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Covered Interest Parity and Long-Term Bonds

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Covered Interest Parity and Long-Term Bonds

by

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Dedicated to all authors, who took the time to write their knowledge down.

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Covered Interest Parity and Long-Term Bonds

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First, the major result of Liao (2016) was reproduced, with 3 additional currencies and 6 more years of data. [Gordon Y. Liao. Credit Migration and Covered Interest Rate Parity. Working Paper 468601, Harvard University, October 2016.] Second, Liao's model was tested using government rates, which showed a better fit than when using swap rates, as in Liao's work. Lastly, CIP deviations were calculated from long-term corporate bond rates. Since 2012, the CIP deviations measured using corporate bonds are lower than those calculated from swap and government rates, and are of a scale where banks could be expected to make arbitrage trades.

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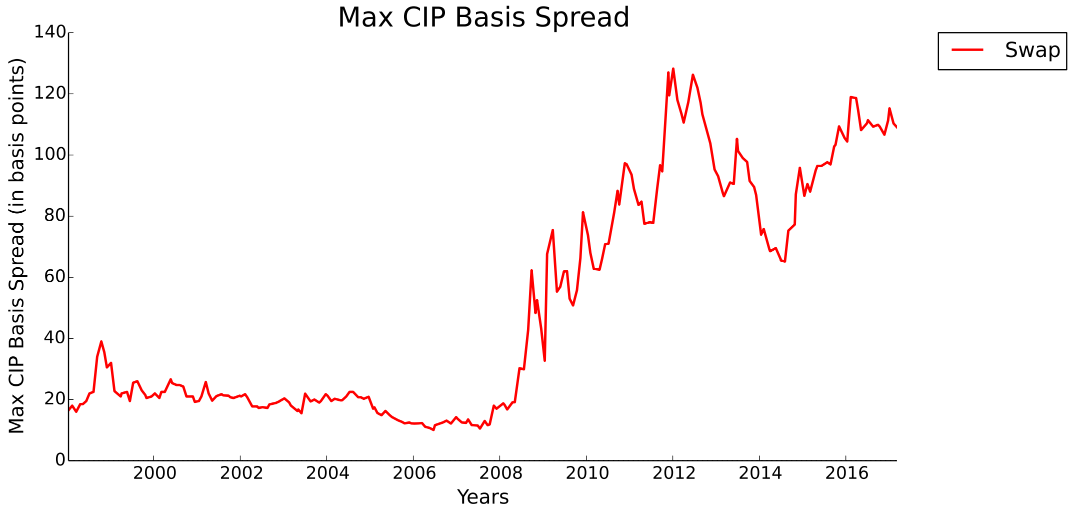
Chapter 1

Introduction

Covered interest parity (CIP) is a no-arbitrage condition relating the prices of international bonds, currencies, and currency forwards. Before the Global Financial Crisis of 2007-2008 (henceforth "the crisis"), the CIP relationship held. That is, from January 2000 to May 2008, the yield from the arbitrage trade (without leverage) using interest rate swaps was under 30bp. After the crisis, the relationship has not held. From November 2009 to March 2017 (the last date studied), the yield from the arbitrage trade (without leverage) has exceeded 60bp, which is more than the value at which banks, even ones restricted by post-crisis legislation, should trade it. (See Figure 1.1.) The research community does not understand why banks are not performing this arbitrage trade, which has a high guaranteed return. This thesis examines the problem, using rates from long-term corporate bonds.

Covered interest parity is best explained by example. Starting with 1M USD, you could invest it in a 5-year U.S. Treasury bond and get a return of 1.7%. Alternatively, you could convert that 1M USD into 0.9M EUR and buy two things: a 5-year German bund with a return of -0.41%, and a forward contract that locks in the price today of exchanging the EUR back into USD in

Figure 1.1: Max CIP basis spread for 5-year horizon



Note: Maximum CIP basis spread, calculated with a 5-year swap rates. The max CIP basis spread is the return an arbitrageur would get when trading without leverage. Here, it is calculated over the 10 currencies studied: USD, EUR, JPY, CHF, GBP, AUD, CAD, SEK, NOK, and NZD.
Source: Bloomberg L.P.

5 years. Investing either of those ways — directly in U.S. Treasury bonds or via EUR in Germany bund — should give the same overall return (assuming both governments are considered equally sound). That condition is called "covered interest parity".

The deviations from CIP were identified soon after the crisis. Some researchers ascribed it to counterparty risk and banks requiring more capital.[1] But the deviations persisted, even after banks had recapitalized. Researchers have started identifying patterns and hypothesizing on both the cause of the deviations and why prices have not returned to CIP. Causes for the deviation include central bank policy[2], regulatory changes[3], and hedging demand[4]. More puzzling has been why prices do not return to CIP. A common explanation has been new banking regulations enacted after the crisis: the Dodd-Frank Act and Basel III Accord lessen the amount of leverage that banks can use.[2, 3, 4] Recently, a paper[5] has suggested that it is because few banks have a good enough credit rating to perform the arbitrage and a news article[6] has suggested debt overhang induces banks away from guaranteed trades like arbitrage.

