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

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December 2011; first version September 2009

Abstract

Arbitrage normally ensures that covered interest parity holds. Yet, this paper shows that this central condition in finance broke down for several months after the Lehman bankruptcy for trades funded in dollars. This anomaly emerges for two popular arbitrage strategies, using both unsecured and secured funding. The secured strategy, newly investigated in this paper, avoids default and rollover risks, thus favoring funding liquidity constraints as an explanation for arbitrage deviations. Additional empirical tests support this hypothesis, although also point to contract risk. Moreover, official policies to alleviate funding liquidity strains, such as foreign exchange swaps, contributed to restoring arbitrage.

JEL classification: F31, G01, G14

Keywords: limits to arbitrage, covered interest parity, funding liquidity, financial crisis, slow moving capital, market freeze, unconventional monetary policy.

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†Many thanks to Jonathan Berk, Sudipto Bhattacharya, Markus Brunnermeier, Colin Bermingham, Alain Chaboud, Mark Dearlove, Darrell Duffie, Ray Fair, Charles Goodhart, Alfred Günter, Rainer Häberle, Harald Hau, Terrence Hendershott, Anil Kashyap, Michael King, Adam Law, Antonio Mele, Michael Melvin, Paolo Pasquariello, Lubos Pastor, Lasse Pedersen, Roberto Piazza, Ronnie Sadka, Hyun Song Shin, Paul Söderlind, Giorgio Valente, Dimitri Vayanos and two anonymous referees, as well as to SNB traders and asset managers Roman Bauman, Brigitte Bieg, Sebastien Kraenzlin, Christoph Meyer, and Martin Schlegel, and seminar participants at the AEA 2011, EFA 2011, IMF, ECB, University of Zurich, University of Freiburg, ESSFM Gerzensee Symposium 2010, Swiss National Bank and the SNB-BOP joint research conference. Finally, we kindly acknowledge Tullet Prebon, ICAP and Eurex, especially Rene Winkler, for providing us with data. The views expressed in this paper are those of the authors and do not necessarily reflect those of the Swiss National Bank.

Arbitrage is the glue of financial markets. It links securities through pricing relationships, and allows for the smooth and efficient functioning of markets. But under sufficient pressure, arbitrage can break down. That this glue can, and does, snap underscores the fragility of the financial system, amplifies financial shocks and potentially calls for policy action. A proper understanding of when and why arbitrage breaks down is therefore fundamental.

The break-down of arbitrage has inspired a vibrant literature currently emerging under the heading of slow moving capital, captured with eloquence in Duffie (2010b). This literature emphasizes that arbitrage needs capital to operate properly and may be disrupted by lack of it. But earlier writings already suggest these frictions are of first order importance. That is the case in Shleifer and Vishny (1997) and notably Keynes who remarked, as early as 1923, that "speculation [in the foreign exchange market may be] exceptionally active and 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, pp. 129-130).

This paper revisits the above insights thereby contributing to the slow moving capital literature by giving an empirical grounding to theories of when and why arbitrage breaks down. The paper's first goal is to accurately measure deviations from arbitrage under various strategies and across different currency pairs and investment horizons. Its second goal is to test, empirically, the various factors brought up in the literature to explain the break-down and persistence of arbitrage. And the third goal is to explore whether policy reactions can restore the proper functioning of markets.

The focus of the paper is on arbitrage between national money markets – borrowing in one currency and lending in another, while hedging foreign exchange risk – usually ensuring that the covered interest parity (CIP) condition holds. This condition is essential to price foreign exchange forwards and short term money market interest rates.

Measuring deviations from CIP arbitrage – this paper's first goal – entails specifying the arbitrage strategy as a trader would actually implement it. The textbook representation turns out to be overly simplistic. The major distinction we draw is that arbitrage can be undertaken by borrowing and lending funds on secured or unsecured terms. The distinction emerges in Brunnermeier and Pedersen (2009) which loosely associates the secured strategy with hedge funds needing to pledge collateral to fund the arbitrage trade. The second strategy is instead more typical of banks' proprietary trading desks (prop desks) using internal funds or funds borrowed on the interbank market on unsecured terms. Importantly, the first strategy is less risky given its collateral insurance. It therefore plays a central role in this paper to study factors other than counterpart default risk in explaining arbitrage deviations.

After describing these strategies and related instruments, we reproduce arbitrage profits. We draw out four main results. First, deviations from CIP arbitrage were insignificant, as expected in theory, until August 2007 when the first signs of the financial crisis arose. When Lehman collapsed, deviations then jumped to 400 basis points, remaining high for nearly three months thereafter. Second, deviations were currency specific, involving the dollar. Third, deviations were directional, involving borrowing dollars. Fourth, deviations were independent of the arbitrage strategy. Both secured and unsecured strategies yield very similar results.

A new dataset allows us to obtain these results with precision. First the data allow us to compute arbitrage deviations using secured funding in three currencies. To our knowledge, this paper is the first to do so. Second, the more ample data relative to unsecured funding, covering more currency pairs and maturities, allows us to cross-check results. Third, the data allow us to replicate very accurately the profits a trader could have realized by engaging in either secured or unsecured arbitrage. Data are intra-day, reflect traded prices, are synchronous across securities, and include transaction costs.

This paper's second goal is to explain the above findings; why did arbitrage break down? Did specific transactions necessary for CIP arbitrage become overly risky? In other words were positive arbitrage profits compensating arbitrageurs for risk, as in a classical asset pricing story?[1] Or was there too little funding liquidity available to carry out arbitrage in sufficient volume, as suggested by the slow moving capital literature? In other words, insufficient arbitrage left positive profits on the table.[2]

We make an inroad into distinguishing explanations based on risk versus liquidity by ways of a structural identification method. The two arbitrage strategies we consider are equal, except in their exposure to risk. Because secured arbitrage involves the pledging of collateral, it excludes counterpart

[1]Note that technically a risky transaction cannot be called arbitrage, as pointed out in Schleifer (2000). We none-the-less stick to the term "CIP arbitrage" following common practice the literature.

[2]An earlier paper also focussing on the inelastic supply of funds for arbitrage, though from a modeling standpoint, is Prachowny (1970).

default risk. For the same reason, funding positions have the same maturity as that of the arbitrage strategy. Instead, unsecured arbitrage requires the daily rolling over of positions. Secured arbitrage therefore also avoids rollover risk. The very similar arbitrage profits between the two strategies suggests that neither counterparty nor rollover risk played an important role in hindering arbitrage. Funding liquidity constraints instead emerge as a natural explanation.

We further investigate the robustness of this hypothesis and its more granular implications by isolating measurable proxies for sources of risk and funding liquidity constraints, and testing their significance as explanatory variables for CIP deviations. We recognize that a perfect alignment of variables with either only risk or funding liquidity constraints is illusory. Yet, results from our empirical tests over a wide array of currency pairs and investment horizons, using different regression methodologies, are all clearly aligned with the results form the more structural identification scheme of comparing arbitrage profits from secured and unsecured arbitrage. We find that funding liquidity constraints are strongly related to deviations from arbitrage. These constraints are in the form of cash lenders' hoarding of liquidity for prudential purposes, balance sheet deleveraging and borrowers' limited capital to pledge for funds. We test for both aggregate funding liquidity constraints, in the spirit of Korajczyk and Sadka (2008), and for individual funding liquidity constraints taken separately. We further confirm that measures of counterparty default risk and rollover risk are almost never correlated to CIP deviations. We do allow for contract risk – the risk of the forward contract falling through, thus transforming covered into uncovered interest rate arbitrage – in both the secured and unsecured arbitrage strategies and find that it is weakly related to deviations from arbitrage.

On this backdrop, this paper's third goal is to test whether policy reactions were successful at alleviating market tensions and restoring arbitrage. We find that it was indeed the case. In particular, the provision of dollar cash on foreign markets through FX swaps and on the domestic market through the various Federal Reserve lending facilities, both had a significantly negative effects on CIP deviations.

In the largely theoretical literature on slow moving capital and market freezes, some papers stand out as providing concrete evidence on deviations from arbitrage. These are Mitchell, Pedersen, and Pulvino (2007) focusing on the convertible bond market, and, during the recent financial crisis, Mitchell and Pulvino (2011) and Garleanu and Pedersen (2011), both addressing the CDS and bond yield spread. More generally, Brunnermeier (2009) and Pedersen (2009) illustrate the role of insufficient liquidity in aggravating the financial crisis.

Other papers have focussed specifically on deviations from CIP arbitrage. Several predate the crisis. Their main result is that deviations from CIP arbitrage, if any, reach a few basis points during merely seconds, over different currency pairs indistinguishably.[3] Those that center on the 2007-2009 period are Baba, Packer, and Nagano (2008), Baba and Packer (2009b, 2009a), as well as Coffey, Hrung, and Sarkar (2009) (summarized with some refinements in Coffey, Hrung, Nguyen, and Sarkar (2009)), Genberg, Hui, Wong, and

[3]The four that stand out are Taylor (1989), Rhee and Chang (1992), Akram, Rime, and Sarno (2008) and Fong, Valente, and Fung (2010). 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. The first paper to have ignited this specific literature was Frenkel and Levich (1975, 1977).

Chung (2009) and Jones (2009).

