial crisis and have deservedly received significant attention in both academic and policy circles. The studies include Baba, Packer, and Nagano (2008), later expanded into Baba and Packer (2008, 2009), as well as Coffey, Hrung, Nguyen, and Sarkar (2009), Genberg, Hui, Wong, and Chung (2009) and Jones (2009). Yet, all approach the question of CIP deviations using Libor rates across currencies as a measure of funding costs, to be compared to the forward premium (the difference between the forward and spot exchange rates). This raises four issues.

First, these data are somewhat different than those that a trader would have faced. Libor rates are an ask price, are indicative and perhaps biased due to mis-representation or strategic signaling. In fact, the accuracy of Libor rates during the crisis became an important subject of controversy, as pointed out by McAndrews (2009).

Second, Libor rates are only available at 11 am London time, thus often not matching the time stamp of the foreign exchange quotes used. This issue is bound to have been especially important during the crisis given the extreme market volatility. Jones (2009) attempts to circumvent the problem by using data on interest rate futures, but admits these may have been relatively illiquid and their inflexible nature would have limited their use in arbitrage.

Third, Libor rates used in the above mentioned studies are of relatively long maturities: 1 or 3 months. But, as documented by Taylor and Williams (2009), their respective markets became exceptionally illiquid during the crisis. This suggests traders would have turned to other markets or used much shorter maturity instruments to undertake arbitrage strategies. That is indeed the approach taken in this paper.

Finally, and importantly, transaction costs grew considerably during the crisis, as will be shown later, a factor overlooked in the above mentioned literature but important to replicate traders' actual profit opportunities.

The papers that have used finer data are few and pre-date the crisis. The four that stand out are Taylor (1989), Rhee and Chang (1992), Akram, Rime, and Sarno (2008) and Fong, Valente, and Fung (2009, forthcoming). These papers all use high frequency data, synchronous among the various markets under study, and inclusive of bid-ask spreads as a measure of transaction costs. In most cases, though, the datasets typically span just a few months.

This paper also provides empirical grounding to the wider, currently very dynamic, and mostly theoretical literature on market freezes, in which liquidity issues often play a central role in explaining limits to arbitrage. But instead of offering a blanket review here, relevant works are mentioned throughout this paper, in support of hypotheses raised to explain CIP arbitrage profits.

The rest of this paper is organized as follows. Section 1 discusses how CIP arbitrage is implemented in practice and derives corresponding specifications of payoffs. Section 2 reviews the relevant data and offers estimations of excess profits from arbitrage. Section 3 focusses on explaining these. It begins by laying out possible hypotheses and tests these in a subsequent empirical analysis. Note that in this paper the following terms are used interchangeably: excess returns or profits from CIP arbitrage, CIP deviations and breakdown of CIP.

1 The structure of CIP arbitrage

1.1 Two types of traders

Basic CIP arbitrage entails borrowing in one currency and lending in another to take advantage of the interest rate differential while avoiding exchange rate risk. The trade is usually described as borrowing in currency k at an interest cost of $r_{k,t}$, exchanging the sum to currency j using the spot forex market, lending the proceeds in currency j at a rate $r_{j,t}$, and eventually exchanging the principal and accrued interest back to currency k to reimburse the original loan with interest. The latter transaction is undertaken using a forward forex contract thereby eliminating exchange rate risk.

Gains from CIP arbitrage are often expressed as,

$$z_{1,t} = \frac{F_{t \cdots T}}{S_t}(1 + r_{j,t}) - (1 + r_{k,t}) \tag{1}$$

where the spot exchange rate S_t is expressed as the price in currency k of one unit of currency j. The same is true of the forward exchange rate, $F_{t \cdots T}$, where the subscript captures the time the contract is written and its maturity.

Because all variables are known at time t, as emphasized by the shared subscripts, textbooks point out that CIP arbitrage is riskless and should therefore yield zero profits. When re-arranged with $z_{1,t} = 0$, the above equation is often referred to as the "CIP no arbitrage condition", or just the "CIP condition" for short.

But the above characterization of the CIP condition leaves out important details mostly related to implementation – central, of course, to this paper. What instruments are used to borrow and lend? What transactions are undertaken? Are there, contrarily to the textbook simplification, hidden costs and risks in a CIP arbitrage trade? What is the term over which CIP arbitrage should hold?[1]

There are two general types of traders involved in CIP arbitrage: hedge funds and prop desks of large financial institutions (banks). The distinction is the same as that in Brunnermeier and Pedersen (2009). Importantly, each trader typically operates on different funding markets. Hedge funds tend to borrow and lend on secured terms, while banks tend to tap the unsecured interbank market.[2] Each strategy involves different interest rates and maturities, and has different risk and liquidity implications. This paper considers both. We refer to the first as secured CIP arbitrage and to the second as unsecured. The comprehensive trade is illustrated in figure 1, where the trader stands between lender L and borrower B, with whom she entertains either unsecured or secured money market transactions. The trader also engages in a spot and a forward transaction with her forex counterparty. All in all, the figure highlights the four transactions involved in CIP arbitrage. The following two sections work out the details and payoffs of the unsecured and secured arbitrage strategies.

[1]Note, in passing, that if there were risks in a CIP trade, it could not, strictly speaking, be called arbitrage. Yet, we continue to use the term as is commonly done in the literature.

[2]Note that hybrid strategies are also possible: borrowing on secured terms and lending on unsecured terms, but these are not considered in this paper for expositional clarity, and because resulting excess profits are a simple positive transformation of the first two cases.

1.2 Unsecured CIP arbitrage

Unsecured CIP arbitrage involves rolling over overnight unsecured money market positions. The reason for using the overnight market is to benefit from greater liquidity and less counterparty default and term risk. The strategy is therefore cheaper on the borrowing side and less risky on the lending side than using term loans. The expected (ex-ante) payoff from such a strategy is given by,

$$z_{2,t} = \frac{F^B_{t\cdots T}}{S^A_t}(1 + r^{C,B}_{j,t\cdots T}) - (1 + r^{C,A}_{k,t\cdots T}) \tag{2}$$

where as earlier the subscript $t \cdots T$ indicates the time of purchase and maturity of a security, respectively, and $r^C_{j,t\cdots T}$ are the cumulative interest rates in currency j given by rolling over overnight loans. More explicitly, these are given by,

$$\begin{aligned} 1 + r^{C,A}_{k,t\cdots T} &= \mathbb{E}_t \left[\prod_{s=t}^{T-1} (1 + r^A_{k,s\cdots s+1}) \right] \\ 1 + r^{C,B}_{j,t\cdots T} &= \mathbb{E}_t \left[\prod_{s=t}^{T-1} (1 + r^B_{j,s\cdots s+1}) \right] \end{aligned} \tag{3}$$

where r without a superscript captures overnight lending rates.

The last thing to note in the above equations are the B and A superscripts. These denote bid and ask quotes, respectively, to incorporate transaction costs related to arbitrage. We assume, as is standard, that the trader pays the ask quotes on what she acquires and the bid quotes on what she sells.[3]

An immediate drawback from such a strategy is interest rate risk. At time t, the above merely reflects the expectation of the future path of overnight interest rates, from which, of course, actual rates may vary substantially. Traders typically hedge this risk by engaging in appropriate interest rate swaps, in this case using overnight index swaps, or OIS.

An OIS is a fixed/ floating interest rate swap with the floating leg tied to the effective unsecured interbank overnight rate, such as the Federal Funds rate in the US, the EONIA in the euroarea, or the SONIA in the UK. A trader borrowing cash overnight in currency k will want to hold an OIS contract

[3]The bid and ask quotes on the forex market perhaps deserve an additional explanation: when a trader buys currency j while selling currency k in the spot market, she pays the *ask* price for the jk exchange rate, where, by convention, the exchange rate is the price of the currency cited first in units of that cited second (such as for EURUSD, where the exchange rate is the price in dollars of one euro).

requiring her to pay a fixed rate and paying her a flexible rate equal, in fact, to the rate she pays on her short cash position. Intuitively, the flexible interest rate streams cancel each other out, leaving the trader to pay a fixed rate known at time t. More explicitly, the OIS rate in currency k, $r^{O}_{k,t\cdots T}$, is given by,

$$1 + r^{O}_{k,t\cdots T} = 1 + r^{C}_{k,t\cdots T} = \mathbb{E}_t \left[\prod_{s=t}^{T-1} (1 + r_{k,s\cdots s+1}) \right] \tag{4}$$

where the absence of bid or ask quotes on the right hand side captures the fact that the flexible leg of the OIS is indexed on an effective, or traded, rate.