CIP has been studied using interest rates from various securities, both short-term and long-term. This thesis's work focuses on long-term corporate bonds, where the firm has issued bonds in multiple currencies. If a firm issued a bond in multiple currencies, those bonds have nearly identical risk, unlike government bonds or swap rates, where the risks differ. If other differences in the corporate bonds (such as maturity) can be accounted for, long-term corporate bonds allow for better measurement of CIP.

The major existing work covering corporate bond rates and CIP was done by Liao[3]. He focused on firms issuing bonds in foreign currencies to get a lower interest rate. He found that firms issued more foreign bonds when overseas interest rates were lower. He defined the "residualized credit spread differential" as a function of corporate bond rates and swap rates, and then showed that this measure was correlated with CIP deviations, when calculated using the swap rate.

Liao's study used swap rates instead of government bond rates for the reference rates measuring CIP deviation. This is common in the field[2, 4, 7]. However, swap rates depend on interbank loan indices, like LIBOR, and bank default risks are not identical across currencies, nor stable during a financial crisis. Moreover, swap rates are the price of a variable contract, not of a bond, and bonds are necessary for measuring CIP.

In this thesis, I reproduce Liao's work with swap rates and then reevaluate it using government bond rates. The results are better (correlations are higher) with government bond rates. I then estimate the CIP deviation using long-term corporate bonds. My results show that, since November 2011, CIP deviations, when calculated using corporate bonds, are lower than when measured with swap rates or government rates. During that period, the median deviation is 48bp, which is the correct scale for the threshold where banks perform the arbitrage trade. I conclude that the CIP deviations measured with corporate bonds fulfill our expectations on how CIP deviations should behave and that they should be preferred to CIP deviations measured with swap rates and government rates.

1.1 Literature Review

There is a long history associated with covered interest parity. Discussion of CIP even predates the creation of the first currency futures in 1970.[8] This section will focus on work done after the crisis and concentrate on those that study long-term bonds.

Shortly after the crisis, CIP deviations were identified and studied. The causes were believed to be transitory: counterparty risk and banks requiring more capital.[1] As the deviations persisted, researchers have started identifying patterns and hypothesizing on both the cause of the deviations and why prices do not return to CIP.

Borio et al.[4] and Sushko et al.[9] focused on the foreign exchange (FX) forward market, which trades less volume than the FX spot and bond markets. They looked at a few causes of deviations in that market: cross-border funding by firms (who borrow in foreign currencies and then hedge the liability) and institutional investors' strategic hedging.

Their explanation for why deviations persist was that banks perceive risk as being higher than before the crisis. Counterparty risk, as proxied by the OIS-LIBOR spread, was higher. Collateral risk, measured by FX options, was also higher. When collateral risk is higher, REPO becomes more expensive and the arbitrage trade to close the CIP deviations is less scalable and less profitable. Other factors included central banks buying bonds, which also drives up REPO rates, and new regulations, which put an upper bound on the leverage banks can obtain.

Du et al.[2] presumed that CIP deviations were caused by persistent imbalances in investment demand and focused on why CIP did not reassert itself. They found significant CIP deviations even when they restricted themselves to looking at bonds in multiple currencies from Kreditanstalt für Wiederaufbau (KfW), a development bank owned by the federal and state governments of German. These bonds are liquid and safe (backed by the German government) and the authors concluded that arbitrage was not limited by transaction costs nor credit risk.

Du et al. used the OIS-LIBOR spread as a proxy for balance-sheet costs and found that it explained at least half of short-term CIP deviations. In the same vein, they found correlations between the CIP deviations and other trades that involve liquidity risk, such as the swap of LIBOR 1M for LIBOR 3M, knows as the "tenor". Du et al. discovered an interesting effect that CIP deviations increase dramatically when the forward contract was not settled before the quarter ends. They believe this was a novel limit to arbitrage where European banks, who have to report their holding at the end of the quarter, were trying to profit from arbitrage only when it would not appear publicly in their books.

Rime et al.[5] did not speculate on the causes of CIP deviation, but looked in detail at the transactions necessary for short-term CIP arbitrage. They found it was important for banks to match the horizon of the funding source and the investment. At the 3-month horizon, banks' cheapest funding was from commercial paper or hedging overseas issuance of commercial paper, versus the more expensive interbank loans and interbank deposits. When performing the CIP arbitrage, banks bought 3-month government bills. This trade could be done only with a limited volume, because high volumes would move the bill's price until the trade was not profitable. The trade was also limited to the few banks that can get a low enough rate on their commercial paper to perform the trade profitably.