We differentiate ourselves from this last set of papers in two ways. First, and most importantly, our paper is the only one which considers arbitrage strategies using both secured and unsecured strategies. This offers a structural test of the importance of specific determinants of the break down of arbitrage since the two strategies are nearly equal except that the secured strategy does not involve counterparty default nor rollover risk. Second, we avoid measuring CIP deviations with Libor rates. Using the Libor can introduce important biases in results. Libor rates can be misrepresentative of actual trading rates as they are indicative and only denote borrowing rates (i.e. ask and not bid quotes), void of transaction costs.[4] Also, while the Libor survey is undertaken at 11 am London time, it is unclear if reported rates represent borrowing costs at any specific time snap; this limits the extent to which price data can be synchronized to replicate actual trading profits. These mis-measurement issues are likely to have been especially acute during the crisis. Using the Libor rate can also lead to biased findings regarding the causes of CIP deviations. Indeed, the Libor contains an important risk premium component. Thus deviations from CIP arbitrage measured with the Libor will tend to be strongly correlated with risk-based measures given that the forward premium (difference between the foreign exchange forward and spot rate used in the arbitrage strategy) are actually priced off less risky instruments. Indeed, unlike this paper, the papers cited above find that risk played a dominant role in explaining CIP deviations. The use of Libor rates may also explain the fact that Baba and Packer (2009b) do not find that FX

[4] McAndrews (2009) emphasizes potential distortions in Libor rates during the crisis, underscored recently by actual legal inquiries into banks' Libor reporting practices.

Swaps introduced by central banks were particularly effective.

In the remainder of this paper we first outline the structure of CIP arbitrage and specify the payoffs and strategies used for secured and unsecured arbitrage. We then summarize our data and illustrate the size and duration of the break-down of CIP arbitrage. Finally, we try to explain this phenomenon by regressing CIP profits on specific measures of either risk or funding liquidity factors, each drawn from theory and tied to specific papers in the literature.

1 The structure of CIP arbitrage

In practice, traders use two major strategies to take advantage of potential CIP deviations. Each strategy is presented below along with its respective payoff function.

1.1 Textbook CIP arbitrage

CIP arbitrage entails borrowing in one currency and lending in another to take advantage of cross country interest rate differentials while avoiding exchange rate risk. The trade is usually described as borrowing in currency k at an interest cost $r_{k,t}$, exchanging the sum to currency j using the spot forex market, lending the proceeds in currency j at rate $r_{j,t}$, and exchanging the principal and accrued interest back to currency k at maturity to reimburse the original loan with interest. The last transaction is undertaken using a forex forward contract thereby eliminating exchange rate risk. To introduce some terminology, in the above example we say the trader is short in currency k and long in currency j.

Profits 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 normally suggest CIP arbitrage is riskless and should 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 the "CIP condition" for short.

1.2 CIP arbitrage in practice, two types of traders

Replicating actual arbitrage profits brings up several questions. Relative to the above characterization of CIP arbitrage, what instruments are used to borrow and lend? What transactions are undertaken? Are there hidden costs? Over what term should CIP arbitrage hold? Are there any risks involved?

There are typically two ways to implement CIP arbitrage, using secured or unsecured funding. The distinction is made in Brunnermeier and Pedersen (2009), and as in that paper we loosely associate the first with a hedge fund and the second with a bank's proprietary (prop) desk. Each strategy involves different interest rates and maturities, has different risk and liquidity implications, and potentially different payoffs.

1.3 Payoffs from secured CIP arbitrage

Secured arbitrage is the most straightforward to implement. The trader borrowers currency k, as in the earlier description, except that she has to pledge collateral in exchange. The interest she pays, $r_{k,t}$, is therefore the private, or interbank, repo rate in currency k. The hedge fund then exchanges this cash to currency j on the spot market and extends a loan in currency j. This is very much as in the simplified earlier example, except that once again the hedge fund requires collateral in exchange for its loan. The interest it receives, $r_{j,t}$, will once again be the private repo rate. In market jargon, the hedge fund carries out a "repo" transaction with counterparty "Lender L" and a "reverse repo" with "Borrower B" (both illustrated in Figure 1).[5] Given the insurance from the collateral, the hedged fund can afford to take term positions; it need not roll-over very short term positions. At maturity, positions unwind very much as described in the textbook case. The hedge fund reimburses Lender L after exchanging proceeds back to currency k using its pre-established forward contract.

The resulting payoff is given by,

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

where r^R are repo rates in currency j or k, set in time t up to maturity T, thus of term $(T - t)$. The B and A superscripts denote bid and ask quotes to incorporate transaction costs related to arbitrage. We follow standard convention in assuming the trader pays the ask quotes on what she acquires and the bid quotes on what she sells.[6]

[5] The term "repo" refers to selling a security as collateral against cash and repurchasing back the security at maturity.

[6] When a trader buys currency j while selling currency k in the spot market, she pays

1.4 Payoffs from unsecured CIP arbitrage

Unsecured CIP arbitrage is slightly more complex. Because this strategy uses unsecured loans, traders will usually avoid term loans in order to minimize counterparty default risk. This was especially true during the crisis according to anecdotal evidence.[7] Thus, in order to implement arbitrage over a desired term, traders roll over very short term – typically overnight – money market positions. In doing so, traders also benefit from the usually very liquid overnight market for funds. This strategy therefore stacks the cards against finding CIP deviations, as risk is minimized while liquidity is maximized.

The expected (ex-ante) payoff from such a strategy is given by,

$$z_{3,t} = \frac{F^B_{t\cdots T}}{S^A_t}(1 + r^{C,B}_{j,t\cdots T}) - (1 + r^{C,A}_{k,t\cdots T}) \tag{3}$$

where $r^C_{t\cdots T}$ are the cumulative interest rates given by rolling over overnight loans from t to T. More explicitly, these are given by,

$$\begin{aligned} 1 + r^{C,A}_{k,t\cdots T} &\equiv \mathbb{E}_t\left[\prod_{s=t}^{T-1}(1 + r^A_{k,s\cdots s+1})\right] \\ 1 + r^{C,B}_{j,t\cdots T} &\equiv \mathbb{E}_t\left[\prod_{s=t}^{T-1}(1 + r^B_{j,s\cdots s+1})\right] \end{aligned} \tag{4}$$

where r in the square bracket captures overnight lending rates.

An immediate drawback from the unsecured arbitrage strategy as described here is interest rate risk. At time t, $r^C_{t\ldots T}$ merely reflects the expectation of the overnight interest rates' future path. In practice, of course, actual rates may vary substantially from this path. Thus, traders typically com-

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).

[7]Discussions with hedge funds and traders and liquidity managers at Barclays.

plement an unsecured arbitrage strategy by hedging interest rate risk with overnight index swaps (OIS contracts, for short).

An OIS is an instrument allowing traders to swap a floating income stream (where floating means time varying and unknown ex-ante) with a fixed rate established ex-ante. The floating leg of an OIS is indexed on an interbank overnight unsecured rate, such as the Federal Funds rate in the U.S., EONIA in the euroarea, or SONIA in the U.K.. A long position in an OIS contract allows one to receive this floating income stream against a fixed payment agreed up-front. Just the opposite is true for a short position in an OIS contract. Importantly, though, an OIS contract involves no exchange of notional upon initiation, but just the settlement at maturity of the net difference between the accrued interest on the floating leg and the fixed rate. Engaging in an OIS contract therefore adds very little risk to any trading strategy.

Given the above characteristics, OIS contracts are a convenient and popular instrument to hedge interest rate risk on cash positions, such as are taken in CIP arbitrage. To illustrate, take the arbitrageur's short cash position in currency k, requiring her to make floating overnight interest payments. By taking, in addition, a long position in an OIS contract denominated in currency k, the trader will receive the same floating overnight interest payments. Indeed, the floating leg of the OIS contract and her cash position will be indexed on the same interbank, unsecured, overnight money market rates. Thus, these two floating income streams will cancel out, leaving the trader to pay only the fixed OIS rate known ex-ante, at time t. The same goes for the trader's long money market position in currency j, which she can hedge with a short OIS position denominated in that currency.

To summarize, the trader rolls over overnight cash or money market positions, short in currency k and long in currency j until maturity T. In addition, at time t, she hedges interest rate risk by engaging in a long OIS position in currency k and a short position in currency j. As a result, the trader's expected payoff from CIP arbitrage is given by,

$$\begin{aligned} z_{4,t} &= \frac{F^{B}_{t\cdots T}}{S^{A}_{t}}\left[(1+r^{C,B}_{j,t\cdots T})-(1+r^{C}_{j,t\cdots T})+(1+r^{O,B}_{j,t\cdots T})\right]+ \\ &\quad \left[(1+r^{C}_{k,t\cdots T})-(1+r^{C,A}_{k,t\cdots T})-(1+r^{O,A}_{k,t\cdots T})\right] \end{aligned} \tag{5}$$

where, in the first square bracket, the first term is the floating income from lending cash in currency j, the last term is the fixed ex-ante OIS rate and the middle term captures the floating payment liabilities of the OIS contract, given by,

$$1+r^{C}_{j,t\cdots T}=\mathbb{E}_t\left[\prod_{s=t}^{T-1}(1+r_{j,s\cdots s+1})\right] \tag{6}$$

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

2 Measuring excess profits from CIP arbitrage

The crux of this section is its third part, showing evidence of substantial and persistent deviations from CIP arbitrage. To get to these results, though, we first review data sources.

2.1 Data for secured CIP arbitrage

Secured CIP arbitrage involves borrowing and lending on the interbank repo market against collateral. It therefore requires interbank repo rates which are notoriously difficult to obtain. Data on USD interbank repo rates were acquired from ICAP whose BrokerTec trading platform accounts for over half the interbank repo market in USD. Data for comparable rates in EUR and CHF come from Eurex AG, whose platform is the dominant trading venue for interbank repos in EUR and CHF.[8]

All repo rates represent actually traded prices and include bid-ask spreads for the EUR and CHF. While the data cover several daily snaps, we focus on the 1:45 pm snap (London time), corresponding to market opening in the U.S., thus ensuring maximum liquidity. For the same reason, we only extract repo rates for one week terms, discarding longer terms. Indeed, most liquidity in the interbank repo market is overnight, with substantial liquidity remaining at the one week maturity, as reiterated in Duffie (2010a). Eurex data for 2009, for instance, suggest only 1% of private repo transactions were of one month or longer maturity.