To summarize, the trader rolls over overnight money market positions, short in currency k and long in currency j. She then hedges away interest rate risk with a long position in a currency k OIS contract and a short position in a currency j OIS contract. As a result, the trader's expected payoff from CIP arbitrage is given by,

$$\begin{aligned} z_{3,t} \quad = \quad & \frac{F^{B}_{t\cdots T}}{S^{A}_{t}} \left[(1 + r^{C,B}_{j,t\cdots T}) - (1 + r^{C}_{j,t\cdots T}) + (1 + r^{O,B}_{j,t\cdots T}) \right] + \\ & \left[(1 + r^{C}_{k,t\cdots T}) - (1 + r^{C,A}_{k,t\cdots T}) - (1 + r^{O,A}_{k,t\cdots T}) \right] \end{aligned} \tag{5}$$

1.3 Secured CIP arbitrage

The trader in this situation (hedge fund), pledges capital to obtain a secured loan from lender L. It then turns around and offers funds to borrower B against collateral. In practice, to the extent that foreign currency collateral is accepted, the hedge fund can use at least some of the collateral received from borrower B to pledge to lender L. But we simplify the conceptual framework again for expositional purposes, requiring the hedge fund to have its own capital to pledge in order to borrow cash. Either way, because counterparty default risks disappear, we assume the hedge fund engages in term loans and no longer rolls over overnight positions. The resulting payoff is given by,

$$z_{4,t} = \frac{F^{B}_{t\cdots T}}{S^{A}_{t}} (1 + r^{R,B}_{j,t\cdots T}) - (1 + r^{R,A}_{k,t\cdots T}) \tag{6}$$

where the R superscript indicates repo rates. Subtleties and indirect costs associated with the above trades are discussed later in the empirical section.

2 Measuring excess profits from CIP arbitrage

2.1 Data for unsecured CIP arbitrage

Moving from theory to data, we make one simplification. Equation (5) requires data on OIS rates in two currency markets as well as half spreads on future overnight money market rates. But the latter are not know to the trader at time t, nor are they available to us. More importantly, these are likely to be very small, especially compared to the size of deviations from CIP that we document later. For estimation purposes we therefore simplify expected payoffs from unsecured CIP arbitrage so that these equal,

$$z'_{3,t} = \frac{F^B_{t\cdots T}}{S^A_t}(1 + r^{O,B}_{j,t\cdots T}) - (1 + r^{O,A}_{k,t\cdots T}) \tag{7}$$

Note that had we not assumed that the trader hedged her interest rate risk, we would have been in a much worse position to estimate ex-ante arbitrage profits. Indeed, as per equation (2), we would have had to know and aggregate traders' expectations of future overnight interest rates. Fortunately, this is precisely what is contained in the OIS rates in the above equation.

To match this payoff, we use data that is (i) synchronous across securities, (ii) representative of participating institutions, and (iii) close to firm quotes. Data were acquired from Tullet Prebon (TP), a leading intermediary in wholesale financial markets facilitating the trading activities of its large client base, including financial institutions, brokers, market makers and hedge funds.

First, data used are perfectly synchronous across the forex and money markets considered, coming from four daily snaps at 9am, 11am, 4pm and 11pm, London time. The first, third and fourth time snaps capture the trading hours of, respectively, the European and Asian, European and US, and US and Asian markets. The second time snap coincides with the Libor fixing.

Second, while all prices are market prices, they are technically indicative. Yet, they are very close to actually traded prices. This is because TP clients emitting quotes often end up trading on the TP platform. Thus, the TP platform is not a venue for marketing purposes. This is especially true for forward contracts for which there are few alternative platforms to trade. It is somewhat less the case for forex spot transactions, where the common alternative is ICAP's Electronic Brokering Services (EBS). A comparison suggests TP data is very close to actual traded prices on EBS.[4]

Finally, data cover EURUSD, USDCHF, USDJPY, GBPUSD, as well as a EURCHF, the later serving as a control rate not involving the dollar. In each case, data cover spot rates, and as well as relevant OIS and forward contracts of 1 week as well as 1, 3, 6, 8, 12 and 24 month maturities. In each case, data are for both bid and ask quotes and span from March 2006 to end of April 2009.[5]

2.2 Data for secured CIP arbitrage

Data on interbank repo rates are notoriously difficult to obtain. We acquired data on USD interbank repo rates from ICAP whose BrokerTec trading platform accounts for over half the interbank repo market in the US. Data are actual traded prices and cover several daily snaps, although we use data from market opening, at 7.45 am New York time, where trading is most liquid. Furthermore, data are for GC as well as Agency collateral, and cover overnight, one week as well as long term maturities. Liquidity is highest for overnight contracts, although substantial liquidity still exists for one week maturities. We focus on the latter contract so as to replicate arbitrage strategies of some duration, as in the unsecured case. Lastly, and importantly, we use repo rate on GC collateral. Not only are these most liquid, but they are also much more closely comparable to repo rates in other currency markets where similar collateral pools of government bonds are offered. Also, using data from non-GC collateral is misleading as rates often reflect the special nature of specific collateral, making data much more volatile and less representative of a benchmark borrower.

Eurex AG were gracious enough to share their data on EUR interbank repo rates, on the basis of the close working relationship between Eurex and the Swiss National Bank. Again, data are traded prices and stem from Eurex's GC Pooling platform accounting for a very substantial share of interbank repo trading for ECB GC collateral (corresponding to the ECB's definition of GC collateral). Comparable CHF GC repo rates are from the Swiss National Bank; this is the only repo dataset for which we also have bid and ask quotes. In both cases, data are for overnight as well as one week term contracts. Again, we focus on the latter.

[4]Average differences in bid-ask quotes between 2007-2008 were less than 1 pip, differences greater than 2 pips only occurred 5%, without ever surpassing 7 pips.

[5]Forward rates are expressed in "pips" to be divided by 10^4 and added to the spot rate. Note also that OIS rates are annualized and thus needed to be adjusted by a multiplier in order to be consistent with their maturity. The multiplier is $\mu = T/360$ where T is maturity in days, except for sterling and yen for which the denominator is 365.

In both the EUR and CHF cases, we have daily trade histories. We therefore pick the trade that is closest to 2 pm London Time, in order to coincide with USD repo data. This unfortunately does not allow us to be perfectly synchronous with the forex market data, although using snaps from 11 am or 4 pm London time barely changes estimated excess returns.

2.3 Summary of findings

We begin with excess returns from unsecured arbitrage, covering a richer dataset of currencies, then proceed to secured arbitrage. Figure 2 shows excess returns in percentage points for 1 month arbitrage trades in the "USD group" (EURUSD, USDCHF, USDJPY, GBPUSD), where each trade is labeled according to its corresponding spot position (as explained earlier, a long EURUSD trade involves borrowing in dollars and lending in euros).

In each case, excess profits are very close to zero in the pre-crisis phase, up to August 2007 (often even slightly negative because of transaction costs). Then, profits increase in both level and volatility during the crisis phase, and peak at the time of the Lehman bankruptcy to the very substantial level of 30 bps over one month, or 360 bps on an annualized basis. Thereafter CIP profits remain surprisingly high until year-end (on average 120 bps annualized). The second peak in excess profits can most likely be associated with window dressing typically visible at end of year, where financial firms unwind positions to favor liquid and safe assets on their balance sheets. Since 2009, profits decreased substantially and remained modest, if at all positive, albeit with sustained volatility. As a comparison, Akram, Rime, and Sarno (2008) study CIP deviations from tick-by-tick data in 2004 over various currency pairs. They find that annualized mean returns from CIP arbitrage range from 2 to 15 pips and last between 2 to 16 seconds.

Figure 3, instead, plots excess profits for the reverse of the above trades, where a long spot position becomes short. In each case, profits are negative throughout the sample, especially during the Lehman phase, as expected. The figure is not a perfect mirror image of the first, though, due to the inclusion of bid-ask spreads which change the price of going long or short in any one currency.

