The validity of interest parity in times of crisis

A theoretical relationship exists between exchange rate developments and the interest rate differential between two currency areas. This relationship is referred to as interest parity. Here, a distinction is made between covered and uncovered interest parity. With covered interest parity, cross-border investments are hedged against exchange rate changes. There is therefore no exchange rate risk when the transaction is concluded. In theory, the interest rate differential between the currency areas should correspond to the rate of change between the forward and spot rates. It should not be possible in this case to make a risk-free profit through trading (interest rate arbitrage). With uncovered interest parity, investments in the other currency area are not hedged against exchange rate changes. Under simplified assumptions, the interest rate differential should correspond to the rate of change between the present and expected future spot rates.

This article begins by examining empirically whether interest parity in its various forms applies for the period up to the end of 2021. The analysis focuses primarily on the income from investing in three-month money in euro or alternative currencies. The observation period covers various crises, in particular the global financial crisis that began in 2007. It can be seen that the relationship between the interest rate differential and the exchange rate changed following the onset of the financial crisis. This was true of both forms of interest parity.

For example, deviations from covered interest parity are clearer and longer lasting than before the crisis. This applies not only between the euro and the US dollar, but also to a large number of other currency pairs. At first glance, such deviations from covered interest parity contradict the assumption usually made in financial market theory that risk-free profit opportunities cannot occur if market participants behave rationally. However, more detailed analyses show that the observed violations of covered interest parity are indeed compatible with rational behaviour. This is because financial market conditions have changed since the financial crisis. Important conditions for the validity of covered interest parity were often no longer met to the same extent as before. For example, counterparty risk increased markedly during severe financial market turmoil, and financial market participants demanded a premium for taking it on. In addition, the costs of interest arbitrage were increased by the Basel III decisions, which were phased in as of 2013. This contrasted at times with one-sided and relatively price-inelastic demand for exchange rate hedging. Taken together, these factors allowed marked deviations to arise even outside times of crisis.

Since the financial crisis, a change has also taken place in the relationship between the exchange rate and interest rates on investments without exchange rate hedging. Trade strategies such as currency carry trades previously played a major role in this relationship. Market participants who were typically speculative preferred to invest in the currency that offered higher-interest investment opportunities. The associated capital movements led to a simultaneous appreciation of the higher-interest currency. Evidence of this empirical relationship, which is contrary to uncovered interest parity, can no longer be found in the period since the global financial crisis. However, it cannot be ruled out that this trading strategy will regain importance as interest rate differentials between the currency areas now grow larger again.

Introduction

Interest parity theory describes relationship between interest rate differential and exchange rate

Interest parity theory describes the relationship between interest rate differential and exchange rate, taking into account the investment behaviour of investors. This theory states that, under some assumptions, the expected return on a fixed-interest investment in domestic currency matches that on an equivalent fixed-interest investment in foreign currency. Covered and uncovered interest parity are distinguished via their different treatment of exchange rate risks. With covered interest parity, investors hedge their open foreign currency position by means of a forward transaction. With uncovered interest parity, on the other hand, the open foreign currency position is left unhedged.

Significant deviations from covered interest parity since the outbreak of the financial crisis

For example, fairly stable regularities can be found up to the outbreak of the financial crisis under covered interest parity. Deviations from covered interest parity were generally relatively small in the early years of monetary union and – taking into account transaction costs – were likely due to data imperfections rather than market inefficiencies, according to an empirical study in the 2005 Monthly Report.[1] Since August 2007, however, significant and longer-lasting deviations have been observed, sometimes even during calm market phases. This applies not only to the relationship between the euro and the US dollar, but also to that between the euro and a large number of other currencies. The more pronounced deviations from covered interest parity since then raise the question of why seemingly safe profit opportunities arising from arbitrage transactions are not exploited.

Uncovered interest parity violated even before the financial crisis

By contrast, empirical support for the uncovered interest parity theory was low even before the outbreak of the financial crisis. The theory states that the currency in which the higher-interest, otherwise equally safe investment is denominated depreciates against the currency with the lower-interest investment over the term, so that the expected return on domestic and foreign interest instruments is the same. However, one result of the empirical studies conducted at the time was that the higher-interest currency appreciated on average over the investment period. This is consistent with the empirical results of numerous previous studies.[2] The observed phenomenon is also related to the fact that currency carry trades were, on average, a profitable investment strategy as investors often received, in addition to the higher interest rate at which they invested using this strategy, a return from currency appreciation.[3] At the beginning of the new millennium, the question of why the uncovered interest parity theory could not be confirmed well empirically was the subject of a large number of theoretical and empirical papers.[4]

Report re-examines relationship between interest rate differentials and exchange rates

This report takes the scientific debate as an opportunity to re-examine the relationship between interest rate differentials and the exchange rate both theoretically and empirically. The main focus is on differences in return between money market investments in other currency areas and those in the euro area.[5] By contrast, the available literature primarily looks

1 See Deutsche Bundesbank (2005), p. 34.
2 See, for example, Fama (1984) and MacDonald and Taylor (1992).
3 At first glance, the result of these studies, i.e. that interest rate differentials forecast excess returns, contradicts the assumption of rational expectations, and has been discussed in the literature as the "uncovered interest rate parity puzzle" or "forward premium puzzle". See Engel et al. (2022).
4 A comprehensive overview of the empirical papers on this topic can be found in Engel (2014). See also the abovementioned article in the Monthly Report, Deutsche Bundesbank (2005).
5 In keeping with the relevant literature, the empirical analysis is based on the London Interbank Offered Rate (LIBOR), which is now only calculated for the US dollar. The calculation was discontinued for other currencies at the end of 2021. The investigation period therefore ends on 31 December 2021. Following news in 2012 of manipulation in connection with the setting of reference rates, notably LIBOR and EURIBOR, the global system of reference rates underwent fundamental reform (see Deutsche Bundesbank (2020)). One result was that LIBOR was initially reformed before being replaced by new reference rates from 2022. For the euro area, it is to be superseded by €STR (euro short-term rate), which the European Central Bank (ECB) only began publishing in October 2019 and is only available retroactively for the period up to March 2017. This is the reason why the empirical examination uses LIBOR rates for the longer-term period under review.

at interest rate differentials vis-à-vis the United States. The report consists of two sections. It deals, first, with covered interest parity and presents various explanatory approaches for the observed deviations from the relationship it postulates. Next, it looks at uncovered interest parity and examines whether, using the aforementioned hypothetical currency carry trade strategy, interest-rate speculators would still have been able to generate profits on average in recent years.

Crises with a potential impact on interest parity

In this context, the relationship between the transatlantic interest rate differential and the euro exchange rate against the US dollar has been linked, amongst other things, to several crises that have weighed on the international financial markets in recent years. The first to be mentioned is the global financial crisis, which began in mid-2007 in the US mortgage market and expanded into an international crisis the following year. Second, the sovereign debt crises in the euro area affected foreign exchange market developments, which first came to a head in October 2009 with the downgrade of Greek creditworthiness and then intensified further. Third, the global spread of the coronavirus from the spring of 2020 onwards and the Russian war of aggression against Ukraine which began in February 2022 have been weighing on the global economic outlook. In each of the affected currency areas, the crises led central banks to recalibrate their monetary policy at different points in time and thus asymmetrically. This was reflected in changing interest rate differentials. In the academic literature, the interest rate differential "breathing" in this manner is usually cited as an important cause of exchange rate fluctuations.

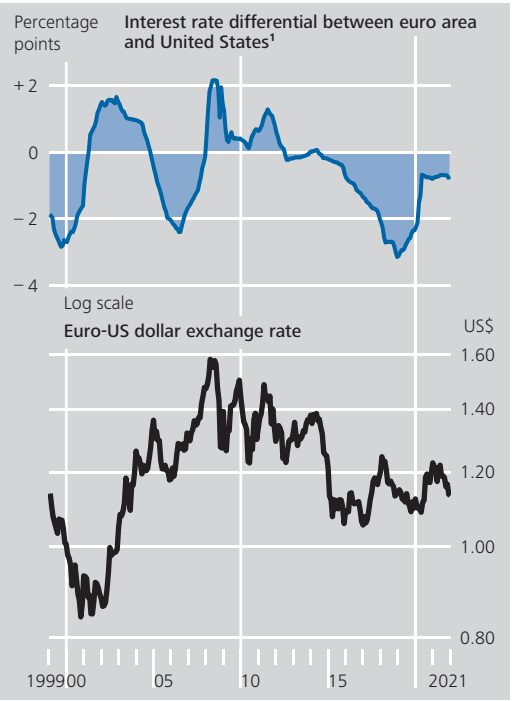
Covered interest parity and euro-US dollar exchange rate

Covered interest parity in theory

According to the covered interest parity theory, under the assumptions of an efficient foreign exchange market, the interest income from a US dollar investment should match that from an equivalent euro investment plus the rate of change of the euro expected in the forward market.[6] This rate of change in the exchange rate expected in the forward market is referred to as the swap rate and is derived from the difference between the forward and spot quotation of the euro-US dollar exchange rate based on the spot rate.[7] As the forward rate is already fixed today, there is no exchange rate risk. The difference between euro area and US interest rates plus the swap rate is referred to as the basis or the cross-currency basis. If covered interest parity exists, this basis should be close to zero. If this is not the case, the theory suggests there is a possibility of generating safe

Interest rate differential and exchange rate

Monthly averages



Sources: ECB, Refinitiv and Bundesbank calculations. **1** Euro LIBOR minus US dollar LIBOR; annualised; three-month maturity.
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6 In such a formulation, it is assumed that no risk premia are demanded that can also be reflected in the forward rate. The prerequisites for an efficient foreign exchange market include free movement of capital, no transaction costs, rational actors, information efficiency and complete market transparency.
7 In the case of an interest rate differential that is formed from US interest rates minus euro interest rates, the forward and spot rates are quoted in US dollars per euro.