In all cases, we use repo rates from General Collateral (GC) repos.[9] This ensures maximum liquidity and minimal risk, and makes data more closely comparable across currency markets. Importantly, no haircuts are applied to GC repos. As a result, their price, on which we have data, is a final measure of their actual cost to the arbitrage trader.[10]

Finally, synchronous spot foreign exchange data, along with bid and ask

[8]Data for both EUR and CHF were graciously shared with us on the basis of the close working relationship between Eurex AG and the Swiss National Bank.

[9]GC repos require a standard basket of collateral set by the national central bank usually composed of a wide array of highly rated government bonds. GC repo rates, as opposed to rates on special repos, do not vary with the need to hold any specific security.

[10]Note that while the risk profile of a GC collateral pool may have varied over time, along with its repo rate, these variations would not have affected the CIP condition. The arbitrage condition, after all, should hold given any interest rate differential, irrespective of the source of fluctuations.

quotes, come from ICAP's Electronic Brokering Services (EBS) and forward rates from Tullet Prebon (TP), a leading intermediary in wholesale financial markets which facilitates the trading activities of its large client base, including financial institutions, brokers, market makers and hedge funds.[11] All data go from March 2006 to April 2009.

2.2 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 these spreads are not known to the trader at time t, nor are they available to us. More importantly, these spreads are likely to be very small, especially compared to the size of deviations from CIP. For estimation purposes and in the spirit of replicating traders' expected arbitrage profits, we therefore ignore this half spread, thereby allowing us to simplify equation (5) to,

$$z'_{4,t} = \frac{F^B_{t \cdots T}}{S^A_t}(1 + r^{O,B}_{j,t \cdots T}) - (1 + r^{O,A}_{k,t \cdots T}) \tag{7}$$

OIS, spot and forward data span the same 2006-2009 time period and are perfectly synchronous across the forex and money markets considered, coming from four daily snaps at 9 am, 11 am, 4 pm and 11 pm, London time. The first snap captures the trading hours of European and Asian markets, the third of European and U.S., the fourth of U.S.and Asian markets and the second coincides with the Libor fixing.

[11] Whereas spot rates are perfectly synchronous with the repo rates, taken at 1:45 pm London time, we use forward rates with time snaps at both 11 am and 4 pm London time as data collection was optimized for exact synchronization first and foremost among the richer dataset used in unsecured arbitrage. But results for secured arbitrage are not sensitive to the use of either forward market snap.

Data cover a wider set of currencies than those considered for secured arbitrage. Currencies used are EURUSD, USDCHF, USDJPY, GBPUSD, as well as EURCHF, the last serving as a control not involving the dollar. These currencies cover two thirds of the global foreign exchange market turnover.[12] For each currency pair, data include the 1 week as well as 1, 3, 6, 8, 12 and 24 month maturities.[13]

The OIS and forward data from Tullet Prebon are technically indicative, although very close to binding bid and ask prices. This is because TP clients emitting quotes most often use the TP platform for actual trading. Indeed, there are few alternative platforms to trade these instruments.

Figure 2 shows the bid-ask spreads related to unsecured CIP arbitrage. Average spreads in the forex market, both spot and forward, became more volatile after the start of the crisis in August 2007, and increased substantially after the Lehman bankruptcy. Only in April 2009 were spreads back to pre-crisis levels. Average OIS spreads followed forex spreads in a stunning jump in September 2008, but remained elevated at end of sample.

2.3 Actual CIP profits

In the case of secured arbitrage, CIP arbitrage profits – as measured by $z_{2,t}$ – are generally negligible or negative, as expected, up to the first signs of the crisis, in August 2007. Profits then increase somewhat, suggesting growing tensions in arbitrage, although levels remain relatively small. The spike

[12]According to the 2010 BIS Triennial Central Bank Survey of Foreign Exchange and Derivative Market Activity, BIS (2010).

[13]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.

coinciding with the Lehman bankruptcy is instead a very clear indication of a break-down of arbitrage.

At their peak, profits reach nearly 400 bps on an annualized basis – a very substantial amount. Moreover, they remain high for about two months. These dynamics are visible in Figure 3 which plots CIP profits for EURUSD and USDCHF trades. In both cases, trades represent short dollar positions in the spot market; in other words the trades involve borrowing dollars to lend in euros or Swiss francs. Following convention, we thus refer to these as long EURUSD and short USDCHF trades.

As a comparison, Akram, Rime, and Sarno (2008) study CIP profits from tick-by-tick data in 2004 over various currency pairs. They find that annualized mean returns from CIP arbitrage, when they occur, range from 2 to 15 pips and last between 2 to 16 seconds.

Two other results emerge. First, the reverse of these trades, involving long dollar positions on the spot market, yield negative returns, as shown in Figure 4. And second, CIP profits over EURCHF are negative independently of the direction of the trade, as plotted in Figure 5. These results suggest that the very unusual arbitrage profits derived from CIP arbitrage are (i) currency specific (involving the dollar) and (ii) directional (involving short dollar spot positions).

These stylized facts are strongly corroborated by results for unsecured arbitrage profits – as measured by $z'_{4,t}$. Indeed, the extent and duration of CIP profits from secured and unsecured strategies over one week terms are nearly the same for EURUSD and USDCHF, as plotted in Figures 6 and 7.

Data for unsecured arbitrage allow us to explore the robustness of results along two further dimensions: more currency pairs and longer terms of arbitrage. Results are very similar to those described above. Figure 8 plots CIP profits for short dollar trades against the euro, yen, sterling and Swiss franc, over a one month, no longer a one week, term. As above, CIP profits increase in August 2007 and spike at the time of the Lehman bankruptcy, reaching nearly 400 bps annualized. Returns remain persistent to year end. The second spike, not visible in either secured or unsecured arbitrage over one week, most likely comes from end-of-year market perturbations often dubbed "window dressing effects" referring to flight from risky and illiquid assets; this is the only noticeable difference from extending the term of arbitrage. As before, CIP returns are negative when spot positions are long in dollars, as shown in Figure 9. And again, returns on EURCHF unsecured arbitrage over a one month term remain negative throughout the sample, irrespective of which currency is used for financing, as illustrated in Figure 10.

To summarize, all measures show that CIP profits were large and persistent after the Lehman bankruptcy. Importantly, profits appear to be dollar specific and directional, as well as insensitive to the arbitrage strategy.

3 Explaining excess profits from CIP arbitrage

Measured profits from CIP arbitrage essentially have three possible explanations. First, prices of the securities used are non-representative. Thus, CIP deviations are just an artifact of mismeasurement and the actual CIP condition continues to hold in practice. Contrarily to the existing literature on recent CIP deviations, we discard this explanation on the basis that our dataset represents traded prices. Second, CIP arbitrage entails some risks and these increased substantially during the crisis. In other words, the CIP condition as in $z_{1,t}$ or $z'_{4,t}$ should actually include a risk premium term for which arbitrageurs are compensated with positive profits. Third, the ability to obtain cash funding to undertake the arbitrage trade, what we call funding liquidity, became unavailable or rationed during the crisis. Thus, insufficient arbitrage left positive profits on the table.

The first and possibly strongest response to these questions is given in the earlier section. Secured and unsecured arbitrage strategies yield very similar profits. Yet, the secured strategy, involving the exchange of collateral and term positions in funding markets, is mostly void of counterparty default and rollover risk. By extension it would seem that counterparty and rollover risk would not have contributed to limiting arbitrage. Instead, both strategies are exposed to funding liquidity constraints, as well as to contract risk.

The exercise in the following subsections aims to test the robustness and investigate further granularity of the above conclusion that CIP deviations are mostly related to funding liquidity constraints. The aim is to test empirically the correlation of CIP profits with measures of risk and liquidity. While it is difficult to clearly associate observable variables with either risk or liquidity, it is easier to do so for the specific sources of risk and liquidity. For instance, while funding liquidity is a general concept, one of its determinants is the hoarding of liquidity, specifically in dollars. This practice can be measured with excess reserves at the U.S.Fed. Using a variety of variables over a wide array of different currency pairs, maturities and estimation strategies, our results emerge as robust and aligned with the more structural identification scheme provided above of comparing arbitrage profits from secured and unsecured strategies.

3.1 Sources of risk

Following the literature, we isolate three possible sources of risk specific to CIP arbitrage. The first is contract risk. This involves the default of the trader's FX forward counterparty during the term of arbitrage. Both Duffie and Huang (1996) and Melvin and Taylor (2009) emphasize this risk. Clearly, contract risk is common to both secured and unsecured arbitrage.

Contract risk involves the early termination of arbitrage and thus exposes the trader to exchange rate risk by having to renew her forward contract or close her positions using the spot exchange rate. In essence the risk is that the covered interest rate arbitrage strategy come more like its uncovered counterpart. The risk is not large relative to losing one's principle, as in counterparty default risk, especially that if the exchange rate is a martingale it can also move in favor of the arbitrage trader. Never-the-less, this source of risk is of some interest as it is the only one shared between secured and unsecured arbitrage strategies. We capture exchange rate risk with one month forex option implied volatility, as in Sarno, Valente, and Leon (2006).[14]

Second, the trader is exposed to rollover risk, but only when engaging in unsecured arbitrage. Indeed, the trader's unsecured trading strategy involves rolling over overnight money market positions for the term of the strategy. At any point in time, though, the trader's cash provider (Lender L in Figure 1) may stop rolling over the trader's debt. Acharya, Gale, and Yorulmazer

[14]Data are taken from Datastream Thomson.