The above can be contrasted with excess profits from CIP trades on the EURCHF rate, shown in figure 4. In this case, CIP arbitrage profits are negative throughout the sample, *independently* of the direction of trade, namely with either short or long spot positions. Volatility did increase during the Lehman phase, but this only made excess profits more negative. At the end of sample, in April 2009, excess profits had returned to normal levels.

Two important takeaways emerge from the above figures. First, excess profits are currency specific: they include trades where the dollar is present. Second, excess profits are directional: they emerge when the dollar is being shorted on the spot market. These two elements are key guideposts to formulate and test a hypothesis explaining the breakdown of CIP arbitrage.

Excess returns from secured arbitrage are presented in figures 5 and 6. Taking a cue from the above findings, results are only presented for arbitrage long in EURUSD and short in USDCHF, over a 1 week term. In both cases, results are compared to the unsecured payoffs over the same term. Note first that excess returns also spike at the time of the Lehman bankruptcy, but for approximately two and one months, respectively, thus less than in the unsecured case. This is primarily a result of the shorter term of arbitrage, a relation that is explored more systematically in the robustness checks to this paper's empirical section. Second, and importantly, excess returns from secured arbitrage are nearly exactly equal to those from unsecured arbitrage. This is especially true for arbitrage in EURUSD, although while a slight gap opens in the case of USDCHF arbitrage, co-movement between unsecured and secured arbitrage profits is very high. This will play an important role in the following empirical analysis. Finally, the absence of the second peak in excess profits is probably due to the shorter 1 week maturity trade not going over year end, and thus not being affected by window dressing activity.

2.4 A brief comparison to the literature

Recall from the introduction that most papers examining the stability of the CIP condition assume a trader uses unsecured term money market instruments proxied by Libor rates, often ignoring transaction costs. The introduction to this paper summarized the main issues with such an approach. None-the-less, we reproduce the methodology for the sake of comparison, and call results "Libor profits". We contrast these with this paper's excess returns from unsecured arbitrage, which we label "OIS profits". Both cases explore a long EURUSD spot position.

The two measures are shown in figure 7. The lighter line plots OIS profits and the darker, Libor profits. Generally, the two illustrate a similar pattern. Yet notable differences arise and, importantly, are time varying. These variations stem from Libor-OIS spreads moving unequally across countries. For instance, in periods when Libor-OIS spreads grow more in the target country j relative to the funding country k, an upward bias is introduced when measuring CIP arbitrage profits with Libor instead of OIS rates, since profits depend positively on target rates. The reverse is of course also true. Thus, Libor-OIS spreads are a mechanical yet substantive driver of fluctuations in CIP "Libor profits". For this reason, the papers that explain CIP "Libor profits" with Libor-OIS spreads are in fact mostly regressing a variable on itself, thereby undermining their claim that risk mostly explains arbitrage deviations.

To close, figure 8 shows the bid-ask spreads related to CIP arbitrage. Average spreads in the forex market, both spot and forward, became more volatile after the start of the crisis in August 2007, but did not increase substantially until the Lehman phase. Only in April 2009 were spreads back to pre-crisis levels. Average OIS spreads instead grew in a step like fashion during the crisis phase, and followed forex spreads in a stunning jump during the Lehman phase. Spreads on funding markets were still at elevated levels in April 2009.

3 Explaining excess profits from CIP arbitrage

3.1 Risk and liquidity factors

Why would excess returns from CIP arbitrage have turned positive during the financial crisis? The general answer will come in the flavor of rationing of funds, limiting arbitrage. Higher – perhaps much higher – interest rates alone would not offer a plausible explanation, since the CIP condition should hold for any interest rate differential. We focus the following discussion around two main explanations of market rationing: one emphasizing risk and the other liquidity factors. In each case, explanations can be linked back to a specific player and transaction in figure 1.

On the risk side, we isolate three causes of excess profits from CIP arbitrage. The first involves the forward transaction between the trader and its forex counterparty. It is therefore shared between both unsecured and secured arbitrage. The risk is that this counterparty defaults during the term of arbitrage; we therefore refer to contract risk. This is as emphasized in Duffie and Huang (1996) and Melvin and Taylor (2009). As a result, the trader would have to close or renew her trading strategy by engaging in a reverse spot transaction, or acquiring a new forward contract. In either case, the trader exposes herself to exchange rate risk.

Second, the trader is exposed to rollover risk, but only in so far as arbitrage is unsecured. Indeed, her unsecured trading strategy involves rolling over overnight money market positions. At any point, though, lender L may stop rolling over the trader's debt, or her management may stop her from renewing her credit to borrower B. This would oblige the trader to terminate her arbitrage strategy early, thereby exposing her to exchange rate risk, as above, as well as to the cost of foregone profits. These stem from the maturity structure of overnight interest rate differentials; if it is elevated early in the term of arbitrage and flat thereafter, potential costs diminish, and vice a versa. Acharya, Gale, and Yorulmazer (2009), among others, focus on rollover risk as stemming from investor sentiment, and potentially leading to market freezes.[6]

Third, the trader faces counterparty default risk, as recently emphasized by Taylor and Williams (2009) relative to money market spreads more generally. Again, the risk is specific to the unsecured arbitrage strategy. Specifically, if borrower B were to default, the trader loses the principal of her loan. The risk is usually small, given the overnight maturity, but existent none-the-less, and potentially dissuasive of lending at times of extreme crisis.

On the side of liquidity, we again isolate three potential causes of excess profits from CIP arbitrage. First, there is evidence that banks were under severe pressure to deleverage during the crisis and especially after the Lehman bankruptcy. The impressive extent to which financial institutions deleveraged is documented and discussed in Adrian and Shin (2008b) and McCauley and McGuire (2009), among others. Garleanu and Pedersen (2009) also focus on deleveraging, and suggest a model in which assets with lower margin requirements – with less impact on the balance sheet – can trade at lower prices.[7] Finally, Cornett, McNutt, Strahan, and Tehranian (2010) suggests that during the crisis the pressure to deleverage was exacerbated by having to honor prior commitments to credit lines, mostly in USD; the paper documents the sharp drop in new loans emanating especially from banks needing to deleverage. Whatever the deeper cause of deleveraging, either strategic or structural, the phenomenon can be captured in our conceptual framework as lender L needing to decrease the size of its balance sheet, thereby reducing

[6] Of other papers emphasizing sentiment shocks, one of the founding papers is Shleifer and Vishny (1997) and Pagano (1989), emphasizing self fulfilling prophecies. In the papers that have followed, investor sentiment continues to play a central role, as in Acharya, Gale, and Yorulmazer (2009), as does the availability of information, as in Hombert and Thesmar (2009) and Morris and Shin (2009), where imperfect knowledge of aggregate losses is paramount. On the empirical side, several papers have focussed on measuring liquidity freezes and relevant policy responses. Some of these are Cecchetti and Disyatat (2009), Drehmann and Nikolaou (2009) and Sarkar (2009).

[7] Other papers also emphasize feedback from balance sheets to asset prices, as Acharya and Viswanathan (2007) and Benmelech and Bergman (2009). Other papers emphasize other, although related, factors, such as the structure of financial institutions, as in Diamond and Rajan (2005), He and Krishnamurthy (2008b) and Duffie (2009), that of markets, as in Allen and Gale (2003) and Allen, Carletti, and Gale (2009), or market imperfections as in Mancini Griffoli (2009) and Heider, Hoerova, and Holthausen (2009) which emphasize adverse selection.

both unsecured and secured lending, thereby choking off arbitrage.

The second reason why lender L may have cut back, or cut off, both unsecured and secured loans to arbitrageurs is prudential, as illustrated in part by McGuire and von Peter (2009). By 2008, banks had accumulated substantial dollar assets, funded mostly on a very short term basis on unsecured terms. When the funding markets dried up and when the assets in question became illiquid, banks faced a severe funding strain. Thus, they hoarded liquidity. Doing so had negative externalities, as funding liquidity became all the more scarce and expectations of future liquidity worsened. The situation was exacerbated by signaling dynamics: banks didn't want to be caught by their peers scrambling for liquidity and they knew that posting sufficient liquidity was essential to maintain their credit rating. As a result, banks gave up on lending profits to build up a liquidity pool mostly in USD. These dynamics emphasizing the vicious circle between market and funding liquidity, as well as cross market contagion effects are modeled more explicitly in Brunnermeier and Pedersen (2009), Adrian and Shin (2008a) and Gromb and Vayanos (2009), and eloquently discussed in Brunnermeier (2009) and Pedersen (2009).