Rime et al. also looked at the overnight horizon. Here, both funding and investment were affected by the central bank's policy on excess reserves, not just the OIS rate. An important difference from the 3-month horizon was that the central bank's rate on excess reserves did not change with volume, like the rate of the 3-month government bills. Thus, very large arbitrage transactions could take place.

If banks did not match the horizon of the funding source to the investment, there was a liquidity premium (or term spread). Thus, using overnight REPO to fund the purchase of a 3-month government bill was possible, but when banks did that, they were reserving funds to address any liquidity crises that might happen. Rime et al. found that, after considering the liquidity premium, funding costs, and investment decisions, the prices in short-term markets could be explained.

Liao[3] is a departure from most of the field by focusing on corporate bonds, rather than bank borrowing or government bonds. He claimed that the price of risk should be the same in all markets and deviations from this are correlated with CIP deviations. Using a data set of 35,000 bonds with prices from 2004 to 2016, he estimated the price of risk by the spread of corporate bonds over swap rates. He found that deviations in that value are correlated with CIP deviations, when calculated with the swap rate. Liao went further and showed that the CIP relationship could be maintained by firms issuing bonds in foreign markets and hedging the liability in FX forward markets.

Liao's work is important to this thesis and will be described further in

Chapter 4. Liao, Sushko et al., Borio et al., Du et al., and others used swap rates to study CIP with horizons longer than 3 months. This will be addressed further in Section 5.1.

1.2 Outline of Thesis

The thesis proceeds as follows. Chapter 2 describes the data and code used to produce the results. Chapter 3 formally defines CIP and CIP basis, and describes some of the securities used in the analysis. Chapter 4 describes work using corporate bonds by Liao and reproduction of those results. Chapter 5 has new work: reevaluating Liao's work using government bonds rates and measuring CIP basis directly using corporate bonds. Chapter 6 concludes.

Chapter 2

Data Sources and Code

This chapter describes the data and code used in the analyses. It covers the sources, the transformations, which data was included, and which data was excluded.

Data was gathered on 10 major currencies, which are listed in Table 2.1. Prior the Euro's creation on 1 Jan 1999, the German Deutsche Mark (DEM) was used. Data was sampled monthly from January 1998 to April 2017. A random day each month was sampled, while excluding weekends, U.S. trading holidays, and some common European trading holidays (e.g., Whit Monday). The randomness was done to avoid repeatedly landing on some unaccounted for holiday. Still, some common holidays, were encountered. Most notably, Easter Monday occurred on 5 April 1999, 9 April 2007, and 28 March 2016 affecting AUD, CHF, EUR, GBP, NOK, NZD, and SEK.

Bloomberg's Professional Services[10] was used for the descriptions of corporate bonds and the prices for those bonds, swaps, and currencies. The data set had over 17,000 corporate bonds from over 800 firms. (See Table 2.1.) The bonds had to be "bullet" bonds, which only pay their principle in a nominal lump-sum at maturity.

Table 2.1: Number of corporate bonds and price samples

Country	Currency	Code	# of bonds	# of price samples
European Union	Euro	EUR	6134	244820
United States	Dollar	USD	5606	206282
Japan	Yen	JPY	1744	90771
Switzerland	Franc	CHF	1136	39445
United Kingdom	Pound	GBP	1044	63987
Australia	Dollar	AUD	595	24018
Canada	Dollar	CAD	466	21225
Sweden	Krona	SEK	201	7935
Norway	Krone	NOK	131	5119
New Zealand	Dollar	NZD	90	3040

Note: Overview of the data set. The currencies studied and, for each, the number of corporate bonds and price samples in the data set.
Source: Bloomberg L.P.

Bonds were excluded if they were callable, inflation-linked, or sinkable. A callable bond contains an option for the issuer to repurchase the bond at a fixed price on certain dates. These were excluded because it is more difficult to compute the yield of the bond. An inflation-linked bond does not have a fixed coupon payment, but a variable one and its payment is linked to an index of inflation. These were excluded because the coupon is variable and it is impossible to compute the bond's yield. A bond is sinkable if the issuer has a "sinking fund", a budget item for incrementally repurchasing the bonds before maturity. These were excluded because Liao had chosen to exclude them and these may contain option-like features allowing the issuer to repurchase them.

The bonds were all investment grade, at least Baa3 by Moody's or BBB- by Standards & Poors (S&P), with an amount issued of at least 150M

USD (equivalent). Durations ranged from 3 to 35 years, all maturing before 2025. The bonds were only used if, after all these requirements, its firm had issued bonds in more than one of the currencies studied.