(2011), among others, suggest that rollover risk may lead to market freezes when investor sentiment turns negative.[15]

Rollover risk entails foregone profits from having to close arbitrage positions early. These losses depend on the maturity structure of current and expected short term interest rate differentials (losses increase when this differential rises in time, since profits are made on the differential). We therefore capture rollover risk with the one week to one month OIS spread in currency j relative to that in currency k.[16] This "term interest rate differential" corresponds to potentially lost profits from closing positions after one week instead of the planned one month (recall that unsecured CIP profits are taken over one month terms in our regressions).

Third, the trader engaged in unsecured arbitrage faces counterparty default risk by lending on the overnight money market. Taylor and Williams (2009), for instance, attribute significant weight to this source of risk to explain the persistence of Libor-OIS spreads. Cash lent in secured arbitrage is instead covered by collateral. In the unsecured case, counterparty default risk is typically small for overnight loans, but exists none-the-less and is potentially dissuasive of lending at times of extreme crisis. We capture counterparty default risk with the first principal component of the 5-year CDS financial sector indices of the U.S.and Eurozone.[17]

[15]Other papers emphasize sentiment shocks, as Shleifer and Vishny (1997) which brings up the prospects of self fulfilling prophecies. The availability of information also plays a central role, as in Hombert and Thesmar (2009) and Morris and Shin (2010), where imperfect knowledge of aggregate losses is paramount.

[16]Data are drawn from Tullet Prebon.

[17]Data are drawn from Datastream Thomson. Although the 5-year term is much longer than the terms used in arbitrage, the 5-year CDS is the most liquid contract. In addition, our main results are based on first differences of variables, and any change in counterparty default risk of financial institutions would show up in the 5-year measure.

3.2 Sources of funding liquidity constraints

Following the literature, we identify three potential sources of funding liquidity constraints. The first is liquidity hoarding. It involves the trader's cash provider (Lender L in Figure 1) hoarding liquidity for prudential purposes or to address her own funding strains. In doing so, she gives up lucrative lending revenue. Again, this phenomenon affects both secured and unsecured arbitrage. We can just as well imagine a money market fund curtailing lending to a hedge fund, or the liquidity management unit of a bank with-holding funds from its trading desks.

McGuire and von Peter (2009) clearly document the importance of this liquidity hoarding channel during the financial crisis. By 2008, banks had accumulated substantial dollar assets, funded mostly on a very short term basis on unsecured terms. On net, McGuire and von Peter estimate that Canadian, Dutch, German, Swiss, U.K. and Japanese banks required an aggregate of USD 1.2 trillion (net) in USD to fund their assets. When funding markets dried up and when the assets in question became illiquid, banks faced a severe funding strain in dollars. The situation was exacerbated by signaling dynamics: banks did not want to be caught by their peers scrambling for liquidity and knew that posting sufficient liquidity was essential to maintaining their credit rating. Acharya and Merrouche (2009) tell a similar story in relating that by August 2007, U.K. banks had increased their liquidity buffers by 30%, and Heider, Hoerova, and Holthausen (2009) give their own account of liquidity hoarding in the euro interbank market. Finally, Gale and Yorulmazer (2011) propose a model of liquidity hoarding specifically. As a result, banks sacrificed lending profits to rebuild their liquidity pools, mostly in dollars. These dynamics emphasizing the vicious circle between market and funding liquidity, as well as cross-market contagion, 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).

We measure the extent of prudential liquidity hoarding in dollars with cash deposits at Federal Reserve Banks in excess of reserve balances.[18] Ashcraft, McAndrews, and Skeie (2011) follow a similar strategy. These represented safe liquidity pools in dollars for banks, held at significant opportunity costs relative to investing the funds (such as in carrying out CIP arbitrage!).

The second possible source of funding liquidity constraints comes from pressure on the trader's cash lender (Lender L in Figure 1) to deleverage, or reduce her balance sheet size. Again, this results on the lender cutting funding, albeit lucrative, to the arbitrage trader. This source of funding liquidity constraint is common to both secured and unsecured arbitrage strategies and reflects the notion in Duffie (2010b) of intermediaries' "balance sheet capacity." The term intermediaries must be taken loosely to also include a bank's treasurer limiting the leverage of internal trading desks. The impressive extent to which financial institutions deleveraged during the recent crisis is documented and discussed in Adrian and Shin (2008b) and McCauley and McGuire (2009), among others. It is unclear how much deleveraging was skewed towards dollar assets, but is is likely that global financial institutions attempted to rebalance the exchange rate exposure of their portfolios. Garleanu and Pedersen (2011) also focus on deleveraging and suggest a model in which assets with lower margin requirements – with less impact on the bal-

[18] Data are available from http://www.federalreserve.gov/releases/h41.

ance sheet – can trade at lower prices.[19] We capture the impetus to deleverage using the measure of balance sheet size of global financial intermediaries developed in Adrian and Shin (2008a).[20]

The third source of funding liquidity constraints is limited capital. According to this theory, reviewed with particular clarity in Gromb and Vayanos (2010),[21] capital to pledge in exchange for cash funding can be insufficient in times of crisis. This is clearest for secured arbitrage for which borrowing requires capital. Following the Lehman bankruptcy, many hedge funds faced increasing redemptions and incurred heavy losses on their portfolios, especially in dollars. In a time when raising equity was nearly impossible, available capital became scarce. As a result, hedge funds were curtailed in their ability to engage in lucrative arbitrage trades. Of course, this source of funding liquidity constraint may also extend, more loosely, to unsecured arbitrage. As for hedge funds, banks' prop desks can be constrained by limited bank capital to the extent that their trading activities use up risk-weighted regulatory capital which had to be used for other purposes across the bank.

[19]Other papers also emphasize feedback from balance sheets to asset prices, as Acharya and Viswanathan (2011) and Benmelech and Bergman (2009). Other papers emphasize related frictions also leading to capital constraints and market freezes, such as the structure of financial institutions, as in Diamond and Rajan (2005), He and Krishnamurthy (2008b) and Duffie (2009), the structure of markets, as in Acharya and Pedersen (2005), Allen and Gale (2003), Allen, Carletti, and Gale (2009) and Lagos, Rocheteau, and Weill (2009), or adverse selection or investor sentiment as in Malliaris and Yan (2010), Mancini Griffoli (2009), and Bolton, Santos, and Scheinkman (2008). 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.

[20]We thank the authors for kindly sharing their data with us.

[21]But also at the heart of 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), Rinne and Suominen (2009) and Shleifer and Vishny (1997)

The literature is less clear as to which variables best track constraints on available capital to pledge for funding. We draw inspiration from Coffey, Hrung, and Sarkar (2009) as well as Gorton and Metrick (2009) in using the spread between Agency MBS and GC repo rates in USD.[22] The idea is that as capital becomes scarce, lenders are in a position to extract higher rents from borrowers in the form of higher repo rates. This is all the more true on riskier collateral, such as MBS. Another possible interpretation is that MBS were one of the asset classes which lost the most value during the crisis and thus contributed most the attrition of capital available to raise funds for trading purposes.

While liquidity was drying up, policy was working to facilitate borrowing conditions. We therefore add two policy measures which represent a more clearly exogenous source of liquidity fluctuations.[23] The first of these is USD swap lines extended by the Fed to other central banks (BOE, BOJ, BOC, ECB and SNB), and the second is the Fed's "Reserve Bank Credits". 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.[24] As this last measure had the goal of improving funding liquidity issues generally, it can be seen as a more indirect measure of policy responses. On the contrary, FX swaps were precisely targeted at solving the shortage of dollar funding.

Funding liquidity is a well specified category; it concerns exclusively the

[22]Data are drawn from ICAP's BrokerTec trading platform.

[23]Papers studying the policy responses to liquidity constraints are Cecchetti and Disyatat (2009), Drehmann and Nikolaou (2009) and Sarkar (2009).

[24]Weekly data is available on the Federal Reserve Bank of New York's website www.federalreserve.gov/releases/h41/

ability to raise the funds required for a trade. That is to be distinguished from market liquidity which describes the costs or ability to carry out a trade. The distinction between market and funding liquidity is raised in Brunnermeier and Pedersen (2009). For consistency with this literature, we also control for market liquidity with the bid-ask spreads on the spot and forward foreign exchange markets as well as the OIS markets involved in CIP arbitrage.

3.3 Specification and methodology

Based on the above arguments and variables, we estimate the following regression,

$$\Delta z_t = \alpha + \gamma \Delta z_{t-1} + \beta_1' \Delta \Sigma_t + \beta_2' \Delta \Psi_t + \beta_3' \ \Delta \Theta_t + \epsilon_t \tag{8}$$

where Σ_t is a matrix of variables capturing "risk", Ψ_t a matrix of "funding liquidity constraints" and Θ_t a matrix controlling for "market liquidity". Recall that the "risk" variables are: foreign exchange implied volatility (contract risk), interest rate term differentials (rollover risk), and CDS of relevant financial institutions (counterparty default risk). The "funding liquidity constraints" are: excess reserves at Federal Reserve Banks (liquidity hoarding), bank balance sheets (deleveraging), agency MBS to GC repo rates (limited capital), central bank swap lines and reserve bank credits (both policy induced liquidity provision). All these variables along with their associated interpretation are summarized in Table I. More details and descriptive statistics on these variables are available in the Web Appendix.

Before engaging in the actual regression analysis, we address two potential pitfalls. The first is collinearity and the second endogeneity. By collinearity we mean the high correlation between the variables included in each category or matrix mentioned above.

To account for collinearity we run seven different regressions for each arbitrage strategy. To start, we include only the first principal components of each category of variables captured in the separate matrices of equation (8). We do so to capture common information and to minimize any issue of collinearity among variables, as in Korajczyk and Sadka (2008). We call the principal components, respectively, the aggregate market liquidity, aggregate funding liquidity constraint and aggregate risk.[25] Given the strong collinearity among market liquidity variables, we continue to use the relevant aggregate measure throughout all regressions. Risk variables are instead quite independent of each other. We thus drop the aggregate measure of risk in remaining regressions in which we include each risk variable side-by-side. The correlation structure is instead mixed among funding liquidity variables.[26] To minimize potential collinearity, we do not include all funding liquidity variables at once, but test for the effects of each one in separate regressions while controlling for the remaining variables using their first principal component.