Finally, the third reason why arbitrage may have broken down in CIP is specific to the trader engaged in secured arbitrage. Borrowing on secured terms requires capital to cover margins or haircuts. The presumption here is that traders, or hedge funds more specifically, were scrambling for capital especially following the Lehman bankruptcy. On the one hand, funds faced increasing redemptions and on the other, they incurred heavy losses on their portfolios. In a time when raising equity was nearly impossible, available capital became scarce. Due to this constraint, funds were not able to engage in lucrative arbitrage trades. The role played by capital constraints is reviewed with particular clarity in Gromb and Vayanos (2010). It is also at the heart of the models in Acharya, Shin, and Yorulmazer (2009), Brunnermeier and Pedersen (2009), Kondor (2009), He and Krishnamurthy (2008b,a), Liu and Longstaff (2004), Gromb and Vayanos (2002) and Shleifer and Vishny (1997), among others.

3.2 Variables, specification and methodology

The earlier section laid out potential explanations for excess profits from CIP arbitrage. These were categorized as mostly involving risk or liquidity factors. The following sections aim to empirically test which explanations seem most correlated to measured excess returns. The general procedure is to regress excess returns from CIP arbitrage on several variables, each of which is intended to capture one of the explanations advanced above. We start by listing and justifying these variables, all of which are summarized in Table 1.

On the side of risk, we had highlighted exchange rate risk from having to renegotiate a forward contract, or taping the spot market to terminate arbitrage. We capture this with 1 month forex option implied volatilities. Rollover risk, only present in unsecured arbitrage, also implied early termination of arbitrage. We capture this with the one week to one month OIS differentials in currency j relative to those in currency k. This corresponds to potentially lost arbitrage revenue from closing positions after one week instead of the planned one month. And finally we use a CDS index of US financial institutions to track counterparty default risk, also specific to unsecured arbitrage. To these we add a more general measure of risk, drawn from the VIX index for equities.

On the side of liquidity, we had first mentioned the impetus to deleverage. We capture this using the measure of balance sheet size of financial intermediaries developed in Adrian and Shin (2008a). Second, we had emphasized prudential hoarding of USD liquidity, which we track with cash deposits with Federal Reserve Banks in excess of reserve balances. Finally, we had raised the prospects of capital constraints to obtain secured funding. Finding a clean related measure is difficult and, to our knowledge, the literature offers little guidance. None-the-less, we draw inspiration from Coffey, Hrung, Nguyen, and Sarkar (2009) and suggest using a spread between Agency MBS and GC repo rates. The idea is that as capital becomes scarce, lenders are in a position to extract higher rents in the form of higher repo rates. All repos become specials, in a way. Yet, the presumption is that the effect is stronger on repos with slightly riskier collateral as are MBS relative to GC. To these, we add two more general liquidity measures: First, TED spreads, as in Brunnermeier (2009) and Brunnermeier, Nagel, and Pedersen (2009), implying that liquid capital is withdrawn from markets when it flies to high quality government bonds, and second Libor-OIS spreads. These measures, though, could also represent a heightened perception of risk, both general and of counterparty default. To a certain extent, the same is true of the other liquidity variables. Thus, when testing for liquidity effects, we always also control for risk using the earlier mentioned risk variables. This includes leaving CDS spreads in the regressions for secured arbitrage.

Furthermore, we test for the relevance of liquidity constraints on excess profits by including two variables tracking policy measures to enhance liquidity. If significant and with the appropriate negative sign, these variables would not only signal that policy was effective, but would explain why excess profits from CIP arbitrage were eventually resorbed. The first of these policy variable is the Fed's "reserve bank credits", and the second USD swap lines extended by the Fed to other central banks (BOE, BOJ, ECB, SNB). Reserve bank credits include securities held outright, but more importantly repos, term auction credits, other loans, as well as credit extended through the commercial paper funding facility and the money market investor funding facility. While these measures had the goal of improving funding liquidity issues generally, on a variety of markets, swaps were more precisely targeted at solving the issue of dollar funding abroad.

A final two variables are considered, intended to capture market liquidity more generally. These are measures of bid-ask spreads in the funding market (on the two OIS transactions) and forex market (on both the spot and forward transaction). Specifically, in the same spirit as Korajczyk and Sadka (2008), we take the first principal component of the bid-ask spreads of each market's relevant transactions. Two latent liquidity variables arise: one for the forex market and one for the OIS or funding market.[8]

In the end, we estimate the following equation,

$$z_t = \alpha + \nu' z_{t-1} + \beta' \, \Theta_t + \gamma' \Psi_t + \delta' \Sigma_t + \epsilon_t \tag{8}$$

where Θ_t is a matrix including the "market liquidity" variables, Ψ_t is a matrix of "funding liquidity" measures, and Σ_t is a matrix of variables capturing various facets of "risk". Note that all variables are taken in growth rates, as it is primarily the impact of the tightening of funding liquidity on the explosion of excess profits from CIP arbitrage that interests us. Results with variables in levels are discussed in the robustness checks. Estimation is carried out both for the EURUSD times series and for a panel including EURUSD, USDJPY, GBPUSD, and USDCHF. The former is estimated using OLS with Newey-West standard errors, and the latter using Seemingly Unrelated Regression with fixed effects, exchange rate specific constants and autoregressive coefficients.

3.3 Estimation results

Regression results are presented in Tables 2, 3 and 4, where the first two tables correspond to 1 month unsecured arbitrage and the last to 1 week

[8]The FX latent liquidity variable is defined as the first principle component (FPC) of the bid-ask spreads of the exchange rates (both spot and forward rates) against the USD. The FPC accounts for more than 80% of the overall liquidity and the loadings are extremely similar across exchange rates. We also tried using a straight average and found, as expected, very similar results. The OIS latent liquidity variable is defined as the FPC that accounts for 60% of the total volatility and the loadings are very similar across currencies (i.e. between 0.42 and 0.54), except for the JPY which has a loading of -0.14. The exclusion of the latter leaves the results essentially unchanged.

secured arbitrage. Tables 2 and 4 display results for the EURUSD time series, and table 3 for the panel. All tables relay results from trades involving short dollar spot positions; results for the equivalent long dollar spot positions are not shown as they are nearly the same in magnitude and significance, but have opposite signs, since excess returns are nearly mirror images, as discussed earlier. In all tables, several regression specifications are shown, each testing for a different combination of risk and liquidity factors. Finally, for expositional simplicity, we focus the analysis on the results from unsecured arbitrage and comment those from secured arbitrage only in so far as these offer a different or similar picture.

We first focus on the market liquidity variables. These are highly significant across the various specification in the panel case (Table 2). The OIS latent liquidity variable loses significance when taken with the TED spread, reminding us that the latter is also a measure of market liquidity. In the EURUSD time series case, market liquidity variables are less often significant, probably because of the more liquid nature of both forex and related money markets. In all cases the coefficient on forex market liquidity is negative, suggesting higher bid-ask spreads make for lower excess returns. This seems straightforward as spreads reflect transaction costs which run against returns. But the always positive coefficient on the OIS latent liquidity variable suggests another interpretation: that bid-ask spreads are also a measure of funding liquidity. Results suggest that as liquidity becomes depressed on funding markets – or as spreads increase – excess returns grow. This initial result already lays its finger on the importance of liquidity issues.

The next section in the tables focusses precisely on funding liquidity. Here, the general approach is to test each measure of funding liquidity separately given the high collinearity between most variables. The policy variables, though, can be thought of as exogenous; we therefore leave one – central bank swap lines – in each regression, except when controlling for the second policy variable, Federal Reserve credits. Note, as mentioned earlier, that in each regression we control for risk premia potentially affecting our liquidity variables by including all risk variables.

TED, Libor-OIS spreads, as well as central bank deposits are all highly significant across both time series and panel regressions. Their positive coefficients indicate that as funding liquidity decreases (an increase in these variables), excess profits from CIP arbitrage increase. That is indeed this paper's central thesis. The Adrian and Shin measure of balance sheet size, though, is not significant. It does gain significance and appears with the expected negative sign in the regressions studied as robustness checks, when all other variables appear in levels.