In comparison, Liao's data set had 35,000 bonds from 4,600 firms. He also used "bullet" bonds where the firm had issued in more than one currency, but his limits were less constrained. He did not require investment-grade bonds and, for the amount issued, he went as low as 50M USD (equivalent) as compared to 150M. His minimum duration for a bond was 1 year. He studied 7 currencies over a 12.58 year period (Jan 2004 to July 2016), and I study 10 currencies over a 19.25 year period.

There were some problems with the data and some details worth mentioning. Bloomberg's bond descriptions were occasionally missing necessary data, like coupon rates, maturity date, and even the unique identifier ISIN. Some had badly formatted credit ratings. All such bonds were excluded.

I used Bloomberg's daily closing price for all securities. Bloomberg's data also included the opening, low, and high prices for the day. Sometimes Bloomberg prices were inconsistent: the closing price was below the low price or above the high price. The closing price was still used in these situations.

Bloomberg's currency prices were "Bloomberg composite prices" made from multiple market quotes. They may not reflect an actual price from a participant in the market. Prices for FX forwards were synthesized from cross-currency basis swaps using the spot rate and swap rates. Cross-currency basis swaps were used because they have more volume than FX forwards and traders of them do not take a directional bet in either currency.

For price-to-yield calculations, I used the open-source software library Quantlib.[11] Different bonds use different conventions for computing yield. The swap rates and corporate bonds also used different calendars and different payment frequencies. This seemingly minor detail is an issue because different conventions can produce noticeably different results.[12] To make everything comparable, I converted all corporate bond yields to a common format, with Actual/Actual daycounts and continuous compounding. If Quantlib's calculation did not converge in 100 iterations, the price sample was discarded.

Because bonds are illiquid, some trades had exceptionally low or high prices which do not reflect their actual value. I discarded data when the yield would have been below -10% or above 30%. This is different from Liao who "windsorized the data, throwing out the 1% that are the extremes."[13]

For some bonds from Australia and Japan, the field in Bloomberg's data labeled "price" actually held the yield. I did not have a definitive way to tell if the "price" was in yield or not. To resolve this, if the "price" value was in my accepted range of -10% to 30% and the result from trying to convert the "price" value to yield (using Quantlib) was outside that range, then the "price" value was considered to be the yield. Otherwise, the value in the "price" field was treated as the price.

The rating associated with each bond was its company's credit rating by

Moody and/or S&P at the bond's issuance. Credit ratings were not updated over the lifetime of the bond. This means that two bonds from the same firm might have difference ratings in the same time period.

The credit ratings on bonds had various modifiers, which were generally ignored. Thus, rating marked "expected" and "preliminary" were treated as actual ratings. Ratings marked as "unsolicited" were actual ratings and were treated as such. Indicators of likely upgrades/downgrades were also ignored.

When a bond was rated by both Moody's and S&P, a "combined" credit rating was generated. This was the average of the number of steps below the top rating from each agency. For example, Moody's "Baa1" was 7 steps below "Aaa". For S&P, "BBB+" was 7 steps below "AAA". If a bond was only rated by one of Moody's and S&P, that rating was used.

After these restrictions and the restrictions imposed by the analyses, the number of usable prices samples from corporate bonds varied by date and analysis, as seen in Table 2.2. In general, the number of prices samples increased by year. However, in there were fewer samples in the 2002 to 2005 time period, especially in 2003. This lack of data increased error in the measurement and sometime caused dates to be dropped. This is addressed with the results of each analysis.

For government bond rates, the data used was that reported by the central banks of the respective countries.[14, 15, 16, 17, 18, 19, 20, 21, 22, 23] These rates were inferred from prices in the secondary markets, using models

Table 2.2: **Price samples by year and usage**

Year	Price Samples Total	Used in Chap. 4	in Sec. 5.1	in Sec. 5.2
1998	15453	8660	9007	4598
1999	19751	13244	12656	4844
2000	26434	17662	17831	6207
2001	29008	18385	18347	6520
2002	21766	12123	11848	2289
2003	20317	8814	8258	276
2004	20685	8372	8169	1535
2005	20947	10053	10025	3694
2006	24883	15185	14445	7088
2007	32427	22646	19157	9350
2008	36334	25117	23823	9335
2009	38508	25939	25608	10990
2010	30656	20453	20375	13135
2011	40304	29231	29203	18395
2012	47737	36018	35554	18092
2013	58085	42011	40934	17903
2014	67185	47606	46704	20637
2015	69583	49337	48115	23009
2016	69729	48400	44386	23306
2017	17081	11581	11434	6489

Note: The number of price samples for corporate bonds, broken down by year and usage. Many were not used because the firm did not have bonds priced in two different currencies on the sampled day. The analysis in Chapter 4 required its bonds rates to have a swap rate available with horizons similar to the bond's maturity. The analysis in Section 5.1 required its bond rates to have a government rate available with maturity similar to the bond's maturity. The analysis in Section 5.2 required bonds with remaining maturity between 3 and 7 years. Notice that this last restriction left very few price samples in 2003 and surrounding years, which caused large errors and some missing results.
Source: Bloomberg L.P.

and methods chosen by the central banks. The data for 5-year bonds was, generally, a point on a curve fitted to prices, so it may be affected by the prices for longer or shorter term bonds and may not reflect the exact price of 5-year government bonds in the market.