Second, we consider the potential for endogeneity. Specifically, the concern is that while CIP profits are affected by our liquidity and risk variables, these may in turn be affected by CIP profits. On intuitive grounds, the concern seems overstated. Why would positive arbitrage profits, or lack of arbitrage, translate into bank deleveraging, liquidity hoarding or, for that matter,

[25]The first principal component of the market liquidity variables explains 70% of the total variance. That number drops to 50% in the case of funding liquidity constraints and to 40% for risk.

[26]Detailed results are available in the Web Appendix. Within funding liquidity variables, cross correlations among variables are very unequal; they are as high as 80% between central bank swaps and reserve bank credits, but is nearly null between swaps and MBS-GC repo spreads.

spur risk or reduce market liquidity? We none-the-less investigate the issue on empirical terms by computing Hausman (1978) tests for endogeneity for each of the three categories of explanatory variables: market liquidity, funding liquidity constraints and risk.[27] In each case, the test consistently rejects the hypothesis of endogeneity, as intuition would have suggested.

We return to our regression specification. All variables are taken in first differences, as it is primarily the impact of the tightening of funding liquidity on the growth of excess CIP profits that interests us. We also do so to work with stationary series. For unsecured arbitrage, estimation is carried out for both the EURUSD time series and a panel including EURUSD, USDJPY, GBPUSD, and USDCHF. Regression results represent the baseline one-month arbitrage strategy, short in USD on the spot leg. We run robustness tests investigating arbitrage profits in separate currency pairs, over shorter and longer terms, as well as for long USD spot positions. We mention some of these results where appropriate and display them in the Web Appendix. For secured arbitrage, results are shown for the baseline strategy long in EURUSD over a one week term. Regressions results for short positions in EURUSD as well as short and long positions in USDCHF are explored in the robustness tests and displayed in the Web Appendix. Time

[27]The intuition behind these tests is to determine if coefficients on the variables potentially causing the endogeneity bias are the same as on their instruments considered in a separate regression. The instruments chosen for aggregate funding liquidity are two: the volume of liquidity injected by the Federal Reserve through the central bank swap lines and that injected through reserve bank credits. As for aggregate risk, the instrument chosen is the VIX index for equities following Brunnermeier, Nagel, and Pedersen (2009). That for aggregate market liquidity is instead the bid-ask spread on U.S.five year treasuries. In all cases, by virtue of being drawn from markets not directly involved in CIP arbitrage, or being the result of political deliberations to facilitate credit in a wide array of markets, the chosen instruments satisfy the standard conditions of being correlated to the independent variable but not to the dependent variable. Detailed results and specifications of the Hausman (1978) tests are available in the Web Appendix.

series regressions are estimated using OLS with Newey-West standard errors. Panel regressions use Seemingly Unrelated Regression with fixed effects, and exchange rate specific constants as well as autoregressive coefficients.

3.4 Estimation results

On the whole, estimation results are very similar across our three main specifications: unsecured EURUSD time series (Table II), unsecured panel (Table III) as well as secured EURUSD (Table IV). The most salient results are discussed below, with references to robustness tests for which results appear in the Web Appendix.

First, funding liquidity constraints are most correlated to deviations from CIP arbitrage. This is as suggested by the comparison of arbitrage profits between the secured and unsecured strategies, reviewed in section 2. A glance down the regression 1 column of Tables II - IV shows the largest coefficient on aggregate funding liquidity constraints, as opposed to aggregate market liquidity and risk variables (note, since principal components are calculated in the same manner across each category of variables, coefficients on these are directly comparable). All robustness tests mentioned earlier closely match these results.

Second, all three potential sources of funding liquidity constraints – liquidity hoarding, deleveraging and limited capital – seem to have been at play. Across each table of results – and again almost without exception in the robustness tests mentioned just above – liquidity hoarding, deleveraging and limited capital are positive and significant, with quite stable coefficients.

Third, the policy response to the funding liquidity constraints was successful, as underscored by the negative and significant coefficients on central banks foreign exchange swaps and reserve bank credits in all three tables of results and across all robustness tests. Policy variables are taken with a one week lag, though remain significant with a slightly lower coefficient when taken contemporaneously. As the volume of funding liquidity provided by policy makers grew, CIP deviations diminished. More specifically, results suggest that every USD 100 billion of FX swaps offered to foreign banks were followed by a reduction of CIP deviations of approximately 50 basis points.

Fourth, risk factors seem hardly correlated to CIP arbitrage deviations. Again, this is as suggested by the earlier comparison of secured and unsecured arbitrage profits, recalling that secured arbitrage is void of counterparty and rollover risk. Indeed, these two measures of risk are almost never significant in any regression considered either in the tables following the text or the robustness tests. Yet, risk still plays some role. In the regressions on unsecured arbitrage, aggregate risk is mostly significant and positive. It is never significant, instead, in the regressions on secured arbitrage (Table IV). To the extent that aggregate risk is significant, it seems to be driven by contract risk. That is clearly the case in the unsecured EURUSD time series regression (Table II) as well as most other unsecured time series regressions considered in the robustness tests.

Finally, aggregate market liquidity is also significant throughout nearly all specifications. The negative sign on coefficients in both regressions with short and long dollar spot positions suggests that whatever the trade, as market liquidity shrinks, transaction costs increase and profits diminish.

3.5 Additional robustness tests

Several other robustness tests were considered, in addition to those already mentioned above. Results are shown in the Web Appendix.

- Identification of coefficients does not rely on the Lehman bankruptcy event alone. Results are mostly unchanged in sign and significance when the regression is estimated from early March 2006 (start of sample) to September 10, 2009, just before the Lehman event. The only coefficients losing significance in some specifications are those tied to the policy responses (central bank swap lines and reserve bank credits). This is natural as these were mostly ramped up after the Lehman bankruptcy.

- Time of day does not seem to affect CIP profits. Results are unchanged when using a 4 pm snap relative to the baseline 11 am snap for unsecured arbitrage (all times are London time). Interestingly, the only coefficient which loses some significance is that on the aggregate market liquidity variable. It would seem that when market liquidity is at its peak, at 4pm London time (when U.S.and European markets are opened), the cost of engaging in CIP arbitrage no longer impinges upon profits.

- Considering unsecured arbitrage over a six month or a one week term, instead of one month, does not affect results.

- Results change very little when estimating coefficients through a VAR allowing for the funding liquidity, market liquidity and risk variables to be endogenous.

- Results change very little for the funding and market liquidity variables when additional controls are added, such as the VIX index in the first principle component of risk and TED spreads in that for funding liquidity constraints.[28] The aggregate risk variable, instead, becomes insignificant. If we instead include both the VIX and TED spreads in the principal components of the funding liquidity constraints as well as risk variables, aggregate risk regains significance though coefficients remain smaller than on the aggregate funding liquidity constraint, underscoring the predominance of the latter.

- Finally, results are nearly unchanged when we replace the counterparty default risk variable with the CDS bank sector indices for the regions of the currencies considered in specific arbitrage strategies: the U.S., Euro-Area, U.K. and Japan.

4 Conclusion

This paper provides empirical evidence for the theory of slow moving capital and limits to arbitrage, and adds to recent studies on the effects of the financial crisis. This paper focused on measuring deviations from covered interest parity (CIP) arbitrage, as well as explaining these. The paper described how such arbitrage strategies are actually implemented in practice, using either secured or unsecured money market transactions. Especially after the Lehman bankruptcy, excess profits from CIP arbitrage were substantial and persistent, involved borrowing dollars and did not depend on whether

[28]TED spreads are the difference in three month T-bill and Libor rates in USD. These are used in Brunnermeier (2009) and Brunnermeier, Nagel, and Pedersen (2009) as a measure of funding liquidity, implying that liquid capital is withdrawn from markets when it flies to high quality government bonds

borrowing was secured or unsecured. These results were found with data which closely match those a trader would have used to undertake arbitrage. Data are intra-daily, synchronized across markets and inclusive of transaction costs. The comparison of arbitrage profits stemming from the secured and unsecured arbitrage strategies offered a structural way to isolate the reasons for the break-down in arbitrage. The very similar profits from both arbitrage strategies suggested the limited role of counterparty and rollover risk, which are void in the secured strategy. This mostly left contract risk and funding liquidity constraints – stemming from liquidity hoarding, balance sheet deleveraging and limited capital to pledge for funds – as the possible explanatory factors. Less structural but more precise empirical tests confirmed this hypothesis. Moreover, policy to provide dollar funding liquidity was an effective tool to alleviate tensions across national money markets.

Looking ahead, these results suggest that policy aimed at avoiding future crises, or at least at containing their effects on the proper functioning of markets, should also take into consideration the role of funding liquidity. More precise recommendations along these lines, building on this paper's results, have already been raised in Kashyap, Berner, and Goodhart (2011) and in the IMF's Global Financial Stability Report (2011) in which CIP deviations are suggested as a measure of systemic liquidity risk to be included in the new Basle III regulatory standards.