(arbitrage) profits from the interest rate differentials. However, since safe profits should be excluded, deviations from covered interest parity are generally a phenomenon that requires a specific economic explanation.

An example by way of illustration

The following example is provided as an illustration. Let us assume there is an interest rate advantage for the United States. An interest rate arbitrageur borrows in euro at the lower interest rate in the euro area, exchanges the borrowed amount for US dollars on the spot market and invests it in a US dollar investment with the same maturity as the loan. At the same time, the arbitrageur hedges against the exchange rate risks and sells the repayment amount of the US dollar investment that will mature in the future against the euro on the forward market today. If the swap rate of the euro-US dollar exchange rate is positive when the contract is concluded, the euro trades more strongly on the forward market than on the spot market (forward price premium). Under these circumstances, the arbitrageur accepts an exchange rate loss (that is already known to them today) when the US dollar investment amount is exchanged back. Where there is covered interest parity, this exchange rate loss that is associated with the hedging transaction more or less compensates for the US interest rate advantage.

However, if there is no covered interest parity and the exchange rate loss associated with the hedging transaction when the US dollar investment amount is exchanged back is smaller, for example, than the US interest rate advantage, the model states that the credit-financed US dollar investment will create a risk-free profit opportunity. The weaker the euro is in the forward market, the greater the profit. By contrast, the credit-financed foreign investment would make a loss if the forward price premium for the euro and the resulting price hedging costs were greater than the interest rate differential.

Up until the onset of the global financial crisis, the swap rate approximately compensated for the differences in money market rates between the currency areas. As mentioned above, after taking transaction costs into account, the observed deviations from covered interest parity pointed to data imperfections rather than to market inefficiencies, and were negligible, all in all. During the course of 2008, however, a relatively large deviation emerged. In the money markets, US dollar interest rates based on the LIBOR rate fell below the corresponding interest rates in the euro area without the swap rate simultaneously taking a negative value, thus compensating for the change in the interest rate differential.[8] A deviation from covered interest parity arose (in this case, a negative dollar basis) which, with the opposite sign, corresponds to a positive euro basis.[9]

Covered interest parity deviations during and after the financial crisis significant, …

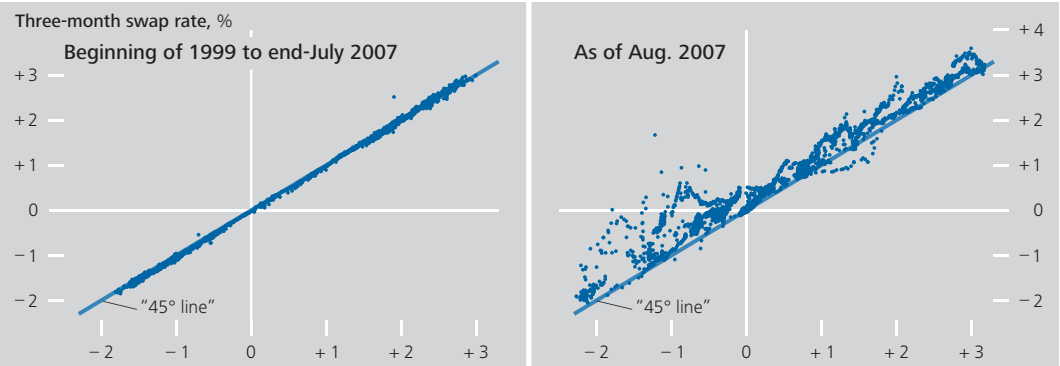
In September 2008, following the bankruptcy of the US investment bank Lehman Brothers, a positive swap rate even came into effect in the short term, although the interest rate differential between the United States and the euro area remained negative. Thus, the forward exchange rate of the euro against the US dollar rose above the spot rate; the forward markets priced in an appreciation of the euro. An investment in the euro area was therefore doubly lucrative, owing both to the interest rate advantage in the euro area and to the forward price premium of the euro. The covered interest parity deviation increased and peaked at 289 basis points annualised in terms of three-month money and expressed as a euro basis. A similar reaction was observed during the intensification of the euro area sovereign debt crises in November 2011, when the euro basis rose to as high as an annualised 149 basis points. Although it gradually decreased again until mid-2014, there were also longer-lasting deviations from covered interest parity despite relatively calm market phases in the time that followed.

In recent years, however, such covered interest parity deviations have remained comparatively

8 For information on the use of LIBOR for the analysis of covered interest parity, see footnote 5 on p. 48.
9 For more information, see the box on pp. 52 ff.

Covered interest parity between the United States and the euro area*

Annualised daily data, 4 Jan. 1999 to 31 Dec. 2021



Sources: Refinitiv and Bundesbank calculations. * A single dot indicates the ratio calculated from exchange rates and interest rates for a given trading day. When covered interest parity holds, the dots should be close to the 45° line shown in the chart. Dots above the 45° line denote a positive euro basis against the US dollar. **1** US dollar LIBOR minus euro LIBOR.

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… but relatively small in recent years

small. For example, the euro basis expanded once again as the coronavirus spread worldwide from March 2020 onwards, but peaked at no higher than 75 basis points before declining again in the second half of March. This was partly due to coordinated action by the Eurosystem and the Fed as well as the central banks of Canada, the United Kingdom, Japan and Switzerland, which had agreed on additional measures to strengthen the provision of US dollar liquidity.[10] This supported the euro against the US dollar in the spot market, reducing the existing forward price premium of the euro and the underlying expectation of appreciation.

Russia's war of aggression against Ukraine has had relatively little impact on deviations from the covered interest parity of the euro. Since February 2022, the interest rate differential between three-month LIBOR for the US dollar and three-month EURIBOR has widened. This is largely attributable to expectations of a faster monetary policy normalisation in the United States than in the euro area, which has grown further in intensity on the back of the Ukraine war. At the same time, however, the forward market has experienced a positive swap rate, which means that the euro has been trading more strongly on the maturity date of the forward contract. As a result, the euro basis has hardly reacted to the war in Ukraine.

Even recently, although fragmentation risks have been discussed in the euro area and the ECB Governing Council in July 2022 approved, against this background, the establishment of an instrument to protect monetary policy transmission (Transmission Protection Instrument, TPI),[11] the euro basis has remained at a comparatively low level.[12]

10 As part of this coordinated move, it was agreed that in order to enhance the provision of US dollar liquidity, US dollar swaps with a seven-day maturity would no longer be offered only weekly, as hitherto, but on a daily basis. This evidently alleviated market participants' concerns regarding providing the banking system with US dollar liquidity and the prospect of a shortage of US currency. The hitherto negative dollar basis of the euro, the yen and the Swiss franc, which is an indicator of tension in the foreign exchange market, subsequently declined rapidly and the high level of exchange rate volatility fell markedly. The measure therefore helped calm the market.

11 "Subject to fulfilling established criteria, the Eurosystem will be able to make secondary market purchases of securities issued in jurisdictions experiencing a deterioration in financing conditions not warranted by country-specific fundamentals, to counter risks to the transmission mechanism to the extent necessary." See European Central Bank (2022).

12 EURIBOR has been used to calculate the euro basis as of 2022 because LIBOR values for the euro were no longer made available after 31 December 2021. In the past, the three-month EURIBOR for the euro was closely correlated with LIBOR. A comparison with the aforementioned crises is therefore generally possible, but should be interpreted with caution, subject to differences in datasets.

On the interpretation of the dollar or euro basis

According to the covered interest parity theory, the returns on a domestic investment and a foreign investment hedged by a forward transaction are equal. International interest rate differentials on the money market are thus roughly offset by the swap rate, i.e. the percentage deviation of the forward rate from the current spot rate in relation to this spot rate. If this is not the case, there are risk-free profit opportunities (if transaction costs are disregarded), which would theoretically be directly reduced by interest rate arbitrage. Where i_t denotes the domestic interest rate, i_t^* the foreign interest rate for money market loans or investments with a maturity of k periods, t the investment date, $t+k$ the repayment date, $w_{t,t+k}^T$ the forward rate agreed at time t for $t+k$ and w_t^K the exchange rate on the spot market, each expressed in foreign currency units per domestic currency unit, the equilibrium condition of covered interest parity, where arbitrage gains are not possible, is approximately:[1]

$$(1) \quad i_t + \frac{w_{t,t+k}^T - w_t^K}{w_t^K} = i_t^*$$

In contrast to theory, however, longer-lasting deviations from covered interest parity have been observed empirically since 2007. In the extensive literature on this topic, this deviation is generally referred to as a basis, or more specifically the cross-currency basis. The cross-currency basis is a dimensionless variable expressed in percentage points. How it is formulated depends on the choice of reference currency. The literature mostly looks at the cross-currency basis of the US dollar. If the partner currency is the euro, the cross-currency basis of the US dollar (the dollar basis) can be written as follows:

$$(2) \quad dollar\ basis_t^{euro} = \underbrace{i_t^{dollar}}_{\substack{costs\ of\ direct \\ US\ dollar\ financing}} - \underbrace{\left(i_t^{euro} + \frac{w_{t,t+k}^{euro\ T} - w_t^{euro\ K}}{w_t^{euro\ K}} \right)}_{\substack{costs\ of\ synthetic \\ US\ dollar\ financing}}$$