Interestingly, results suggest the policy responses during the crisis were very successful at alleviating the constraint on funding liquidity, and thus contributing to restoring the CIP condition. Coefficients on the reserve credits as well as forex swap lines, in both the time series and panel regressions, are all highly significant. Their negative sign suggests that as these policy measures were implemented, excess CIP profits decreased. Note that both variables are taken with a one week lag, to allow for the transmission of policy. This is when significance is highest, although a two week lag, as well as contemporaneous correlations, are also significant.

Next, we move to the risk variables. The implied volatility (IV) variable is always positive and significant in the EURUSD time series regressions, although the picture is less clear in the more representative panel case. Generally, though, it would seem that exchange rate risk, from having to renegotiate a forward contract or close one's positions early by tapping the spot market, did play some role in propping up excess arbitrage profits.

Results are quite weak for the other risk factors. The CDS and VIX variables are never significant and the interest rate differential is only significant in half the panel regressions, while it is never so in the time series regressions. Thus, counterparty, rollover and more general risk do not seem to have played a role in dissuading arbitrage. This is as expected. We had already mentioned that comparing profits from unsecured and secured arbitrage offered a natural test for the relevance of rollover and counterparty risk. And indeed, since the two arbitrage strategies yield nearly equal results, these risks ought not to have played an important role.

We end with a closer look at regression results from secured arbitrage. The first thing to notice is that results, on the whole, change only very little with respect to the case of unsecured arbitrage, even if the term of arbitrage is different. This is certainly the case for the market and funding liquidity variables, whose importance is thereby emboldened. The CDS and VIX variables also do not change, in that they remain insignificant. And the implied volatility variable loses significance in two of the eight cases, although retains the approximate size of its coefficient. Second, the repo spread variable (Agency MBS to GC repo spreads) is significant, loosely suggesting that there may have been funding liquidity constraints due to finite capital to pledge in exchange.

Generally, then, the above results mostly suggest that CIP deviations can be explained mostly without recourse to risk factors, except for exchange rate risk arising from the default of the forward counterparty. Lack of funding liquidity, and to some extent market liquidity, turn out to be the primary factors explaining why the CIP condition failed in the wake of the Lehman bankruptcy.

3.4 Robustness checks

This section briefly reviews the robustness tests undertaken. For the most part, results are described verbally for the sake of brevity. None-the-less, any specific result is available upon request.

First, we explored the effect of time of day on profits from CIP arbitrage. Results are nearly unchanged with respect to the benchmark 11.00h time snap, when using data from the 16.00h time snap when US markets are also opened.

Second, we explored the effect of maturity on profits from CIP arbitrage. In general, profits from shorter maturities are less persistent, but higher at their peak. Thus substantial deviations continue to exist and regression results hardly change, as already noted earlier, when considering excess returns from arbitrage over shorter maturities.

Third, we divided the data in sub-samples: a pre-crisis phase, lasting up to August 2007, a crisis phase, between August 2007 and the Lehman bankruptcy in September 2008, and a Lehman phase since then. Liquidity variables in both the Θ_t and Ψ_t matrices are not significant during the pre-crisis phase. They then become significant in the crisis phase, and their coefficients grow substantially in the Lehman phase. The risk related variables remain mostly insignificant throughout, as in the main results presented earlier.

Fourth, we also checked to see if results changed when using CDS spreads of European banks instead of US banks. But results are nearly perfectly unchanged. Again, differences in cross country risks are peripheral to our story.

Fifth, results are unchanged to including all explanatory variables in levels. Signs, sizes and significance of coefficients are particularly stable.

Sixth, the same is true when including all variables explored earlier in a single regression. The only exception are TED spreads which lose significance, due to their collinearity with Libor-OIS spreads.

Seventh, results do not change if the risk variables are included separately in the regression.

Eighth, Pastor and Stambaugh (2003) construct a supplementary measure of stock market liquidity which has recently received significant attention. Unfortunately, the fact that this measure is monthly did not allow us to include it directly in our regression. Yet, its correlation with our measures of liquidity in matrix Θ_t is more than 80%.

And finally, in terms of panel estimation, we tried several variants including specific coefficients for the AR term and other estimation methods such as ARCH Maximum Likelihood (Marquardt). Results remain unchanged.

4 Conclusion

This paper focussed on limits to arbitrage as illustrated by covered interest parity, following the Lehman bankruptcy. It described how such arbitrage trades are actually implemented in practice, using either unsecured or secured money market transactions. This paper showed how deviations from CIP arbitrage existed for months after the Lehman bankruptcy, were substantial and persistent, and mostly involved trades with short dollar spot positions. These results were found with data which closely resembles what a trader would have faced at the time of undertaking arbitrage. Data are intra-daily, synchronized across markets and inclusive of transaction costs. Explaining such deviations from arbitrage followed a two step process. The first laid out the hypotheses and the second tested each empirically. Results suggest that it was especially the lack of dollar funding liquidity – due to deleveraging imperatives, prudential hoarding and limited capital to pledge in exchange for liqudity – that limited the extent of arbitrage, and thus failed to balance the CIP condition.

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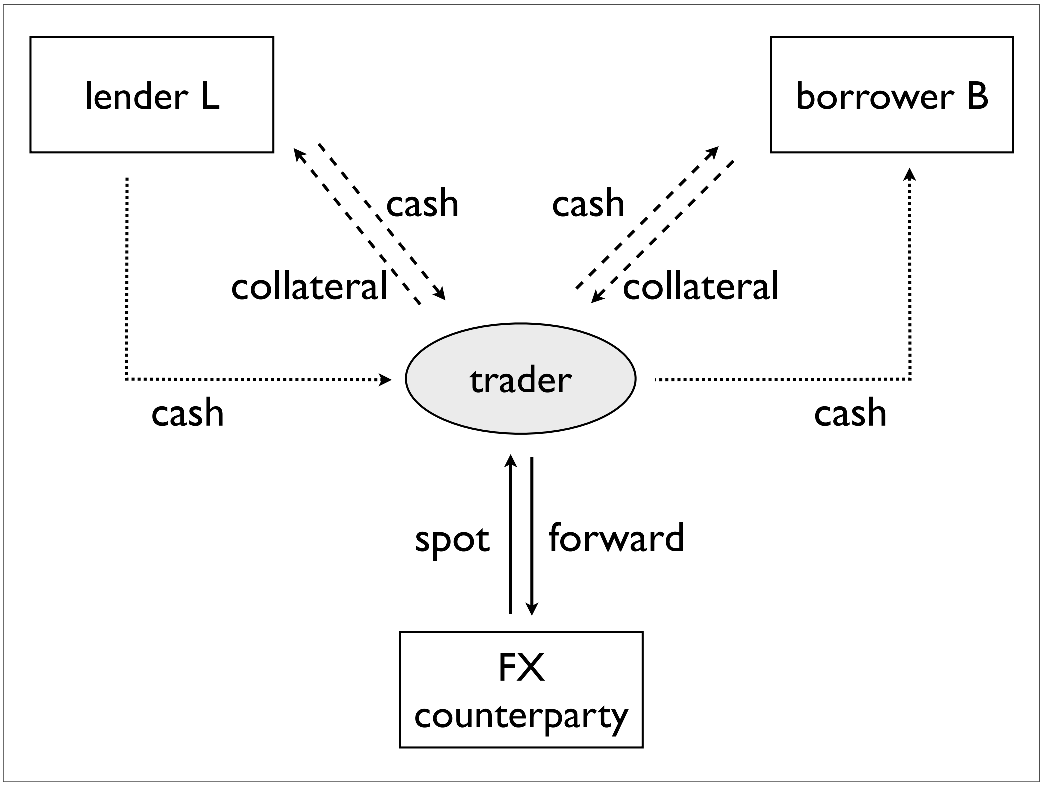

Figure 1: *An illustration of CIP arbitrage: the trader can be thought of as either a hedge fund or the prop desk of a large financial institution. Typically, the former borrows and lends on secured terms by exchanging cash against collateral (hashed lines), and the latter does so on unsecured terms (dotted lines). Both are money market transactions. The trader also engages in two forex transactions with appropriate counterparties, one spot and one forward. In all, CIP arbitrage involves four transactions.*