Most code was written in Python. R was used for regressions. C Sharp was used to download prices from Bloomberg. Matplotlib was used to generate plots in this thesis.

The code used for this project is available upon request. The data is available if the recipient can demonstrate access to a Bloomberg terminal.

Chapter 3

Covered Interest Parity

This chapter defines covered interest parity, how deviations from it are measured, and how banks respond to deviations. Also covered is why researchers sometimes use interest rates swaps to measure CIP deviation.

3.1 Covered Interest Parity

Covered interest parity is the condition that investing in a bond domestically and investing in a bond through any foreign currency should yield the same rate of return. For this section, I consider EUR to be the domestic currency and USD to be the reference foreign currency. Covered interest parity is:

$$1 + r_{EUR} = S(1 + r_{USD})/F \tag{3.1}$$

where r_{EUR} and r_{USD} are the rates of return for investing in EUR and USD bonds, S is the spot exchange rate, and F the forward exchange rate. The left-hand side of the equation is the result from investing 1 EUR domestically at rate r_{EUR}. The right-hand side is the result of converting the 1 EUR to USD at rate S, investing overseas for a result of $1 + r_{USD}$, and, finally, converting back to EUR at the forward exchange rate F. The prices r_{EUR}, S, r_{USD} and

F are all known before the investment is made.

CIP has a "horizon" over which it is measured, such as 5 years. The USD and EUR bonds must mature in that time period and the currency forward must have its delivery date at the end of the time period.

If both bonds have identical risks, and the forward is risk-free[1], then investing locally or overseas is equivalent and should produce the same payout. CIP is then a no-arbitrage condition.

3.2 CIP Basis

The CIP basis[2] is a measure of the CIP deviation. It is equal to the implied rate from investing in reference foreign currency (USD) minus the rate of investing natively. It is defined by a transform of equation 3.1.

$$b_{EUR} = \frac{S}{F}(1 + r_{USD}) - (1 + r_{EUR}) \tag{3.2}$$

where b_{EUR} is the CIP basis for EUR in reference to USD. In this thesis, the CIP basis will always use USD as the reference currency. CIP basis with a different reference currency can be computed by subtraction. For small values of CIP basis, $b_{EUR} - b_{JPY}$ approximates the CIP basis for EUR with JPY as the reference currency.

[1] This can be approached by either purchasing it on a futures exchange where every member of the exchange insures every contract, or requiring the remaining value of the contract to be kept in escrow, to avoid counterparty default.

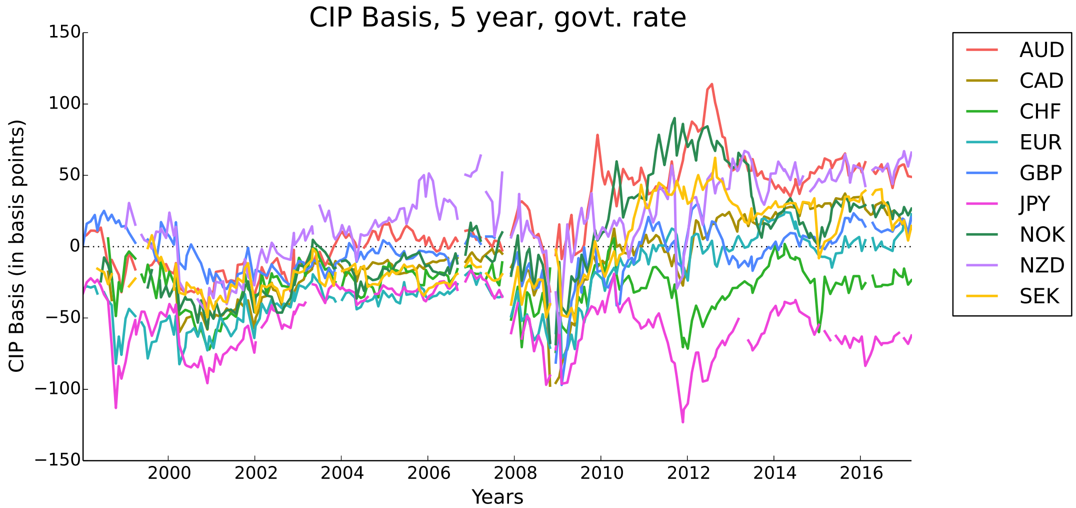
[2] CIP basis is called "premium" or "cross-currency basis" in [2] and "gain" in [24].