The exchange rate w^{euro} is defined here in units of US dollar per euro.[2] The academic literature on this topic focuses in particular on the frequently observed phenomenon of a negative dollar basis. The dollar basis can be interpreted as the difference between direct US dollar financing and "synthetic" US dollar financing.[3] The difference between these two financing options played a role in the financial crisis, when foreign commercial banks were no longer able to directly refinance their US dollar-denominated liabilities via US dollar loans in

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1 The no-arbitrage condition can be derived as follows: an interest rate arbitrageur receives a safe return of $(1+i)$ for a certain investment amount A expressed in domestic currency and invested domestically. If, instead, the arbitrageur were to invest investment amount A abroad, they would first have to convert it into foreign currency units on the spot market. The return on the alternative foreign investment in foreign currency is therefore $[(1+i^*) \cdot w_t^K]\ A$. It is assumed that the interest rate arbitrageur hedges against exchange rate risks on the forward market; they sell the income from foreign investment expressed in foreign currency at t in a forward transaction $t+k$ at the forward exchange rate $1/w_{t,t+k}^T$ for domestic currency and receive $[(1+i^*) \cdot w_t^K/w_{t,t+k}^T]\ A$. The risk-neutral interest rate arbitrageur is indifferent to investing domestically versus investing abroad if the yields from the investments are equal. This condition is met if $(1+i)\ A = [(1+i^*) \cdot w_t^K/w_{t,t+k}^T]\ A$ or equivalent $(1+i) \cdot w_{t,t+k}^T/w_t^K = (1+i^*)$ and $((1+i^*) - (1+i))/(1+i) = (w_{t,t+k}^T - w_t^K)/w_t^K$ or $(i^*-i)/(1+i) = (w_{t,t+k}^T - w_t^K)/w_t^K$. If i is relatively small, the literature approximates $1+i \approx 1$ or $i^*-i \approx (w_{t,t+k}^T - w_t^K)/w_t^K$.

2 In order to improve comparability, the quantity quotation of the euro has been retained here, contrary to what is often the case in the literature.

3 A negative dollar basis means the cost of direct US dollar financing is lower than the cost of synthetic US dollar financing. At the same time, from the perspective of an investor from the United States, the yield on a money market investment in the euro area is higher than that on a comparable investment in the United States.

the US interbank market (direct US dollar financing).[4] Instead, they relied on synthetic financing. This is where a loan is taken out in a currency other than the US dollar, i.e. in euro, for example, and then exchanged for US dollars. At the time of transaction t, the loan amount denominated in euro is sold against US dollars using a swap transaction at the then-valid spot rate $w^{euro\ K}$ and at the same time bought back at the forward exchange rate $w^{euro\ T}$ agreed today for the end of the term $t+k$. The dollar basis of the euro as the difference between the money market rates in the United States, i^{dollar}, and the sum of the money market rate in the euro area, i^{euro}, and the swap rate exactly corresponds to the difference between the two types of financing described. The cost of synthetic dollar financing is higher than the euro interest rate, i^{euro}, only if the forward exchange rate of the euro is traded at a mark-up against the spot price, i.e. where $w^{euro\ T} > w^{euro\ K}$. A negative dollar basis implies that the cost of direct US dollar financing is lower than the cost of synthetic US dollar financing. At the same time, from the perspective of an investor from the United States, the yield on a money market investment in the United States is lower than that of a comparable investment in the single currency area.

This report looks at the euro basis instead of the dollar basis. The euro basis corresponds exactly to the US dollar basis with the sign inverted.[5]

(3) $$euro\ basis_t^{dollar} = \underbrace{i_t^{euro}}_{\substack{costs\ of\ direct\\ euro\ financing}} - \underbrace{\left(i_t^{dollar} - \frac{w_{t,t+k}^{euro\ T} - w_t^{euro\ K}}{w_t^{euro\ K}} \right)}_{\substack{costs\ of\ synthetic\\ euro\ financing}} = -dollar\ basis_t^{euro}$$

Transaction costs have not been taken into account in previous analyses of the cross-currency basis. The equations assume that it is possible to buy and sell at the same rate. In fact, however, two rates are usually quoted in the financial markets. First, the bid rate, i.e. the price at which a currency can be sold from an arbitrageur's perspective. Second, the ask rate, at which it can be purchased from an arbitrageur's perspective. The bid rate is, in this case, below the ask rate.[6] In the case of synthetic euro financing, which an interest rate arbitrageur would use when the euro basis is positive, the relevant factors are the euro ask rate (purchase of euro today, i.e. at t) for the spot transaction described above and the euro bid rate (sale of euro at the forward rate known today, i.e. at t, at time $t+k$) for the forward transaction.[7] If the conditional equation for the cross-currency basis of the euro (3) is corrected by the transaction costs resulting from the bid-ask spread, the fol-

4 See also pp. 56.
5 If the euro basis is positive, the cost of direct euro financing is higher than the cost of synthetic euro financing.
6 From an arbitrageur's perspective, under these circumstances, buying and selling the euro at the same time entails a loss that usually represents the transaction costs.
7 In the case of synthetic euro financing, a US dollar loan is taken out in the US money market at the favourable US interest rate i_t^{dollar}. The US dollar loan amount is exchanged for euro on the spot market. This means that the arbitrageur purchases euro today, i.e. at t, on the spot market at the ask rate $w(ask)_t^{euro\ K}$. In order to be able to repay the US dollar loan amount at maturity $t+k$, without exchange rate risks, the arbitrageur sells the euro amount set to be freed up at $t+k$ in a forward transaction at the bid rate $w(bid)_{t,t+k}^{euro\ T}$ known at t.

Euro basis and transaction costs

Basis points, monthly averages

Source: Refinitiv. **1** Euro basis calculated using money market rates (three-month LIBOR). **2** Transaction costs derived from the bid-ask spread.

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lowing is true in the case of synthetic euro financing:[8,9]

$$(4)\quad euro\ basis_t^{dollar} = i_t^{euro} - \Bigg(i_t^{dollar} - \frac{w_{t,t+k}^{euro\ T} - w_t^{euro\ K}}{w_t^{euro\ K}} \underbrace{- \frac{w(bid)_{t,t+k}^{euro\ T}}{w(ask)_t^{euro\ K}} + \frac{w_{t,t+k}^{euro\ T}}{w_t^{euro\ K}}}_{correction\ factor} \Bigg)$$

As the correction factor of synthetic euro financing is positive,[10] the costs of synthetic euro financing on the basis of the actual bid and ask rates are higher than those shown in the (uncorrected) cross-currency basis. The positive, unadjusted euro basis is therefore reported as too high.[11]

Transaction costs, which are reflected in bid-ask spreads, mean that the uncorrected cross-currency basis overestimates arbitrage opportunities. A necessary but insufficient condition for arbitrage is that the uncorrected cross-currency basis is higher in terms of value than the transaction costs captured in the correction factor. This was indeed the case when the euro basis expanded markedly against the US dollar during the crises and between 2015 and 2020. The observed deviations from covered interest parity can therefore only be explained to a small extent by the bid-ask spread.

8 The correction consists of replacing the swap rate on the basis of mid-market rates with the swap rate on the basis of euro ask-spot and bid-forward rates. The euro basis (equation (3)) is thus: $euro\ basis_t^{dollar} = i_t^{euro} - i_t^{dollar} + (w(bid)_{t,t+k}^{euro\ T} - w(ask)_t^{euro\ K})/w(ask)_t^{euro\ K}$. Reformulation produces: $euro\ basis_t^{dollar} = i_t^{euro} - i_t^{dollar} + (w(bid)_{t,t+k}^{euro\ T}/w(ask)_t^{euro\ K} - 1)$. 1 can be replaced by the expression $-(w_{t,t+k}^{euro\ T} - w_t^{euro\ K})/w_t^{euro\ K} + w_{t,t+k}^{euro\ T}/w_t^{euro\ K}$. Taking into account the relevant bid and ask rates, the euro basis is therefore: $euro\ basis_t^{dollar} = i_t^{euro} - i_t^{dollar} + w(bid)_{t,t+k}^{euro\ T}/w(ask)_t^{euro\ K} + (w_{t,t+k}^{euro\ T} - w_t^{euro\ K})/w_t^{euro\ K} - w_{t,t+k}^{euro\ T}/w_t^{euro\ K}$. Finally, reformulation produces equation (4). For information on the importance of the spread between bid and ask rates in the event of deviations from covered interest parity due to a decline in market liquidity, see Borio et al. (2016b), pp. 48-49.

9 If the euro basis were negative, the foreign exchange trader would, by contrast, sell euro on the spot market and buy it back on the forward market. In these circumstances, the selling price of the euro (bid rate) would be relevant for spot transactions and the purchase price of the euro (ask rate) would be relevant for forward transactions.

10 The correction item is positive because the mid-market rate (w) is lower than the ask rate and higher than the bid rate.

11 The bid and ask rates differ for money market instruments, too, although this is not taken into account in the above equation. If these transaction costs were also taken into account, the correction factor would be even greater.

Causes of uncovered interest parity deviations

Risk premia, the resulting liquidity bottlenecks in foreign currencies, additional regulatory provisions for banks and unilateral monetary policy easing measures are cited in the academic literature as possible causes of a violation of covered interest parity. The aforementioned reasons either contribute to a shift in the demand for exchange rate hedging[13] or to a reduction in arbitrage opportunities.