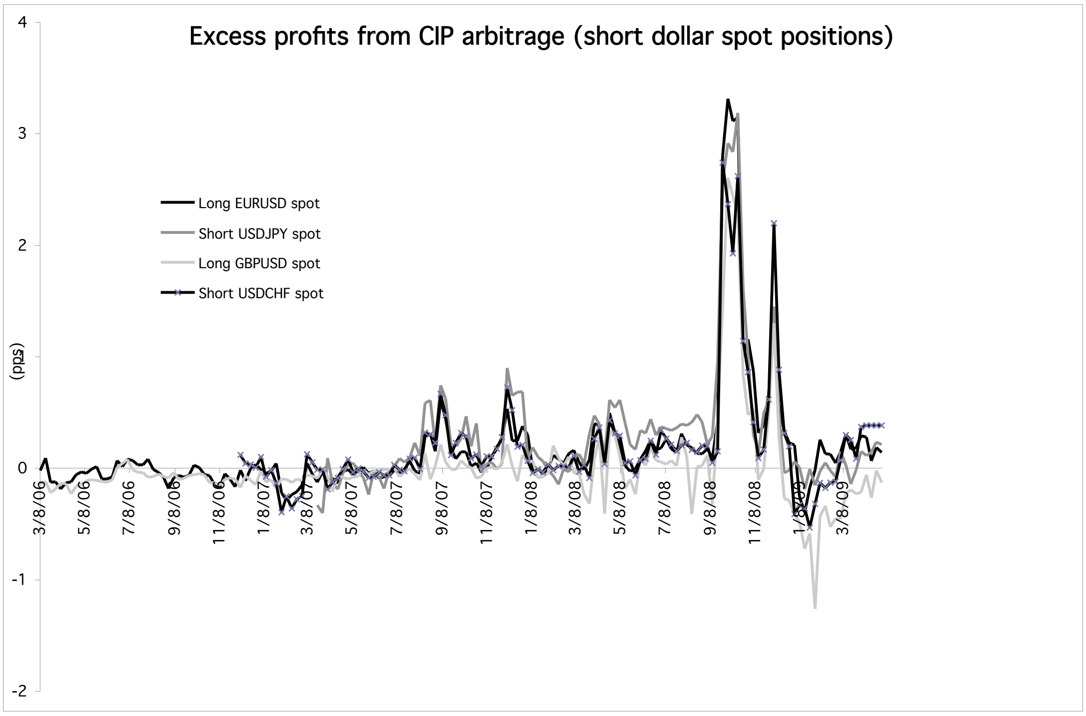

Figure 2: *Excess profits from unsecured CIP arbitrage on trades involving a short USD spot position, over a 1 month term.*

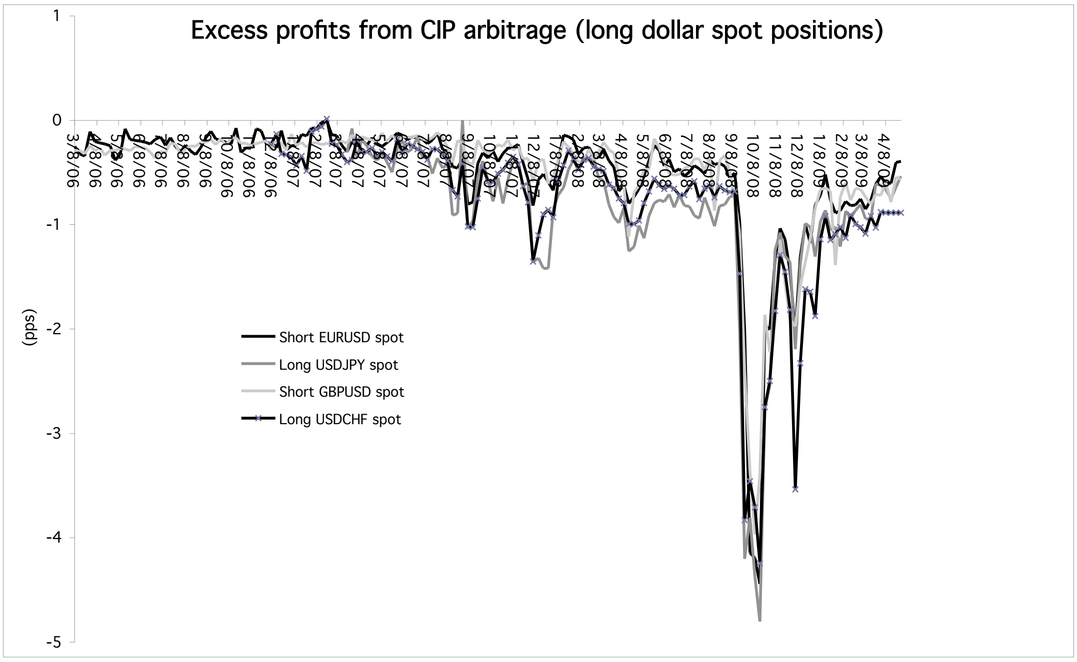

Figure 3: *Excess profits from unsecured CIP arbitrage on trades involving a long USD spot position, over a 1 month term.*

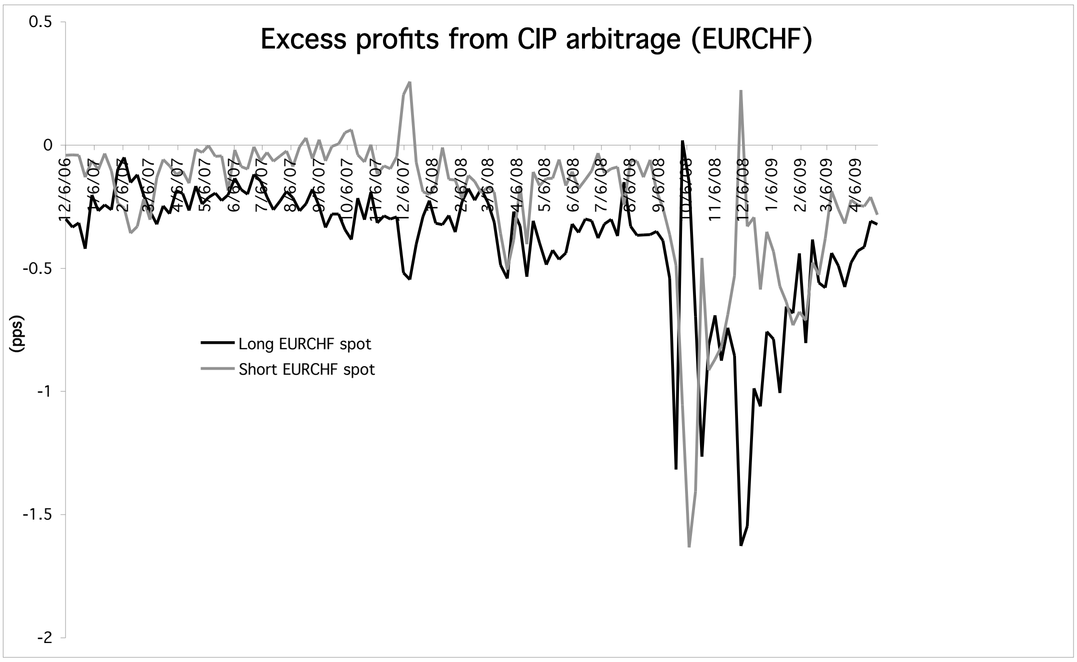

Figure 4: *Excess profits from unsecured CIP arbitrage on trades involving both a long and a short EURCHF spot position.*