CIP basis can be seen as the yield from a portfolio that is long 1 unit of local currency invested in the reference currency's bonds and short 1 unit of local currency invested in local bonds. Thus, positive values of CIP basis indicate that it is more profitable to invest overseas. Likewise, negative values indicate that it is more profitable to invest domestically.

In order to calculate CIP basis, all the bonds must have the same risk. Government bonds can be used, if we assume they are risk-free. This is a questionable assumption since only Germany, Switzerland, and Norway were top-rated by all three major credit rating agencies (S&P, Moody's, Fitch) for the period of this study, from Jan. 1998 to March 2017.[25] The risk of government bonds will be discussed again later, when they are compared to corporate bond rates. For the moment, government rates are assumed to be risk-free.

Figure 3.1 plots the values of CIP basis over time for various currencies (in reference to USD). The figure uses government bond rates to calculate CIP basis, with a 5-year horizon. If USD were to be plotted on the graphs, it would coincide with the x-axis, since $b_{USD} = 0$.

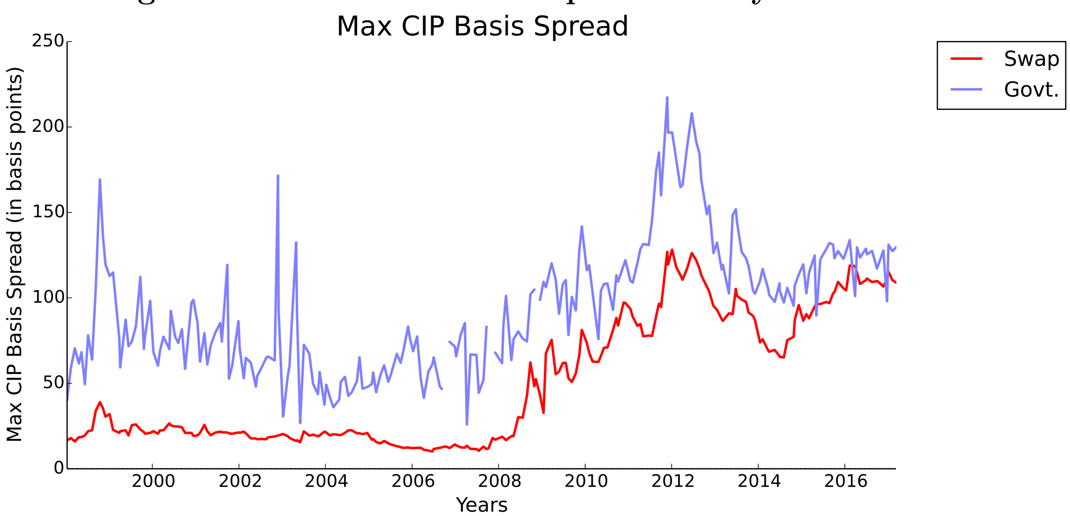
Figure 3.1: CIP basis using government rates with 5-year horizon



Note: CIP basis is the yield of an arbitrage trade (without leverage) when going long the USD bond and short the other currency's bond. Prior to 2008, the median spread from the lowest CIP basis to the highest was under 60bp. After 2012, that spread is over 115bp.
Source: Central banks, Bloomberg L.P.

I define the "maximum CIP basis spread" as the maximum CIP basis for any currency with any reference currency, over the set of 10 currencies studied. For small values of CIP basis, another approximate definition is the spread between the maximum CIP basis and the minimum CIP basis, over all currencies, when the reference currency is USD. The max CIP basis spread is the maximum yield that an arbitrageur can make, when not using leverage. See Figure 3.2. For example, the 5-year CIP basis using government rates has, on 9 January 2007, a max CIP basis spread of 70bp, but that grows to 186bp by 5 Jan. 2012.

Figure 3.2: Max CIP basis spread for 5-year horizon



Note: Maximum CIP basis spread for CIP basis when calculated with a 5-year horizon using swap rates or government bond rates. The max CIP basis spread is the return an arbitrageur would get when trading without leverage.
Source: Central banks, Bloomberg L.P.

3.3 Practical Aspects of Arbitrage

The values we can expect for CIP basis are, in part, determined by banks' trading behavior. If the max CIP basis spread gets far enough from 0, banks and other financial institutions will trade the bonds and currencies. This section discusses the banks' behavior and its resulting effect on values for CIP basis.