The US dollar often appreciates in times of crisis, as it is considered particularly safe

In times of crisis, investors often weight their portfolios more heavily in favour of US dollar-denominated securities because these investments are considered to be particularly safe. As a result, the euro and other major currencies frequently trade weaker against the US dollar on the spot market.[14] Empirical evidence shows that a positive euro basis can build up in such times. This is because, in these cases, risk and market players' aversion to risk increase so sharply that trading activity, which could exploit profit opportunities, decreases or even dries up completely.

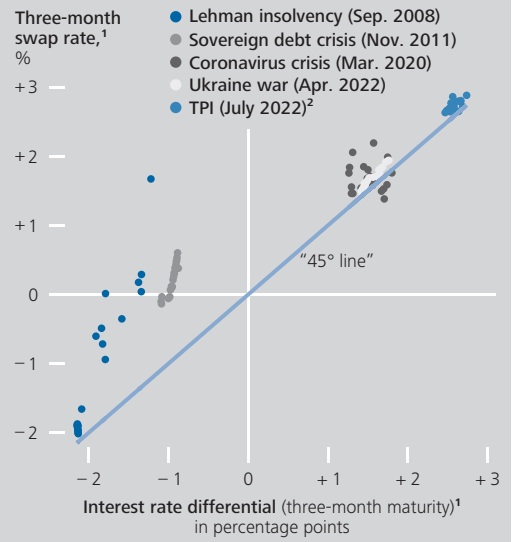
At the same time, risk premia build up

This is mainly due to credit risk. With covered interest arbitrage, arbitrageurs do hedge against exchange rate risk. However, the risk of a counterparty defaulting is not covered. In such a case, the profit opportunities resulting from a covered interest parity deviation are therefore not risk-free. If interest rate arbitrageurs are risk-averse and institutions in the different currency areas are affected by a default risk to varying degrees, the relatively safer counterparty demands a premium for assuming the relative counterparty risk. This premium is likely to be high, especially in times of crisis, and it is reflected in a deviation from covered interest parity. The amount of the premium is influenced, in particular, by market participants' attitude to risk and the level of the assumed relative counterparty risk.

The relevant literature often uses the Cboe Volatility Index (VIX) of the S&P 500 stock index as an important measure of general risk appetite in the financial markets.[15] A more specific measure of counterparty risk is the LIBOR-OIS spread. Unlike LIBOR, the rate at which banks provide each other with unsecured loans on average, the overnight index swap (OIS) involves only the difference between the interest payments owed to each other being exchanged. The OIS therefore entails a comparatively low credit risk. For this reason, the literature uses the LIBOR-OIS spread for the euro to approximate the systemic risk of euro area counterparties defaulting.[16] Empirically, it can be observed that, especially in times of crisis,

Covered interest parity between the United States and the euro area in crisis periods*

Annualised daily data



Sources: Refinitiv and Bundesbank calculations. * A single dot indicates the ratio calculated from exchange rates and interest rates for a given trading day. When covered interest parity holds, the dots should be close to the 45° line. **1** Until end-2021 LIBOR rates for three-month money market funds; from 2022 LIBOR rates for the United States and EURIBOR rates for the euro area. **2** The ECB Governing Council approved the Transmission Protection Instrument (TPI) on 21 July 2022.

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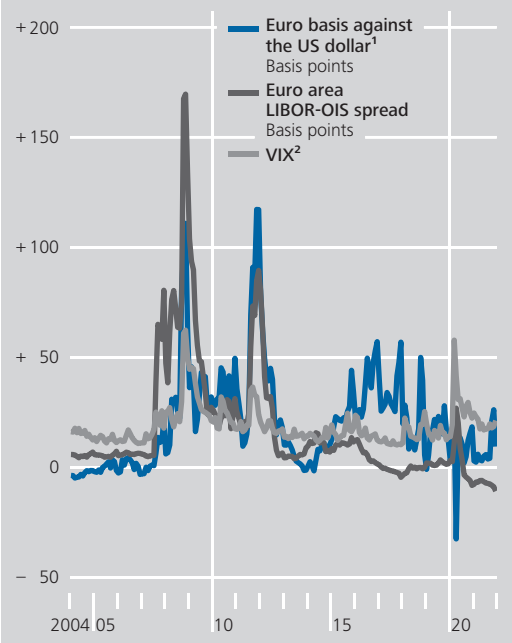
13 See Abbassi and Bräuning (2021).
14 For a more in-depth analysis of the relevant relationships, see Deutsche Bundesbank (2014). On the basis of the empirical results contained therein, the Swiss franc can be described as a safe haven currency in addition to the US dollar.
15 The VIX is calculated and published in real time by the Chicago Board Options Exchange (Cboe). Although it refers to the US stock market, it is also often deployed as a general measure of global uncertainty. See Scheicher (2003).
16 See, for example, Borio et al. (2016b).

Euro basis against the US dollar, euro area LIBOR-OIS spread and volatility index

Monthly averages



Sources: Refinitiv and Bundesbank calculations. **1** Euro basis calculated from money market rates (three-month LIBOR). **2** Cboe Volatility Index derived from the S&P 500 index.

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the VIX and LIBOR-OIS spreads have a positive relationship with the euro basis against the US dollar. All three variables often rise markedly in times of financial turmoil.[17]

Our own econometric estimates point to the importance of relative counterparty risk in the banking sector when explaining the euro basis against the US dollar.[18] They show that investors taking counterparty risk into consideration when financial markets are strained can be one reason for the covered interest parity deviations that have been identified.

Shortage of US dollars forces players to turn to indirect dollar financing

As a result of the sharp loss of confidence in the interbank sector from mid-September 2008 onwards, some players apparently withdrew from those markets that are important for interest rate arbitrage during this period. A US dollar shortage ensued in the sense that European banks were no longer able to refinance their US dollar-denominated loans – raised, for example, to invest in the US mortgage market – through the US interbank market. Since dollar financing through US commercial banks almost came to a standstill at that time, European banks began to finance their dollar liabilities indirectly by entering a swap. To do so, they were able to obtain euro loans from the Eurosystem, which they transferred in US dollars via a foreign exchange swap with other commercial banks. This increased demand for foreign exchange swaps, where euros were sold against US dollars on the spot market and bought back in a forward transaction. As demand for foreign exchange swaps was largely one-sided because US banks were not willing to offer the necessary offsetting transactions at the given exchange rates owing to the high perceived counterparty risk, a forward price premium for the euro built up.[19] This resulted in the aforementioned covered interest parity deviations of up to 289 basis points, which represented a significant increase in the price of indirect dollar financing.

Unlimited swap lines eliminated foreign currency shortage

The establishment of unlimited US dollar swap lines between the Fed and the ECB as well as other central banks as of 13 October 2008 made it possible for banks outside the United States to obtain US dollar funding via their na-

17 See Schlegel and Weiss (2017).
18 See the box on pp. 57 ff.
19 See Baba and Packer (2009). The study concludes that, after the onset of the financial market turmoil, swap rates reflected relative counterparty risks in the period from 9 August 2007 to 12 September 2008. In addition, it comes to the conclusion that "[a]fter the failure of Lehman Brothers in September 2008, deviations from covered interest parity (CIP) were negatively associated with the creditworthiness of US financial institutions (as well as that of European institutions), consistent with the deepening of a dollar liquidity problem into a global phenomenon. US dollar term funding auctions by the ECB, SNB, and BoE, as well as the US Federal Reserve commitment to provide unlimited dollar swap lines are found to have ameliorated the FX swap market dislocations." For data availability reasons, the sample period of our own econometric study does not begin until October 2008, meaning that the effect of the US dollar shortage, which pushed the euro basis against the US dollar to a record level at the end of September and was eliminated by the unlimited swap lines in mid-October, plays only a minor role.

Empirically testing the validity of uncovered and covered interest parity

The validity of uncovered and covered interest parity can be tested using econometric methods.[1] The estimations for different periods and currency pairs presented below are based on data for the period from the beginning of 1999 to the end of 2021.[2]

Uncovered interest parity

To test the validity of uncovered interest parity between the euro area and four other currency areas, the United States (US), the United Kingdom (UK), Japan (JP) and Switzerland (CH), the econometric equation

$$ln(w_{t+k}^K) - ln(w_t^K) = \alpha_0 + \alpha_1(i_{k,t}^* - i_{k,t}) + \varepsilon_{t+k}$$

is estimated for the respective currency pairs using the least squares estimator.

Here, w_t^K denotes the spot rate in quantity quotation (units of foreign currency per euro) at time t, w_{t+k}^K the same rate at time $t+k$, $i_{k,t}$ the interest rate on three-month money market funds in the euro area and $i_{k,t}^*$ the same rate abroad (US, UK, JP and CH). Since the interest instruments have a maturity of three months, the exchange rate change is calculated over the same period.[3] The parameter k is set to 90 calendar days.[4] In order to avoid inherent overlaps in the dependent variables resulting from the use of daily data, only the respective end-of-quarter values are used in the estimations. The estimation results are consistent with uncovered interest parity if the common null hypothesis $\alpha_0 = 0$ and $\alpha_1 = 1$ is not rejected at a given significance level.

The following compares results for three different samples: the first runs from the establishment of monetary union (the first quarter of 1999) up to but not including the outbreak of the financial crisis (the first quarter of 2007),[5] the second runs from the outbreak of the global financial crisis (the third quarter of 2007) to the fourth quarter of 2021, and the third covers both samples, i.e. the first quarter of 1999 to the fourth quarter of 2021. The full sample was subdivided in order to see whether the relationship between the exchange rate change and the interest rate differential might have altered.