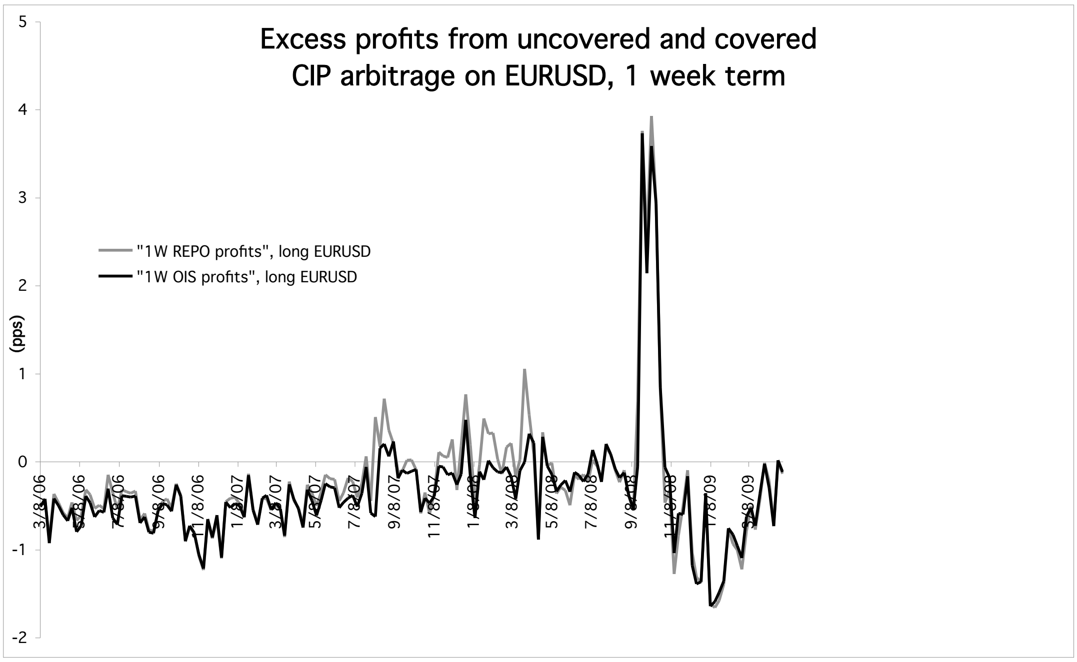

Figure 5: *Excess profits from CIP arbitrage on trades involving a short USD spot position, when funding is secured ("repo profits") and unsecured ("OIS profits"), over a 1 week term.*

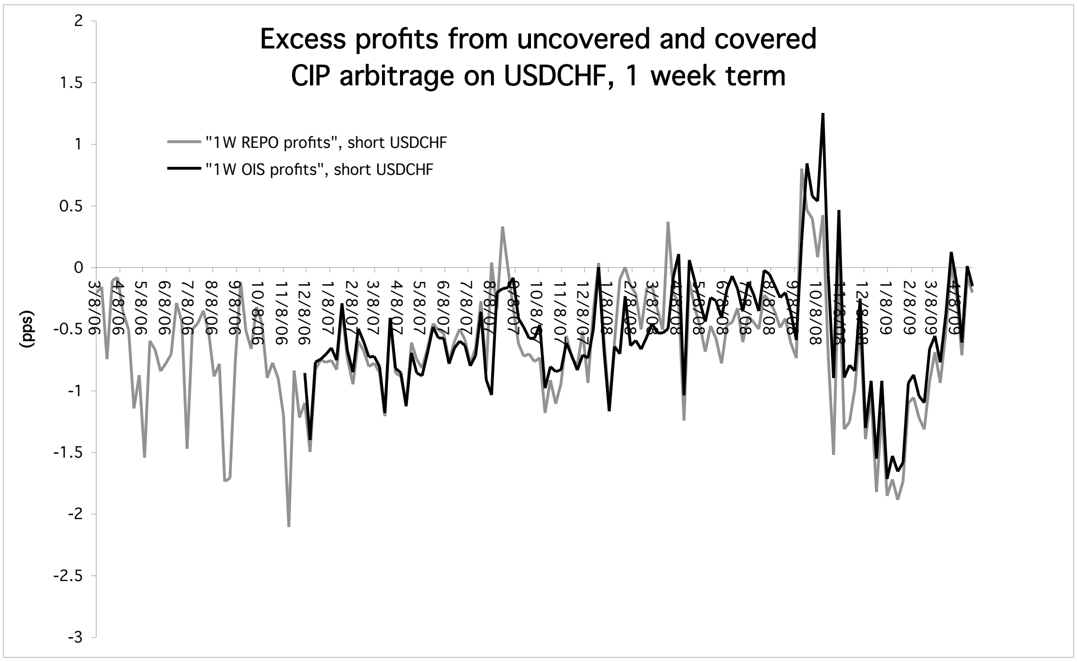

Figure 6: *Excess profits from CIP arbitrage on trades involving a short USD spot position, when funding is secured ("repo profits") and unsecured ("OIS profits"), over a 1 week term.*

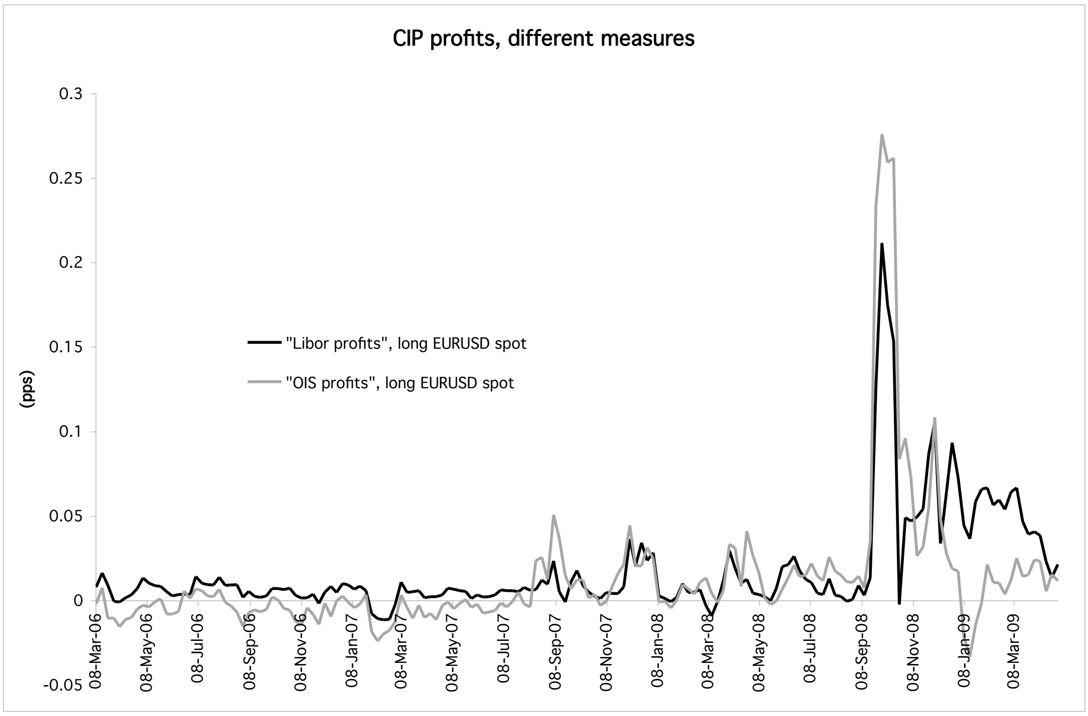

Figure 7: *Excess profits in percentage points from CIP arbitrage with 1 month maturity. "Libor profits" are calculated with Libor rates and matching 11am forex quotes, yet without any transaction costs. "OIS profits" are calculated with synchronous OIS and forex rates, including transaction costs; these correspond to the profits shown in earlier figures.*

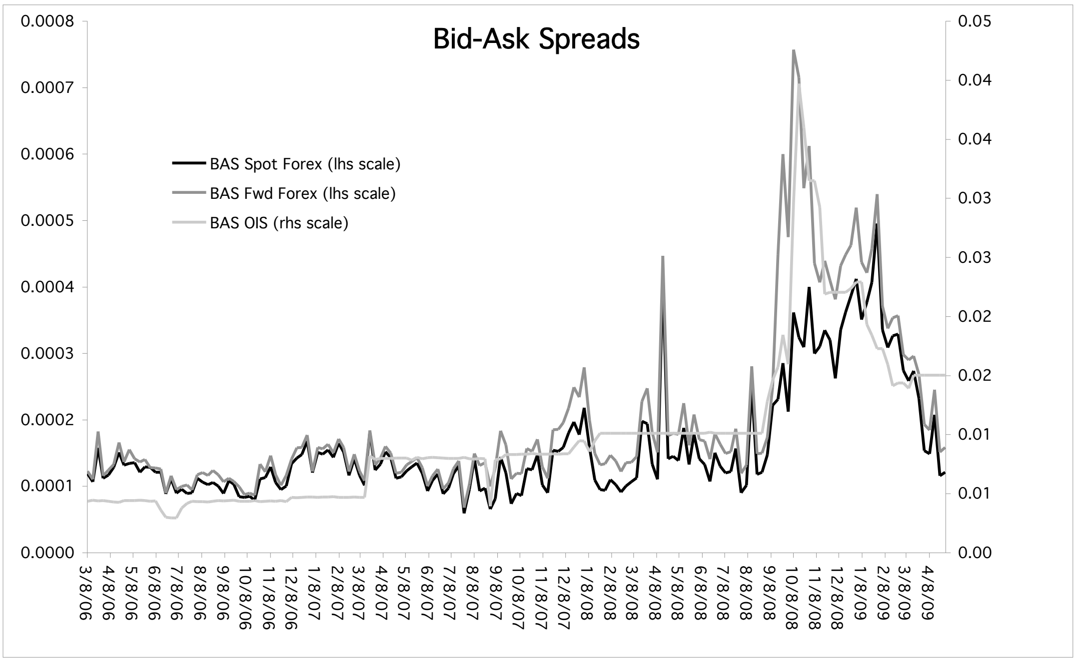

Figure 8: *Average bid–ask spreads in the forex spot and forward markets, as well as OIS market. Bid–ask spreads are calculated as* $(Ask - Bid)/C$ *where* C *is the average midquote.*