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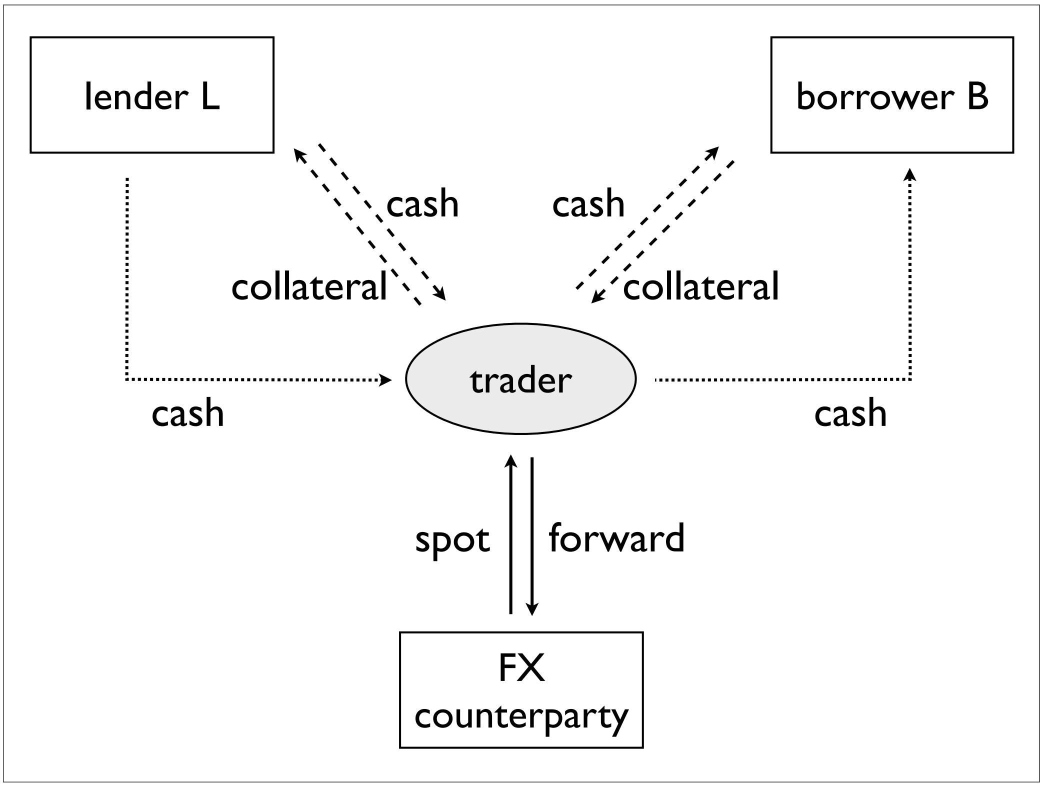

Figure 1: *An illustration of CIP arbitrage: the trader can be thought of as either a hedge fund or the prop desk of a large financial institution. Typically, the former borrows and lends on secured terms by exchanging cash against collateral (hashed lines), and the latter does so on unsecured terms (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.*

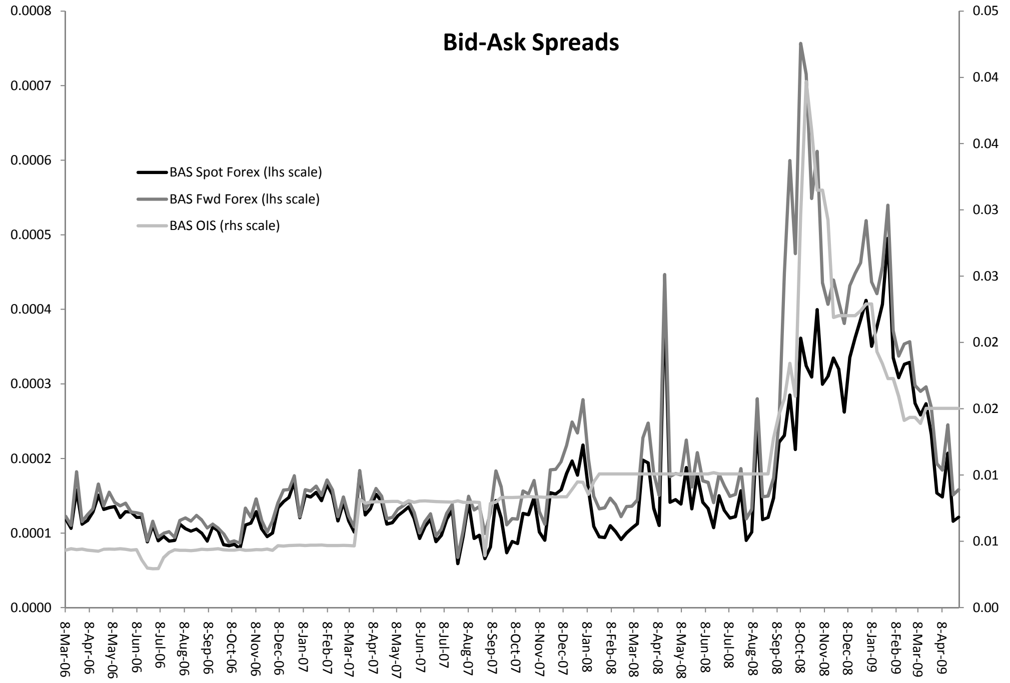

Figure 2: *Average bid–ask spreads across currency pairs in the forex spot and forward markets, as well as OIS market. Bid–ask spreads are calculated as* $(Ask - Bid)/C$ *where* C *is the average midquote.*

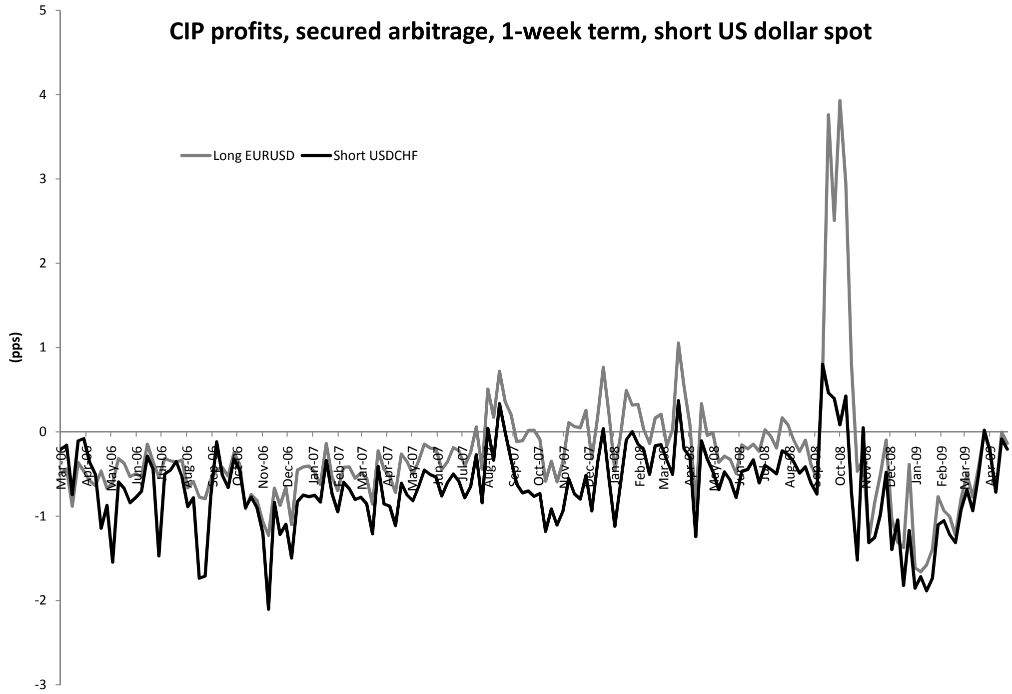

Figure 3: *Excess profits are large and persistent from secured CIP arbitrage on trades involving a short USD spot position, over a 1 week term.*

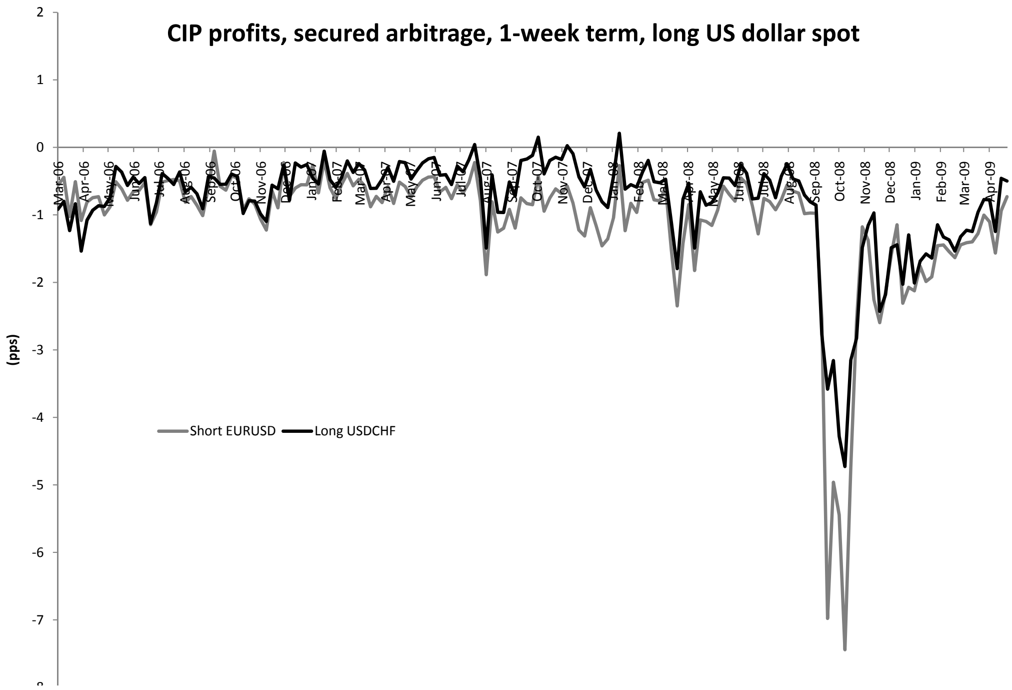

Figure 4: *Excess profits are negative from secured CIP arbitrage on trades involving a long USD spot position, over a 1 week term.*