If b_{EUR} was positive, a bank could profit by buying USD government bonds and shorting EUR government bonds.[3] Using REPO[4], the bank could use the USD bonds as collateral to borrow more dollars and go long more USD government bonds and short more EUR government bonds. Thus, the bank can lever up the trade. The bank's profit is limited by the transaction costs, REPO haircut and by the bank's internal balance sheet limits.

Transaction costs could affect banks' trading, but transaction costs are generally low. The markets are large and liquid, with U.S. Treasuries averaging over 500B USD traded daily and the smallest market, FX forwards, averaging over 0.7B USD (equivalent) daily.[26]

The REPO haircut might affect banks' trading of some securities. Government bonds are considered excellent collateral and the haircut is 0 for government bonds in at least USD, JPY, and CHF.[2] For EUR, the European Central Bank is the lender of last resort and requires a haircut of 0.5% to 5.5% for the German Bund, depending on its maturity.[27] Bund of 5 to 7 years of maturity have a haircut of 3%. Basel II, an international accord on financial laws, had a top "standard supervisory haircut" of 4% for government bonds.[28] However, Basel II's implementation was interrupted by the crisis.

[3] In practice, it may be difficult to short government bonds, but a similar effect can be gotten by shorting bond futures, shorting bond ETFs, or purchasing put options on bonds.

[4] REPO is a repurchase agreement. The bond holder sells the bond today and agrees to buy it back again tomorrow. In effect, it is a loan where the bond holder uses the bond as collateral, gets cash today, and gets the collateral back tomorrow. The bond holder does not get cash equal to the full value of the bond; they get the cash value minus a fraction known as the "haircut". The haircut provides a margin to the lender in case of default and an incentive for the borrower to repurchase the collateral tomorrow, since the collateral is more valuable than the cash.

After the crisis, governments passed laws to limit banks' leverage, which affected banks' trading of all currencies. The Graham-Dodd Act was passed in the United States on 21 July 2010 and it instituted a minimum "leverage ratio" of 3%. That is, that for every investment, the bank must set aside capital matching at least 3% of the investment. For "too big to fail" banks, the minimum leverage ratio was 5% or, for FDIC-insured entities, 6%. Basel III is an international accord on financial laws that states a minimum leverage ratio of 3%. Basel III began being implemented in 2013 and is expected to be finished by 2019. As of January 2015, European banks must publish their leverage ratio quarterly.

After the crisis, we can therefore expect banks to be restricted by the largest of the REPO haircut and leverage ratios, which are both measures of investment volatility. If banks are limited to a 3% leverage ratio, they can lever 1-to-33.33. Assuming banks expect a 10% return on their capital, the banks will trade if the max CIP basis spread is at least 30bp.[2] If banks are limited to a 6% leverage ratio, they trade if the max CIP basis spread is at least 60bp.[5]

There are other factors that affect trading. The Graham-Dodd Act also contains the Volcker Rule, which forbids American commercial banks from proprietary trading, like CIP arbitrage. The power of that regulation has been questioned, since banks can still trade currencies and can choose what securities they want to hold. Another factor is perception. Du et al. reported that CIP held less at the end of each quarter, because banks did not want to list currencies (which are perceived as volatile) in their books which get published quarterly. Nonetheless, the banks are assumed to be enforcing the CIP relationship if the max CIP basis spread does not dramatically exceed 60bp.

As can be seen in Figure 3.2, the max CIP basis spread, computed using swap rates, has exceeded 30bp since Aug. 2008 and exceeded 60bp since Nov. 2009. This is the covered interest parity problem: there is a large spread in CIP basis and it exceeds the bounds where banks should trade it. Given that the trade is low risk and involves large liquid markets, it seems unlikely that the max CIP basis spread should exceed those limits for long periods of time.

Even if major banks are not performing arbitrage, the question still remains: Why don't long-only investors, like pension funds and insurance companies, buy the least expensive bonds and push bond and FX prices closer to CIP? This can be done until the max CIP basis spread is equal to transaction fees. Cochrane claims that 50bp is "not a huge difference to long-only investors"[29], who do not use leverage. Liao claims the investment does not happen because funds are often restricted to buying domestic bonds.[3] So, instead of pension funds buying foreign bonds and hedging their exposure, it falls to the foreign firms to issue bond in the pension funds' domestic markets and hedge the FX exposure internally to the firm.[5]

[5] The market has names for these overseas bonds. They are called "yankee bonds" when issued in USD, "samurai bonds" in JPY, etc.