	Factor	Unsecured arbitrage proxy	Secured arbitrage proxy
Risks			
	Contract	Implied volatility (IV)	Implied volatility (IV)
	Rollover	Interest differential	NA
	Counterparty default	CDS	NA
	General/ controls	VIX, CDS	VIX/ CDS
Funding liquidity			
	Deleveraging	Balance sheet (CPG)	Balance sheet (CPG)
	Prudential hoarding	CB deposits	CB deposits
	Limited capital	NA	Repo spreads
	Policy measures	CB swaps, Reserve credits	CB swaps, Reserve credits
	General/ controls	TED, Libor-OIS	TED, Libor-OIS
Market liquidity			
	Transaction costs	OIS & FX BAS spreads	OIS & FX BAS spreads

Table 1: *Summary of various explanatory factors for excess profits from CIP arbitrage, categorized according to risk, funding liquidity and market liquidity. Each factor is intended to be captured by a corresponding "proxy" or variable. Since some factors are not relevant to both unsecured and secured arbitrage strategies, some proxies are market as not applicable (NA).*

Time series, long EURUSD unsecured CIP arbitrage (1M)

	Specification						
	1	2	3	4	5	6	7
Market Liquidity							
FX liquidity	-0.021	**-0.039**	**-0.039**	-0.032	-0.026	-0.040	**-0.041**
	-0.906	-1.671	-1.747	-1.331	-1.153	-1.573	-2.171
OIS liquidity	**0.302**	**0.321**	**0.374**	0.089	0.129	**0.330**	**0.237**
	2.661	2.741	3.150	0.740	1.139	2.666	2.924
Funding Liquidity							
CB swap		**-6.704**		**-4.618**	**-4.721**	**-6.743**	**-7.537**
		-4.498		-3.303	-3.468	-4.120	-8.198
Reserve credits			**-4.289**				
			-3.300				
TED Spread				**0.655**			
				4.032			
Libor-OIS					**0.765**		
					4.426		
Adrian-Shin CPG						1.433	
						0.661	
Deposit							**1.009**
							10.649
Risks							
IV		**1.697**	**1.581**	**0.967**	**1.397**	**1.853**	**1.074**
		3.104	2.920	1.796	2.763	3.050	2.802
Interest Diff.		-0.246	-0.293	-0.205	-0.154	-0.291	-0.124
		-1.219	-1.415	-1.102	-0.840	-1.317	-0.939
CDS		-0.305	-0.270	-0.477	-0.243	-0.335	0.118
		-0.808	-0.704	-1.329	-0.695	-0.776	0.475
VIX		0.446	0.257	0.179	0.075	0.358	-0.191
		0.968	0.564	0.393	0.166	0.701	-0.565
Adj. R2	0.040	0.237	0.185	0.345	0.380	0.223	0.637

Table II: *Time series results for long EURUSD spot positions. For each variable, estimated coefficients appear above corresponding t-statistics. Numbers in bold represent significance at least at the 10% level. AR(1) coefficients are all significant but not shown to simplify the table.*

Panel, short USD unsecured CIP arbitrage (1M)

	Specification						
	1	2	3	4	5	6	7
Market Liquidity							
FX liquidity	**-0.073**	**-0.077**	**-0.083**	**-0.075**	**-0.072**	**-0.079**	**-0.065**
	-3.838	-4.014	-4.281	-4.195	-4.455	-3.792	-4.029
OIS liquidity	**0.349**	**0.350**	**0.387**	0.134	**0.161**	**0.354**	**0.271**
	3.949	4.050	4.270	1.606	2.216	3.955	4.037
Funding Liquidity							
CB swap		**-5.741**		**-3.494**	**-3.854**	**-5.945**	**-7.184**
		-5.648		-3.759	-4.658	-5.456	-9.676
Reserve credits			**-2.417**				
			-3.133				
TED Spread				**0.739**			
				6.985			
Libor-OIS					**0.850**		
					8.505		
Adrian-Shin CPG						0.171	
						0.119	
Deposit							**0.898**
							11.641
Risks							
IV		**0.856**	0.587	0.194	**0.671**	**0.929**	**0.832**
		2.112	1.406	0.529	2.073	2.081	2.658
Interest Diff.		-0.091	-0.072	**-0.172**	**-0.157**	-0.103	**-0.149**
		-0.951	-0.712	-2.002	-1.851	-1.002	-1.908
CDS		0.155	0.383	-0.214	0.053	0.221	0.044
		0.575	1.354	-0.898	0.245	0.720	0.214
VIX		0.576	0.346	0.182	0.003	0.522	-0.042
		1.634	0.952	0.564	0.009	1.365	-0.149
Adj. R2							
EURUSD	-0.045	0.124	0.012	0.281	0.298	0.101	0.614
USDJPY	0.006	0.246	0.098	0.446	0.514	0.253	0.436
GBPUSD	0.127	0.171	0.128	0.295	0.381	0.142	0.402
USDCHF	-0.061	0.133	-0.033	0.306	0.404	0.115	0.528

Table III: *Panel results for USD group exchange rates, involving short USD spot positions. For each variable, estimated coefficients appear above corresponding t-statistics. Numbers in bold represent significance at least at the 10% level. AR(1) coefficients are all significant but not shown to simplify the table.*

Time series, long EURUSD secured CIP arbitrage (1W)

	Model							
	1	2	3	4	5	6	7	8
Market Liquidity								
FX liquidity	-0.062	-0.065	-0.067	**-0.080**	**-0.068**	-0.053	**-0.086**	**-0.092**
	-1.539	-1.626	-1.609	-2.072	-1.714	-1.222	-2.639	-2.433
OIS liquidity	**0.746**	**0.776**	**0.854**	**0.491**	**0.658**	**0.765**	**0.738**	**0.483**
	4.166	4.568	4.536	2.899	3.857	4.369	5.673	2.976
Funding Liquidity								
CB swap		**-10.413**		**-8.128**	**-9.371**	**-9.860**	**-12.529**	**-7.637**
		-5.448		-4.440	-4.949	-4.846	-8.586	-4.352
Reserve credits			**-4.374**					
			-2.968					
TED Spread				**0.819**				
				4.055				
Libor-OIS					**0.529**			
					2.348			
Adrian-Shin CPG						2.713		
						1.060		
Deposit							**1.109**	
							7.643	
Repo spread								**0.612**
								2.685
Risks								
IV		**1.521**	0.803	1.013	**1.515**	**1.611**	**1.379**	0.887
		1.983	0.977	1.419	2.043	1.909	2.372	1.291
CDS		0.099	0.264	-0.003	0.166	0.239	0.284	-0.114
		0.205	0.494	-0.007	0.357	0.438	0.778	-0.191
VIX		0.379	0.011	-0.167	-0.022	0.087	-0.300	-0.138
		0.579	0.015	-0.268	-0.033	0.123	-0.581	-0.325
Adj. R2	0.159	0.267	0.156	0.357	0.298	0.260	0.528	0.396

Table IV: *Time series results for long EURUSD spot positions. For each variable, estimated coefficients appear above corresponding t-statistics. Numbers in bold represent significance at least at the 10% level. AR(1) coefficients are all significant but not shown to simplify the table.*

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