The table on p. 58 shows the estimation results for the various samples and currency areas. It includes the point estimates for the constant α_0 and the slope coefficient α_1, their individual statistical significance and also the results of an F-test, which is used to test the validity of the aforementioned null hypothesis implied by uncovered interest parity.

While the validity of uncovered interest rate parity for the pre global financial crisis sample must be rejected at a 5% significance level for all four currency pairs, its validity in the post global financial crisis sample is now rejected at the same significance level

1 For more information on the theoretical foundations of the econometric methods presented, see Deutsche Bundesbank (2005).
2 Data sources: Refinitiv and Bundesbank calculations.
3 As the interest rate on three-month money market funds is expressed as a percentage per annum, the dependent variable has been multiplied by a factor of 400 so that the rate of change is also expressed as a percentage per annum.
4 If no value is available for the exchange rate at either time t or time t+90, the corresponding observations are excluded from the estimations.
5 As the value of the exchange rate from the following quarter is used in the calculation of the dependent variables, this sample already ends two quarters before the outbreak of the financial crisis.

Estimation results for uncovered interest parity*

Item	USA	UK	Japan	Switzerland
Full sample (Q1 1999 to Q4 2021)				
Constant	0.57	0.19	0.37	–3.91
Slopes	–1.53	0.59	0.30	–2.16
p-value ($H_0: \alpha_0 = 0$ and $\alpha_1 = 1$)	0.18	0.97	0.79	0.22
Pre global financial crisis (Q1 1999 to Q1 2007)				
Constant	4.78*	5.72	–7.90	–9.82**
Slopes	–4.95***	–3.78	–3.56	–6.52**
p-value ($H_0: \alpha_0 = 0$ and $\alpha_1 = 1$)	0.00(***)	0.04(**)	0.05(**)	0.00(***)
Post global financial crisis (Q3 2007 to Q4 2021)				
Constant	–2.37	–4.54*	0.20	–2.94
Slopes	1.29	11.08**	4.01***	0.41
p-value ($H_0: \alpha_0 = 0$ and $\alpha_1 = 1$)	0.60	0.09(*)	0.04(**)	0.11

* The econometric models were estimated using least squares regressions, with Newey-West standard errors being applied to account for potential heteroscedasticity and autocorrelation of the residuals. A p-value of less than 0.01 (***), 0.05 (**) or 0.10 (*) in the bottom row of the respective estimation period-specific table section implies rejection of the null hypothesis, i.e. validity of uncovered interest parity, at a significance level of 1%, 5% and 10%, respectively, for the corresponding period.

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only for the yen.[6] These results should be interpreted with caution due to relatively low estimation accuracy and unstable parameter values.[7] It is noticeable, however, that the estimated slope coefficients in the more recent sample are significantly higher than those in the pre financial crisis sample and now all have a positive sign; in the earlier sample, their signs were still consistently estimated to be negative. The results imply that since the global financial crisis – in contrast to beforehand – it has tended to be the currency in which the higher-interest investment is denominated that depreciates over the investment period. Despite the low estimation accuracy, it can therefore be concluded that the empirical evidence for the post financial crisis sample – when taken as a whole – is more in line with uncovered interest parity than is the case for the earlier sample running from the establishment of European monetary union to the outbreak of the financial crisis.

Covered interest parity

The following econometric equation (which is broadly similar to the above approach) is estimated in order to test the validity of covered interest parity:

$$ln(w^T_{t,t+k}) - ln(w^K_t) = \beta_0 + \beta_1(i^*_{k,t} - i_{k,t}) + v_t$$

This estimation uses all available daily data and not just the end-of-quarter values, as the forward rate $w^T_{t,t+k}$ (unlike the exchange rate 90 calendar days later) is already known at time t, meaning that no information is included in the estimation that is not yet available at time t.[8] Newey-West standard errors are again used to control for autocorrelated residuals. If the common null hypothesis $\beta_0 = 0$ and $\beta_1 = 1$ cannot be rejected, this indicates the validity of covered interest parity.

Based on the results of the F-tests, covered interest parity is clearly rejected for both the pre and post financial crisis samples. This may come as a surprise initially, given that

6 If a significance level of 10% is assumed, the validity of uncovered interest parity must be rejected in the more recent sample for the pound sterling as well.
7 The low estimation accuracy is revealed in the large (in absolute terms) standard errors. Rolling estimations point to a comparatively high degree of instability in the parameters, including within the respective samples.
8 In order for the dependent variable (forward price premium) to be expressed as a percentage per annum like the explanatory variable (international interest rate differential of three-month money market funds), the former was multiplied again by a factor of 400 before the estimations were carried out.

Estimation results for covered interest parity*

Item	USA	UK	Japan	Switzerland
Full sample (1 Jan. 1999 to 31 Dec. 2021)				
Constant	0.16***	0.12*	–0.05	–0.04*
Slopes	0.97***	0.90***	0.99***	0.97***
p-value ($H_0 : \beta_0 = 0$ and $\beta_1 = 1$)	0.00(***)	0.00(***)	0.23	0.10
Pre global financial crisis (1 Jan. 1999 to 31 July 2007)				
Constant	–0.03***	–0.11***	–0.13***	–0.01
Slopes	1.01***	1.01***	0.98***	1.01***
p-value ($H_0 : \beta_0 = 0$ and $\beta_1 = 1$)	0.00(***)	0.00(***)	0.00(***)	0.00(***)
Post global financial crisis (1 Aug. 2007 to 31 Dec. 2021)				
Constant	0.28***	0.15	–0.04	–0.07***
Slopes	0.94***	0.89***	0.92***	0.88***
p-value ($H_0 : \beta_0 = 0$ and $\beta_1 = 1$)	0.00(***)	0.02(**)	0.01(***)	0.00(***)

* The econometric models were estimated using least squares regressions, with Newey-West standard errors being applied to account for potential heteroscedasticity and autocorrelation of the residuals. A p-value of less than 0.01 (***), 0.05 (**) or 0.10 (*) in the bottom row of the respective estimation period-specific table section implies rejection of the null hypothesis, i.e. validity of covered interest parity, at a significance level of 1%, 5% and 10%, respectively, for the corresponding period.

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the point estimates – when compared with those for uncovered interest parity – are very close to the postulated values for the parameters. However, the estimation accuracy is much higher for these estimations than for the estimations of uncovered interest parity, which increases the discriminatory power of the tests and leads to the null hypothesis being rejected if the estimated coefficients deviate even slightly from the postulated values. Notwithstanding the qualitatively unchanged test results, these figures show that the estimated values – in particular for the slope coefficients – for the post global financial crisis sample and for every currency pair differ much more than before from the values that are in line with covered interest parity.

Therefore, a further simple econometric analysis was conducted to examine the impact of some of the explanatory variables described in this article on the euro basis against the US dollar, which denotes the difference between euro area and US money market rates plus the euro-US dollar swap rate.[9] The analysis is complicated by the fact that data are not available for all explanatory variables over the full sample and that some of the various explanatory variables are themselves closely empirically related. Both factors influence the statistical inference. The estimated econometric model is:

$$
\begin{aligned}
euro\ basis_t^{dollar} = \\
&\gamma_0 + \gamma_1 (LIBOR_t^{euro} - OIS_t^{euro}) \\
&+ \gamma_2 (LIBOR_t^{dollar} - OIS_t^{dollar}) \\
&+ \gamma_3 (deposit_t^{euro} - LIBOR_t^{euro}) \\
&+ \gamma_4 (deposit_t^{dollar} - LIBOR_t^{dollar}) \\
&+ \gamma_5 BaselIII_t + \zeta_t
\end{aligned}
$$

The explanatory variables are the LIBOR-OIS spreads in the euro area and the United States, the IOER-LIBOR spreads in the two currency areas and a Basel III dummy.[10] As shown on pp. 56/57 and 62, the LIBOR-OIS spreads are intended to approximate coun-

9 For reasons of consistency with the previous estimations, the euro basis was also calculated in the following empirical analysis on the basis of the logarithmic forward and spot exchange rates. However, this has little impact on the estimation results.

10 In the literature, such equations are usually estimated in first differences, as often the non-stationarity of the basis cannot be rejected. However, as this is not the case for the currency pair and three-month maturity examined here, the estimation can be conducted with data in levels. This approach is also consistent with Borio et al. (2018), according to which the basis for three-month money market funds is stationary, whereas in the case of longer maturities it is usually necessary to assume non-stationarity. Nevertheless, this series also shows some persistence.

Estimation results for the euro basis against the US dollar*

Item	Estimated coefficient
Constant	14.81**
LIBOR-OIS spread euro	117.64***
LIBOR-OIS spread dollar	–67.10**
Deposit-LIBOR euro	11.14
Deposit-LIBOR dollar	–17.34
Basel III	16.54*
Coefficient of determination (R^2)	0.56

* The basis is expressed in basis points. The model was estimated using a least squares regression, with Newey-West standard errors being applied to account for potential heteroscedasticity and autocorrelation of the residuals. ***, ** and * denote coefficients which, at a significance level of 1%, 5% and 10%, are statistically different from 0. Owing to data availability constraints, the estimation period was reduced somewhat compared with the previous estimates to 14 October 2008 to 31 December 2021.