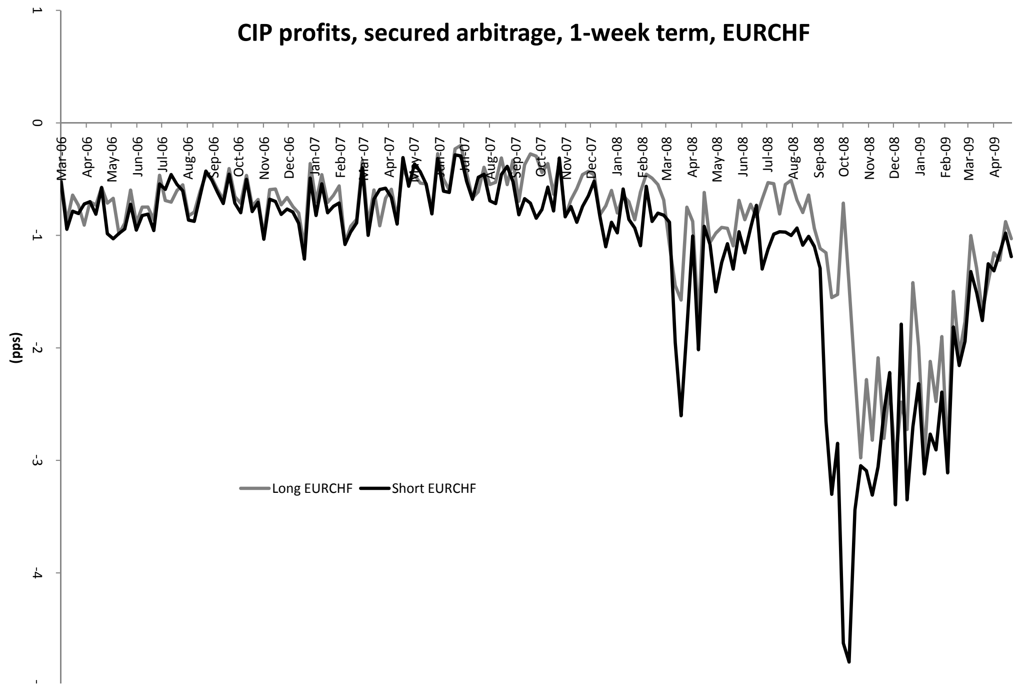

Figure 5: *Excess profits are negative from secured CIP arbitrage over a 1 week term on trades in EURCHF, irrespective of the currency used for financing.*

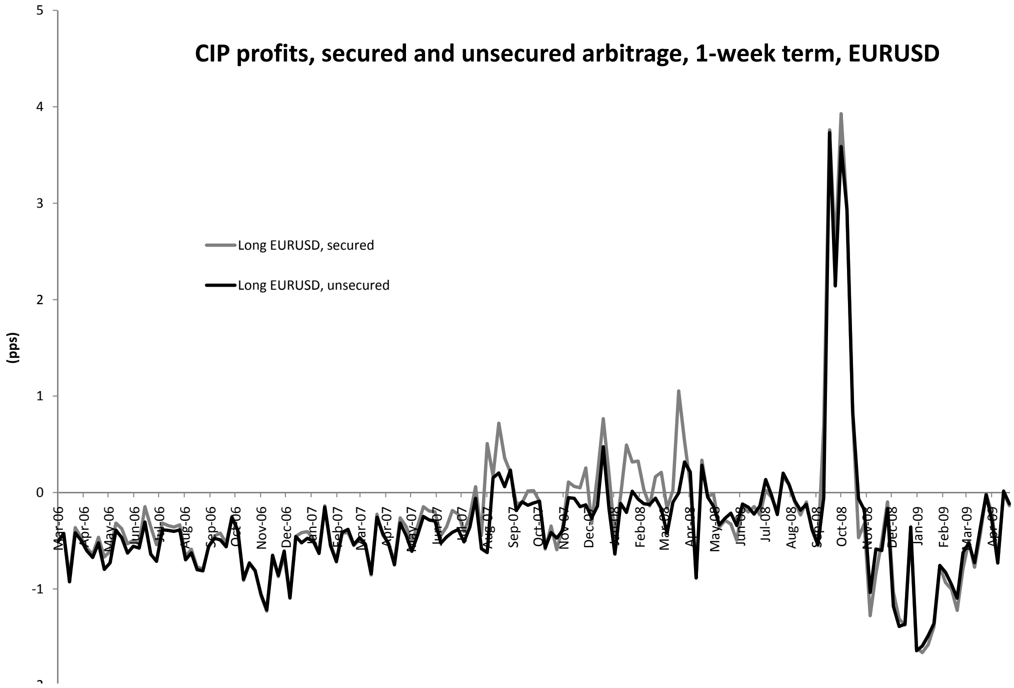

Figure 6: *Excess profits are exactly the same on secured and unsecured CIP arbitrage over a 1 week term on trades involving a short USD spot position.*

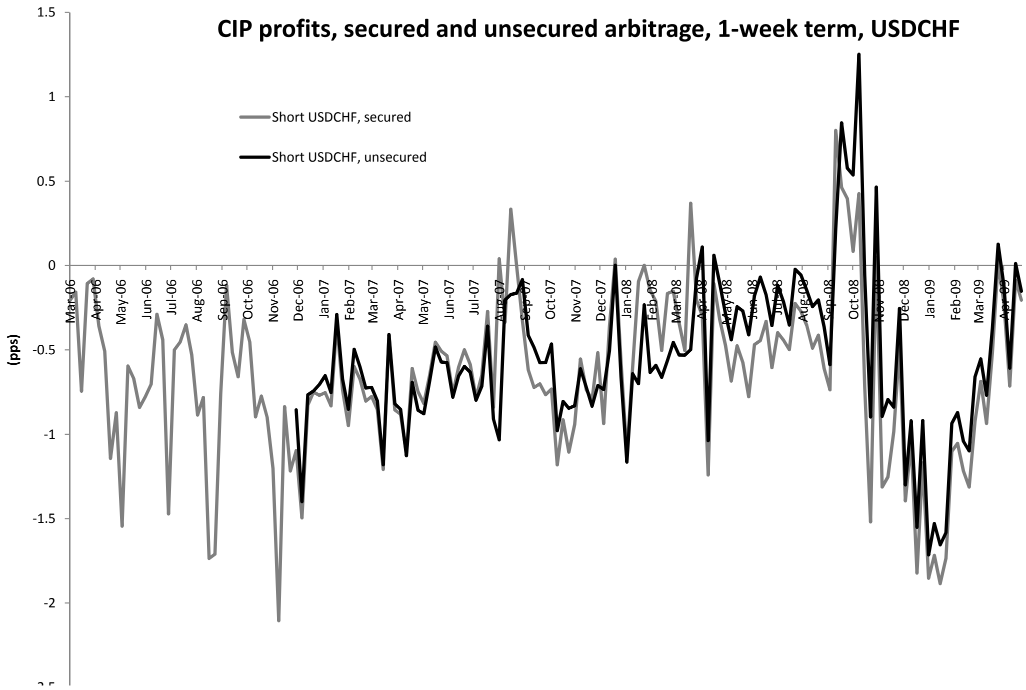

Figure 7: *Excess profits are nearly the same on secured and unsecured CIP arbitrage over a 1 week term on trades involving a short USD spot position.*

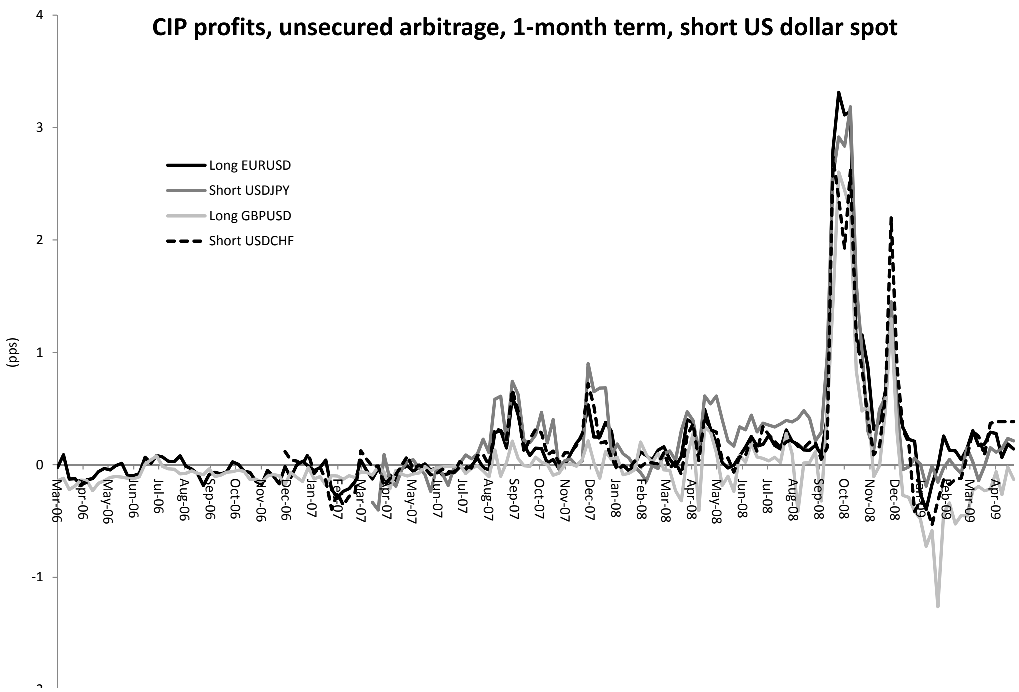

Figure 8: *Excess profits are large and persistent from unsecured CIP arbitrage on trades involving a short USD spot position, over a 1 month term.*