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terparty risk and the IOER-LIBOR spreads are intended to approximate the minimum limit for the cost of equity in the respective currency areas. IOER (interest rate on excess reserves) is the interest rate paid to commercial banks for excess reserves at the central bank. The Basel III dummy has a value of 1 as of 2015, before which it is equal to 0. This is a simple way of controlling for regulatory changes in connection with the implementation of the Basel III decisions.[11]

The estimated coefficients in the above table all show the expected signs.[12] However, only the coefficients of the LIBOR-OIS spreads and those of the Basel III dummy are also statistically significant. The insignificance of the other parameters could, however, be due to the high correlation between the corresponding variables and the spread variables already contained in the model.[13] The econometric estimates identify relative systemic counterparty risk in particular as an important factor in explaining the euro basis against the US dollar. In addition, they suggest that the stricter regulatory rules in the banking sector also have an impact on the level of deviations from covered interest parity.[14]

11 See also Du et al. (2018), in which an equivalently coded dummy variable is used to model the potential effect on the dollar basis of the introduction in 2015 of the leverage ratio. Its statistical significance supports the hypothesis that the leverage ratio introduced in 2015 is a factor in arbitrage considerations.
12 Interest rate spreads have been added to the model separately for both currency areas and not in relation to each other, as it is not necessarily possible to assume that the euro basis against the US dollar will respond symmetrically to changes in the corresponding variables in the United States and the euro area.
13 Adding more explanatory variables, such as the VIX volatility index, would further exacerbate the multicollinearity problem, as this variable and the LIBOR-OIS spreads are likewise closely linearly related.
14 The marginal significance level of the Basel III indicator variable is 0.06. It is thus slightly above the 5% significance level but clearly below the 10% significance level.

tional central banks.[20] The swap agreement enabled the central banks to provide domestic banks with unlimited quantities of US dollars without having to use their foreign reserves.[21] As a result, the US dollar shortage and, in turn, the deviations from covered interest parity receded again, to begin with.[22]

Significant and persistent deviations from covered interest parity possible even outside times of crisis, …

However, the explanations provided so far are less able to explain why, since the end of 2014, there have been repeated instances of noticeable and persistent deviations from covered interest parity, including in periods of market calm. Researchers from the Bank for International Settlements (BIS) provide a possible explanation.[23] According to their studies, two necessary conditions must be met for such deviations to occur outside times of crisis. First, there needs to be imbalanced and relatively price-inelastic demand for hedging FX risk – for example, FX hedging demand for US dollars against the euro. In this example, this led to market pressure towards a positive euro basis. Second, there must be reasons why seemingly risk-free arbitrage does not occur as soon as the basis begins to widen.

… if two conditions are met

According to the studies mentioned, the relatively price-inelastic demand for hedging from the various market participants is key to a positive basis in terms of size. Thus, banks demand foreign exchange swaps to hedge a currency mismatch on their balance sheets. Such mismatches can arise, for example, if a substantial portion of their deposits are denominated in a bank's domestic currency, e.g. euro, but its exposures are denominated at least partially in foreign currency, e.g. US dollars. Institutional investors like insurers and pension funds, meanwhile, hedge a portion of their international exposures against exchange rate risks using forward contracts.[24] Non-financial corporations also demand forward contracts to hedge against exchange rate fluctuations, for instance.

Before looking more closely at the supply-side reasons why seemingly available arbitrage opportunities are left untaken, this article first examines whether the demand-side condition for the existence of a positive and relatively persistent euro basis against the US dollar since the end of 2014 has been met. The unilateral monetary easing in the euro area and the associated increase in the interest rate differential are indeed likely to have contributed to an imbalance in the demand for foreign exchange swaps.[25] Hence, the difference in return probably prompted euro area investors to invest more money in the United States, while at least partially hedging the resulting exchange rate risks.

Monetary policy contributes to deviations from covered interest parity

At the same time, the empirical evidence suggests that US firms stepped up their issuance of euro-denominated bonds. Thus, issuance volumes of euro-denominated US corporate bonds (reverse yankees) rose markedly between 2015 and 2018, for instance, even though hedging costs were high. Brophy et al. (2019) find that quantitative easing in the euro area significantly lowered credit risk premia in euro area bond markets. For some US firms, this reportedly made issuance in euro bond markets more attractive than in US dollar bond markets,[26] while the hedging of the associated

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20 On 13 October 2008, the Bank of England, the Bank of Japan, the ECB, the Federal Reserve and the Swiss National Bank announced joint measures to improve liquidity in short-term US dollar funding markets. These were tenders of US dollar funding at 7-day, 28-day and 84-day maturities at fixed interest rates for full allotment. In order to accommodate whatever quantity of US dollar funding is demanded, unlimited US dollar swap lines were introduced between the Federal Reserve and the three aforementioned European central banks. See Federal Reserve (2008).
21 See European Central Bank (2016).
22 For more information on the effectiveness of the US dollar swap lines, see Bahaj and Reis (2022), who use an empirical study to demonstrate that the swap lines put a ceiling on deviations from covered interest parity.
23 See Borio et al. (2016a, 2016b, 2018).
24 Borio et al. (2018) cite findings by Barclays (2015), which find that Japanese insurers hedge around 60% to 70% of their exchange rate risk, while Japanese pension funds did not transact any such hedging for the foreign currency-denominated bonds in their portfolios.
25 Borio et al. (2016b) refer in this context to divergent monetary policies in an ultra-low interest rate environment. For information on how monetary policy contributed to deviations from covered interest parity, see European Central Bank (2017), p. 42.
26 See also Cerutti et al. (2021).

currency positions contributed to an increase in the swap rate over and above the US interest rate advantage. On balance, the authors note, the violation of covered interest parity had been exacerbated by the increasing issuance of reverse yankees. Both effects thus had a unilateral supportive impact on demand and generated the aforementioned pressure from the demand side. Both euro area investors investing in the United States and US firms issuing euro-denominated bonds hedged against a depreciation of the US dollar against the euro.

Interest rate arbitrage more costly due to regulatory adjustments, …

On the supply side, the BIS's studies refer to regulatory adjustments and a change in banks' risk management practices which, in combination, make it costly to expand the balance sheet, thus inhibiting arbitrage.[27] The BIS found that the balance sheet expansion associated with arbitrage called for the provision of relatively high-yielding capital once it exceeded a certain limit. If the euro basis only just offsets the cost of capital or is even less than that, arbitrage is not worthwhile. Consistent with this approach, there is no return equalisation below the floor represented by the cost of equity associated with the arbitrage trade. Hence, the euro basis does not close.[28]

… as a result of the Basel III decisions …

The Basel III decisions are cited in connection with the rising cost of interest rate arbitrage owing to a tightening of the capital rules. These decisions were announced in December 2010 and envisaged the phasing-in of additional regulatory requirements for banks between 2013 and 2019.[29] The reform package saw the Basel Committee learn the lessons from the financial crisis, in particular by strengthening the resilience of the banking sector by improving the regulatory capital base in qualitative and quantitative terms.

… and due to amendments to the minimum capital requirement

Thus, according to these decisions, the minimum capital requirement – i.e. the prescribed minimum ratio between regulatory capital and risk-weighted assets – has been supplemented by various capital buffers. These buffers were phased in between 2016 and 2019.[30] In addition to stricter quantitative requirements, higher standards have also been set for the quality of equity capital. Thus, the minimum Common Equity Tier 1 ratio was raised by a total of 2.5 percentage points to 4.5% between 2012 and 2015.[31] Banks are thus required to hold more capital of a higher quality against their risk-weighted assets. This gives banks greater scope to absorb going concern losses, but it also drives up the cost of risk-weighted assets and thus tightens limits to arbitrage.

More attention paid to risk

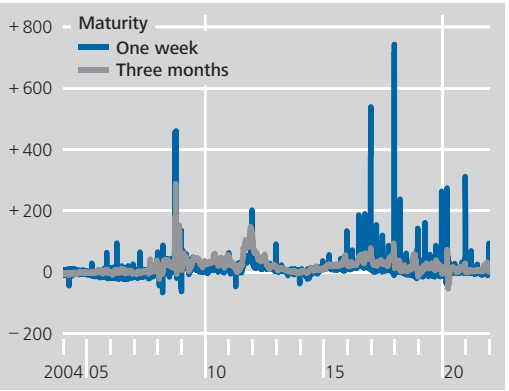
At the same time, the regulatory requirements were increased to give greater consideration to risk and tighten the calculation of risk-weighted assets. This made it less easy to achieve the

27 See Borio et al. (2016a and 2016b).
28 For the calculation of the floor, see Du et al. (2018).
29 See Deutsche Bundesbank (2011) and Basel Committee on Banking Supervision (2010).
30 The revision of the regulatory definition of capital and the introduction of new minimum requirements are discussed in Deutsche Bundesbank (2011), p. 11 and p. 19.
31 The Common Equity Tier 1 ratio expresses Common Equity Tier 1 capital as a percentage of risk-weighted assets. The components of Common Equity Tier 1 capital are presented in Deutsche Bundesbank (2011), p. 11. Overall, the stricter regulatory requirements under Basel III result in additional costs for interest rate arbitrage that cannot be recorded directly. Du et al. (2018) use the positive difference between the interest rate on excess reserves at the Fed (IOER) and the US LIBOR rate/federal funds rate as a proxy floor for the cost of capital at US banks. This is based on the notion that "… [in] the absence of balance sheet costs, banks should borrow at the federal funds rate/U.S. LIBOR rate and invest risk-free at the IOER, until the federal funds rate/LIBOR rate increases and both rates are equal". Capital costs are also incurred in cases where the positive euro basis is used to borrow at favourable interest rates in the United States and invest the principal in the euro area. The assumed profits need to be adjusted for the cost of capital associated with the investment. If the computed deviations in covered interest parity are adjusted using the aforementioned proxy constructed by Du et al. (2018) for a floor on capital costs at US banks, the hypothetical arbitrage profits of the euro basis against the US dollar are, according to own calculations, around 40% lower on average for the period from 1 January 2015 to 30 December 2018. According to the calculations of Du et al. (2018), the hypothetical arbitrage profits of a negative dollar basis against the Swiss franc, the Danish krone, the euro and the yen decline by around 33% on average between 1 January 2009 and 15 September 2016. The calculations suggest that the deviations in the basis from covered interest parity since the Basel III decisions came into force can probably mainly be attributed to the cost of capital backing, especially as the correction represents merely the estimated cost floor.

prescribed Tier 1 capital ratio.[32] To limit a bank's leverage not only relative to its risk-weighted assets, which are usually based on model assumptions, but in general, a leverage ratio was additionally introduced at a general Tier 1 capital ratio of 3% of a bank's total exposures.[33] Although the leverage ratio must be complied with at all times, it only needs to be disclosed at the end of each quarter. This means that swaps with terms of less than three months are initially only reported on the quarterly balance sheet if they have not yet expired at the end of the quarter.

Annualised euro basis against the US dollar for different swap maturities*

Daily data in basis points



Sources: Refinitiv and Bundesbank calculations. * Euro basis calculated using money market rates (three-month LIBOR).

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Empirical evidence for relevance of leverage ratio

One indication of the relevance of the leverage ratio introduced by supervisors is that quarter-end dates since 2015 have seen a marked increase, with numerous deviations from covered interest parity being calculated for a one-week or one-month investment period. As the leverage ratio is calculated at a certain point in time in the EU and reported to supervisors on the basis of quarter-end levels, banks may have desisted from undertaking swap transactions at the end of the quarter in order to report higher leverage ratios and save capital costs.[34]

Basel III decisions safeguarding bank liquidity reduce scope for arbitrage

A further rule under the Basel III decisions is designed to safeguard bank liquidity. The financial crisis saw a decline in trading activity in secured and unsecured money markets – as exemplified by the US dollar shortage – which led to liquidity bottlenecks in the banking sector and meant that short-term funding was no longer assured in some cases. To keep liquidity risk in check, measures aimed at safeguarding bank liquidity were adopted as part of the Basel III regime. Since January 2015, commercial banks have been required to meet a minimum liquidity coverage ratio (LCR), which was phased in incrementally.[35] This requirement is intended to ensure that a bank has an adequate stock of unencumbered high-quality liquid assets (HQLA) to meet its liquidity needs for a 30 calendar day liquidity stress scenario.[36] This rule meant that

32 Overall, the denominator in the Tier 1 capital ratio has increased because greater consideration is given to risk. Thus capital has to be set aside for over-the-counter (OTC) derivatives such as foreign exchange swaps to cover the risk of a deterioration in the derivative counterparty's credit quality. Potential risk under stressed conditions is another factor that is accounted for. Thus, all institutions that have supervisory approval to use their own market risk models must additionally calculate a risk amount that estimates the expected change in value in the current portfolio in a stressed market situation. The idea behind this rule is for the denominator to also include those assets which were classified as safe under the previous trading book rules but are nonetheless a source of risk in the event of systemic tension.

33 The leverage ratio was initially introduced purely as an observation ratio before becoming a binding minimum requirement in January 2018. This ratio expresses a bank's Tier 1 capital as a percentage of the sum of its assets and off-balance sheet items, with the risks associated with an item being given as little consideration as possible.

34 See Abbassi and Bräuning (2021). The Basel Committee issued a statement (2018) in response to such leverage ratio window-dressing behaviour, stressing that such behaviour is unacceptable and that the leverage ratio should be complied with not only at the end of the quarter but on an ongoing basis. The BIS notes in this statement (2018) that window dressing, in the form of temporary reductions of transaction volumes with a view to lowering the leverage ratio, runs counter to the aim of sustainably reducing the vulnerability of the banking sector to crises. The incentive to engage in window dressing can be mitigated by switching from quarter-end levels to quarterly averages. In the European Union, however, it was decided that the disclosure and reporting of average leverage ratios should be limited to "large institutions" (Article 451(2) of EU Regulation No 575/2013). The detailed reporting and disclosure rules were implemented in two Implementing Technical Standards that only entered into force in 2021.

35 Introduced as at 1 January 2015, the LCR is defined as the ratio of the stock of HQLA and net cash outflows over the next 30 days. The term "total net cash outflows" is defined as the total expected cash outflows minus total expected cash inflows in the specified stress scenario for the subsequent 30 calendar days. The minimum requirement was set at 60% in 2015 and rose in equal 10 percentage point annual steps to reach 100% in 2019. The rules are outlined in Basel Committee on Banking Supervision (2013), pp. 2-45.

36 See Basel Committee on Banking Supervision (2013), p. 4.

the potential profits from arbitrage were lower than they would have been, had they been calculated using LIBOR rates.

To illustrate how these factors interact, let us assume that US banks (via their branches in the euro area) are able to use the Eurosystem's deposit facility and, for liquidity reasons, prefer to make a higher-interest investment in the private money market.[37] Under these circumstances, the arbitrage profits available in theory should be calculated not using the euro LIBOR but the rate on the Eurosystem deposit facility (for the three-month investment period under consideration), as in Rime et al. (2019).[38] As the Eurosystem deposit facility rate has been below the euro LIBOR over extended periods since 2015, the authors conclude that the opportunities for reaping arbitrage profits that would appear to exist when calculated based on LIBOR rates either did not exist at all or did not exist in the magnitude shown.

It may be concluded overall that important conditions for interest rate arbitrage – conditions that had previously kept deviations from covered interest parity to a minimum – have no longer been met since the financial crisis.

Uncovered interest parity and euro-US dollar exchange rate

Equilibrium mechanism of uncovered interest parity

If investors attempt to capitalise on international interest rate differentials even without hedging, their realised profits will largely depend on how the spot rate evolves. Thus, for example, an investment in the United States, from a domestic investor's perspective, was more lucrative with hindsight than an investment in the euro area if a given US interest rate advantage was not cancelled out or was in fact more than offset by an appreciation of the euro. Since it is not known at the time of investment how exchange rates will develop in future, the investor's investment decision is determined not only by the interest rate differential but also by the expected exchange rate change. According to the uncovered interest parity theory, in the absence of capital controls and given the complete substitutability of investment alternatives, risk-neutral investors will, in the example described above, shift their portfolio into US investments as long as the US interest rate advantage is not eroded by an expected appreciation of the euro against the US dollar. This reallocation has two effects. First, it narrows the interest rate differential. Second, the capital exports to the United States resulting from said reallocation put downward pressure on the euro's exchange rate against the US dollar, all other things being equal. The theory assumes that, given unchanged fundamentals, the exchange rate expected when the investment is unwound is also fixed. An observed depreciation of the euro therefore generates expectations that the single currency will increase in value. This mechanism, taken together, means that returns align perfectly with each other such that uncovered interest parity holds. Accordingly, if investors are risk-neutral, an assumed US interest rate advantage over the euro area for three-month money would have to be offset by an expected appreciation of the euro against the US dollar over the investment period of three months.

Testing uncovered interest parity empirically …

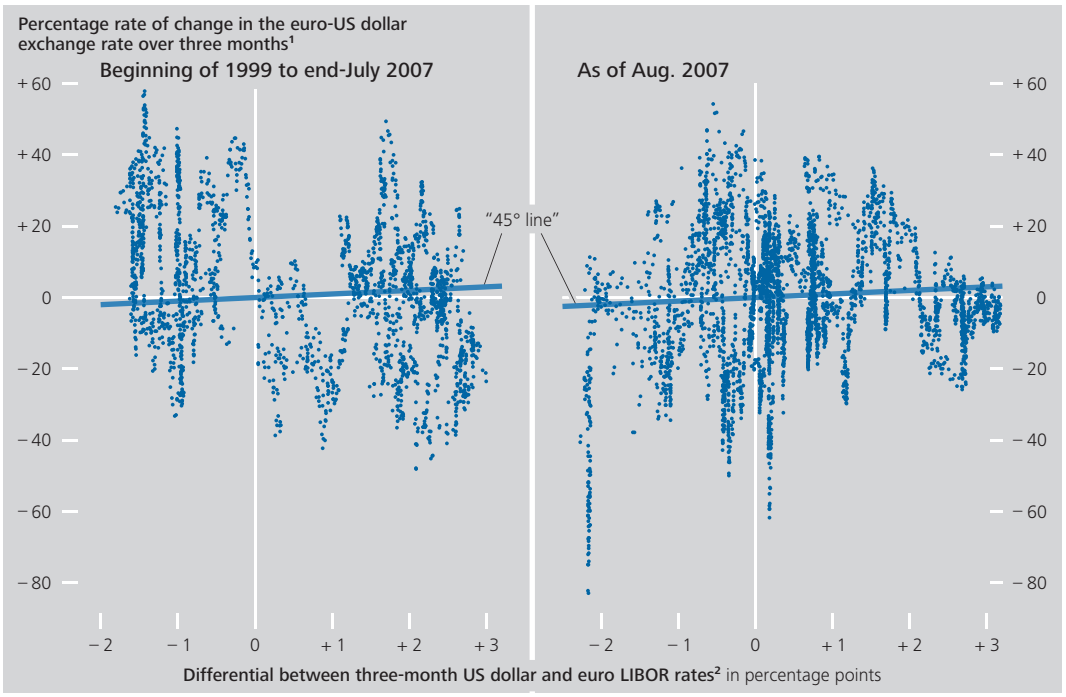
An empirical study of the uncovered interest parity theory conducted recently by the Bundesbank approximates the expected adjustment of the exchange rate based on its actual movements. This approach was already chosen

37 According to the remarks by the Basel Committee on Banking Supervision (2013), assets are eligible as HQLA only if they can be converted easily and immediately into cash at little or no loss of value. The liquidity of an asset depends on the volume to be monetised and the timeframe considered. Assets issued by financial institutions are considered to be relatively illiquid in times of liquidity stress in the banking sector. Balances held in central banks' deposit facility are counted toward the required stock of high-quality liquid assets, meanwhile. The treatment of central bank balances in the LCR is outlined in Federal Financial Supervisory Authority (2015).