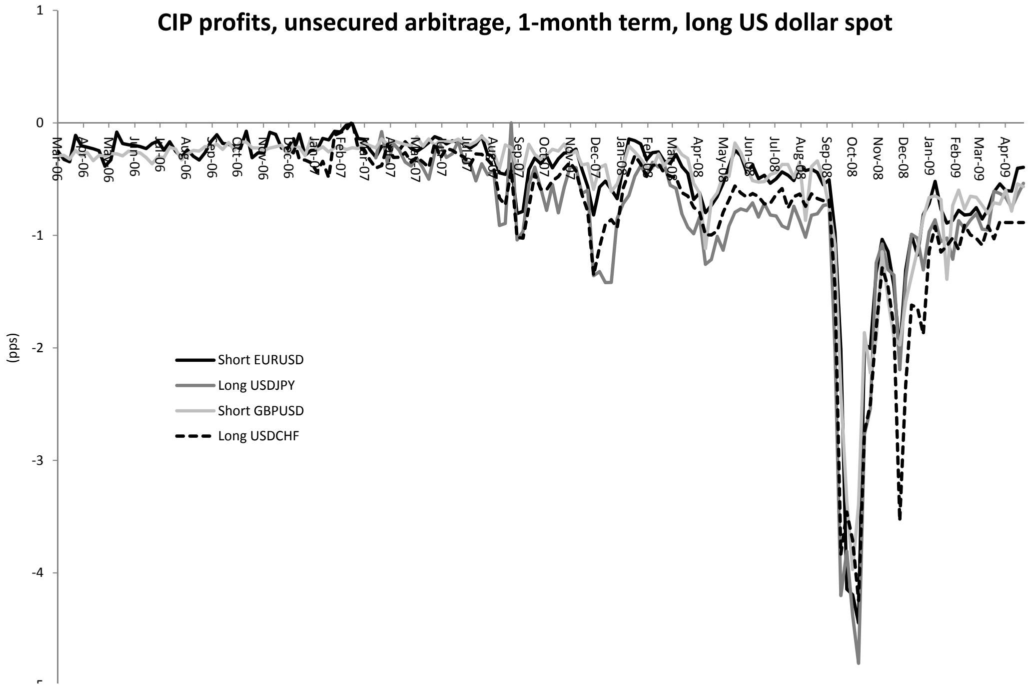

Figure 9: *Excess profits are negative from unsecured CIP arbitrage on trades involving a long USD spot position, over a 1 month term.*

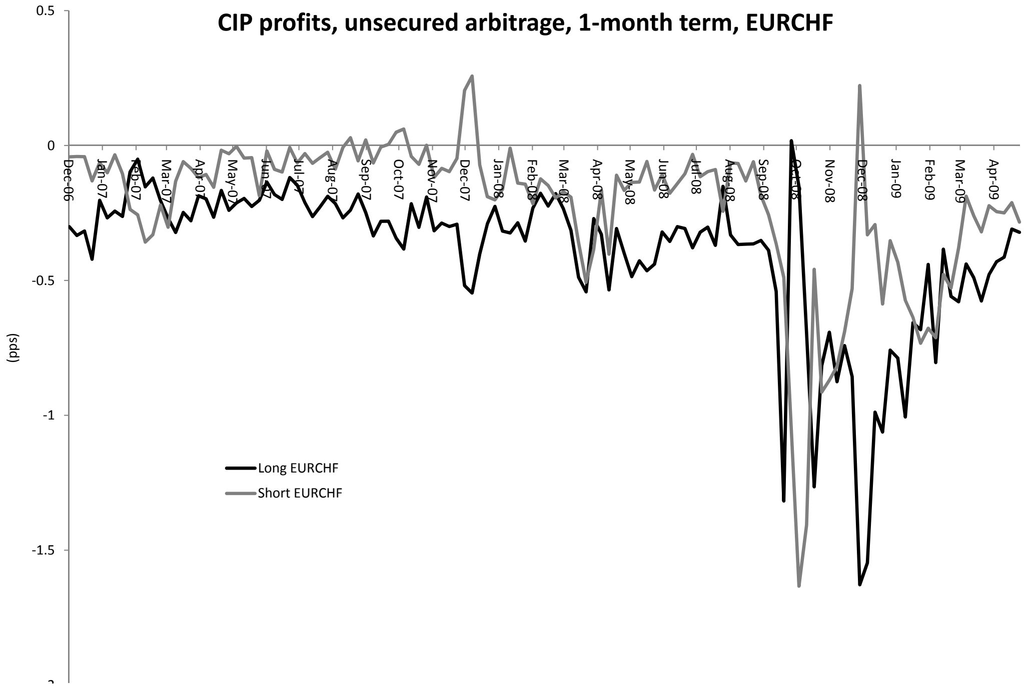

Figure 10: *Excess profits are negative from secured CIP arbitrage over a 1 month term on trades in EURCHF, irrespective of the currency used for financing.*

	Factor	CIP arbitrage proxy
Risks		
	Contract	Implied volatility (IV)
	Rollover*	Term interest differential
	Counterparty default	CDS (U.S., Eurozone financials)
Funding liquidity		
	Liquidity hoarding	Fed deposits
	Deleveraging	Balance sheet
	Limited capital	MBS-GC repo spreads
	Policy measures	CB swaps, Reserve bank credits
Market liquidity		
	Transaction costs	OIS & FX BAS spreads

Table I: *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. (*) indicates variables not applicable to secured arbitrage.*

Time series regression, Long EURUSD unsecured CIP arbitrage (1M)

	Specification						
	1	2	3	4	5	6	7
Market Liquidity	**-0.066**	**-0.055**	**-0.054**	**-0.055**	**-0.051**	**-0.058**	**-0.056**
	-4.184	-3.296	-3.353	-3.314	-3.080	-3.754	-3.111
Funding Liquidity Constraints	**0.084**	**0.109**	**0.090**	**0.078**	**0.064**	**0.115**	**0.101**
	6.646	8.106	6.154	5.052	3.800	9.276	6.582
CB swaps			**-0.480**				
			-4.212				
Reserve bank credits				**-2.906**			
				-3.172			
Liquidity hoarding					**0.666**		
					6.281		
Deleveraging						**2.669**	
						2.076	
Limited capital							**0.231**
							2.233
Risk	**0.047**						
	7.122						
Contract risk		**0.131**	**0.139**	**0.145**	**0.081**	**0.133**	**0.130**
		5.121	5.654	5.546	3.058	5.466	4.739
Rollover risk		0.034	0.104	0.130	0.152	0.028	0.061
		0.313	0.966	1.128	1.379	0.269	0.516
Counterparty default risk		0.271	0.333	0.306	0.120	0.297	0.317
		1.233	1.593	1.320	0.594	1.416	1.338
Adj. R2	0.423	0.347	0.402	0.295	0.416	0.403	0.348

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 always significant, while the constant is never so; neither are shown to simplify the table.*

Panel regression, Short USD unsecured CIP arbitrage (1M)

	Specification						
	1	2	3	4	5	6	7
Market Liquidity	**-0.067**	**-0.048**	**-0.046**	**-0.059**	**-0.055**	**-0.046**	**-0.048**
	-3.773	-2.571	-2.829	-3.136	-3.363	-2.799	-2.827
Funding Liquidity Constraints	**0.093**	**0.097**	**0.081**	**0.044**	**0.053**	**0.101**	**0.088**
	6.965	6.869	5.606	2.710	3.292	7.888	6.147
CB swaps			**-0.312**				
			-3.569				
Reserve bank credits				**-1.419**			
				-2.238			
Liquidity hoarding					**0.593**		
					7.088		
Deleveraging						**4.201**	
						4.445	
Limited capital							**0.245**
							2.317
Risk	**0.040**						
	5.007						
Contract risk		0.012	**0.021**	0.002	0.004	0.011	0.011
		1.108	1.948	0.152	0.420	1.088	0.999
Rollover risk		0.060	0.015	0.023	0.103	0.037	0.040
		0.846	0.213	0.315	1.592	0.560	0.593
Counterparty default risk		0.130	0.087	0.126	0.138	0.106	0.124
		0.797	0.558	0.772	0.955	0.715	0.792
Adj. R2							
EURUSD	0.346	0.195	0.241	-0.006	0.348	0.299	0.204
USDJPY	0.176	0.105	0.153	-0.059	0.146	0.148	0.106
GBPUSD	0.060	0.050	0.050	0.089	0.178	0.091	0.060
USDCHF	0.409	0.274	0.324	0.006	0.280	0.327	0.285

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 always significant, while the constant is never so; neither are shown to simplify the table.*

Time series regressions, Long EURUSD secured CIP arbitrage (1W)

	Specification						
	1	2	3	4	5	6	7
Market Liquidity	-0.063	**-0.074**	**-0.068**	**-0.090**	**-0.082**	**-0.077**	**-0.114**
	-1.612	-1.879	-1.805	-2.326	-2.171	-1.993	-3.041
Funding Liquidity Constraints	**0.143**	**0.150**	**0.141**	**0.157**	0.035	**0.146**	**0.178**
	4.678	4.957	4.466	4.900	0.876	4.884	6.660
CB swaps			**-0.554**				
			-3.179				
Reserve bank credits				**-4.321**			
				-4.058			
Liquidity hoarding					**0.886**		
					4.714		
Deleveraging						**5.243**	
						2.522	
Limited capital							**1.102**
							5.340
Risk	0.007						
	0.412						
Contract risk		0.460	0.955	**1.005**	0.359	0.640	0.393
		1.342	1.599	1.720	0.579	1.068	0.737
Counterparty default risk		0.039	0.036	0.037	0.031	0.032	0.021
		0.765	1.317	1.368	1.059	1.102	0.821
Adj. R2	0.146	0.184	0.228	0.222	0.471	0.172	0.296

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 always significant, while the constant is never so; neither are shown to simplify the table.*