38 It should, however, be borne in mind that deposits placed in the deposit facility are callable on a daily basis, which thus gives rise to (minimal) interest rate risk. Covered interest parity, on the other hand, considers investments whose interest rates are fixed over the investment period.

Uncovered interest parity between the United States and the euro area*

Annualised daily data, 4 Jan. 1999 to 31 Dec. 2021



Source: Refinitiv. * A single dot indicates the ratio calculated from exchange rates and interest rates for a given trading day. When uncovered interest parity holds, the dots should be close to the 45° line shown in the chart, which is very flat owing to the different scales of the axes. Deviations from that line should be randomly distributed. **1** A positive value indicates an appreciation of the euro against the US dollar. **2** US dollar LIBOR minus euro LIBOR.

Deutsche Bundesbank

in the 2005 Monthly Report, meaning that the results are comparable.[39] Assuming rational expectations and risk neutrality on the part of investors, the actual movement of the exchange rate ought to match the expected adjustment on average. Deviations that actually occur ought to be purely random in nature.

… provided no indications of its validity until 2005

If, for individual trading days, the exchange rate change of the euro-US dollar spot rate over three months is compared with the interest rate differential applying in each case to three-month money between the United States and the euro area, marked deviations from uncovered interest parity are evident, with the exchange rate change exceeding the interest rate differential many times over, on average. This phenomenon was evident both between early 1999 and mid-2005 and in the period thereafter. The empirical study presented in the 2005 Monthly Report found, furthermore, that the higher-interest currency tended, on average, to appreciate more than the lower-interest one, which is at odds with the theory.[40] The lack of evidence for the uncovered interest parity theory has been the subject of a host of theoretical and empirical papers.[41] The academic literature listed time-varying risk premia, forecasting errors concerning rational expectations and a phenomenon known as the "peso problem" as potential causes.

Against this backdrop, it is striking that the aforementioned empirical finding cannot be

39 See Deutsche Bundesbank (2005), p. 35. The current study follows the approach used in the 2005 Monthly Report, using the difference between the logarithmic spot rates to approximate the exchange rate change. This avoids the Siegel paradox which arises because otherwise the appreciation rate of one currency does not match the depreciation rate of the other.

40 See Deutsche Bundesbank (2005); this article examines returns on hypothetical currency carry trades between the launch of monetary union and 30 June 2005. As outlined below, a currency carry trade involves borrowing funds in a low-interest currency and investing them in a high-interest currency, and not hedging the transaction.

41 For a comprehensive overview of the literature on the empirical results and explanatory approaches in connection with uncovered interest parity, see Engel (2014).

Less empirical evidence of rejection of this theory since the financial crisis

confirmed for the subsequent period after mid-2005. In the sample from mid-2005 to the end of 2021, the higher-interest currency appreciated on roughly as many days as it depreciated in line with the uncovered interest parity theory. Similar results can be obtained if uncovered interest parity is tested by regressing the actual exchange rate change on the interest rate differential and a constant for different periods.[42] To this end, a dedicated analysis[43] of the euro's exchange rate against the US dollar, pound sterling, yen and Swiss franc was performed, with the investigation period being divided into two samples. The first covers the period from the beginning of 1999 to immediately before the onset of the financial crisis in August 2007, while the second covers the period since its onset to the end of 2021. The full sample was subdivided in this manner in order to see whether the relationship between the exchange rate change and the interest rate differential had altered.

The econometric study does indeed indicate that the results depend heavily on the underlying sample. While the validity of uncovered interest parity for the sample in question (launch of European monetary union until immediately before the global financial crisis) is rejected for all four currency pairs considered here, this is only the case for the yen, statistically speaking, in the post-global financial crisis period. In the more recent sample, the estimated slopes are all significantly higher than those in the pre-global financial crisis sample and – unlike in the earlier sample – now have a positive sign. The results imply that since the onset of the global financial crisis, it has tended to be the currency in which the higher-interest investment is denominated that depreciates over the investment period. Overall, then, the empirical evidence observed post global financial crisis has been more consistent with uncovered interest parity than in the earlier sample. However, whether this finding is robust and can be traced back to an actual change in the underlying relationship cannot be assessed conclusively owing to the high estimation uncertainty and unstable parameter values, even within the respective estimation periods.

Lack of evidence for uncovered interest parity theory possibly amplified or even induced by carry trade strategies

A currency carry trading investment strategy can be used to generate profits from deviations from uncovered interest parity. A currency carry trade involves borrowing funds in a low-interest currency and investing them in a high-interest currency. Since investors choose not to hedge these transactions, returns on currency carry trades crucially depend on how the exchange rate between the currency pair actually develops up to the end of the investment period. A currency carry trade is particularly lucrative if the higher-interest currency appreciates, as was the case on average between 1999 and 2005: the investor makes exchange rate gains on top of the interest rate advantage. Thus, if an investor had applied the currency carry trade strategy to the euro area and the United States in a thought experiment, they would have generated an average annualised return of around 15% between the beginning of 1999 and mid-2005. Seeing the higher-interest currency appreciate may have encouraged speculators to invest further in carry trades, which would have strengthened the appreciation of the higher-interest currency and thus the deviation from uncovered interest parity. On balance, the empirical finding that the higher-interest currency appreciated on average between the beginning of 1999 and mid-2005 may therefore have been amplified or even induced by carry trade strategies.

Carry trade strategies risk heavy losses

However, an assessment of more recent periods shows that this strategy can produce a far smaller return. Thus, the illustrative carry trade strategy described above would have produced

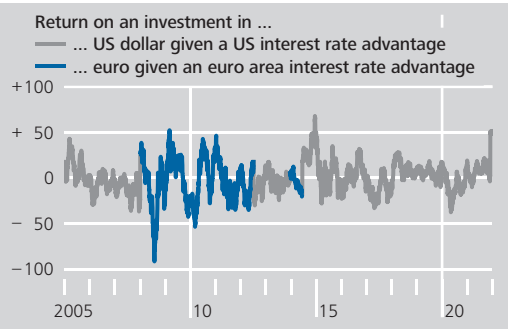
42 For more on this, see also Engel et al. (2022). The authors test the relationship between the US dollar and various currencies for one period up to the end of 2006 and a second period as of 2007. They find that the signs of the estimated coefficients depend on the sample examined and find, for the period as of 2007, that "[…] the evidence for a UIP puzzle is weak". Bussière et al. (2022) conclude that the sign switches primarily because the correlation between interest rate differentials and expectations errors changes.

43 See the box on pp. 57 ff.

a loss on average (-1%) between mid-2005 and the end of 2021, compared with -14% when the financial crisis was at its peak (defined here as the period between the beginning of August 2007 and the end of 2008), and only a slim profit of just over 1% from then until the end of 2021. This shows that the return on carry trade investments fluctuates strongly owing to the high volatility of exchange rates over time, and illustrates that carry trades are a highly speculative and risky investment strategy. The turmoil that has repeatedly weighed on financial markets in recent years is likely to have had two effects. First, it will have dampened the appetite for risk, at least for a time. Second, international interest rate differentials have narrowed in the global low interest rate environment. Taken together, these two factors have probably worsened the expected risk-return profile of carry trade strategies and reduced carry trade activity, at least temporarily.

Return on a hypothetical currency carry trade investment strategy*

%, annualised daily data



Sources: Refinitiv and Bundesbank calculations. * Funds are borrowed in a low-interest currency and invested in a higher-interest currency. Return on investments in three-month money market funds from the point of view of euro area investors.

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Conclusion

The period since the global financial crisis has seen considerable and at times persistent deviations from covered interest parity. This came as a surprise because it had been assumed that these deviations would offer foreign exchange market participants the opportunity to generate risk-free profits. As it turns out, though, important conditions for interest rate arbitrage, which had previously kept deviations from covered interest rate parity low, have no longer been met since the crisis. For example, counterparty risk grew in significance for potential interest rate arbitrageurs, prompting them to demand a correspondingly high premium in return for taking on the risk of default. The Basel III decisions phased in since 2013 have furthermore driven up the costs of interest rate arbitrage, which reduced the scope for arbitrage further still. Swap lines agreed between central banks to improve banks' liquidity in foreign currency counteract an abrupt increase in the cost of hedging against exchange rate risk in times of crisis and help stabilise financial markets.

Deviations from uncovered interest parity are evident throughout the full sample. Econometric studies suggest, however, that the relationship between the spot exchange rate and the interest rate differential has changed since the financial crisis. They indicate that unlike in the pre-financial crisis period, it tends to be the currency in which the higher-interest investments are denominated that depreciates over the three-month period under review. A finding of that kind is generally consistent with the uncovered interest parity theory. However, these results are subject to a high degree of estimation uncertainty. One reason for the change in correlation might be that the expected risk-return profile of carry trade strategies deteriorated during the low interest rate period, resulting in less currency carry trading activity. It cannot be ruled out that this trade strategy will regain importance as interest rate differentials between the currency areas grow larger again.

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