3.4 Risky Investments

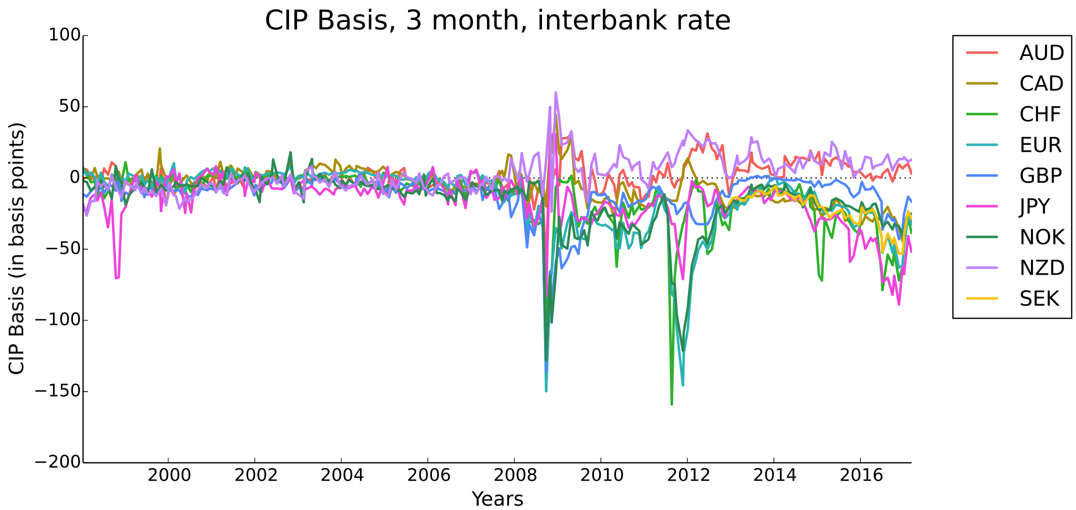
CIP can only be applied to foreign and domestic bonds that have identical risks. This applies to government bonds, if we assume they are risk-free. It also applies to an individual firm's bonds that are issued in multiple currencies, if they have the same properties (maturity, etc.) and we assume default is handled identically in every country. However, many studies in the literature use securities that do not have identical risks.

Many researchers use OIS or interbank loans (e.g., LIBOR), which do not have identical risk in foreign and domestic currencies. Du et al. in footnote 5[2] credit Frenkel and Levich[30] for this practice. There are reasons for this: Banks' risk is traditionally low. The transaction fees for OIS and LIBOR may be lower than with government bonds. And if shorting is necessary, banks are more likely to borrow to perform a currency transaction than a government is. Thus, despite their risks, the max CIP basis spread has been smaller for these bank borrowing rates than government rates.[30] The small value for max CIP basis spread can be seen prior to 2007 in Figure 3.3, which uses 3-month interbank loan rates.

These rates are short-term: OIS is an overnight loan and interbank loans, like LIBOR, usually extend 3 months. For a longer-term approximations to them, researchers have used swap rates.

The swap rate comes from interest rate swaps, which are defined as the exchange of a variable-rate bond for a fixed-rate bond. The variable rate is

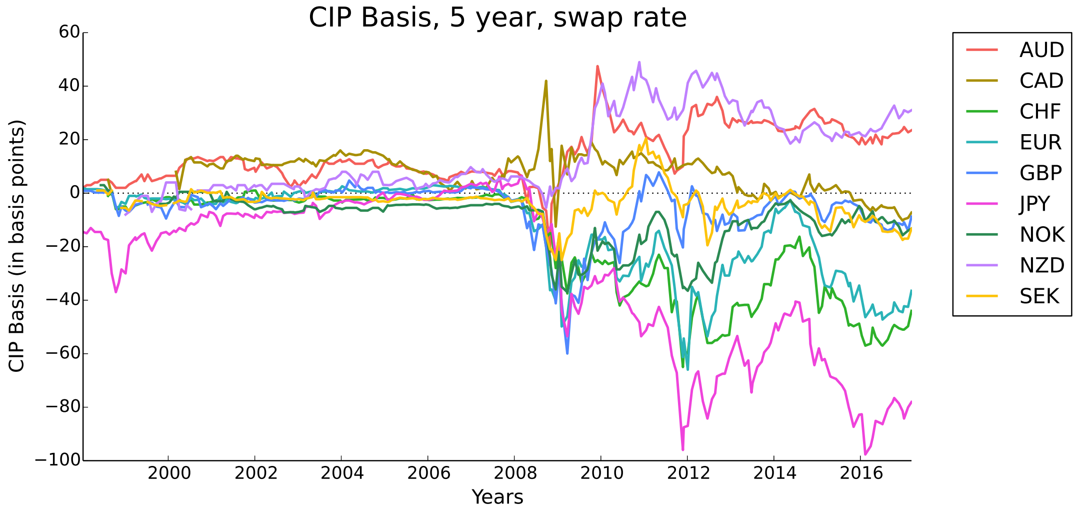
Figure 3.3: CIP basis using 3-month interbank loans



Note: CIP basis is the difference between the return from investing in USD and investing locally, without leverage. In this graph, the investments are 3-month interbank loans (LIBOR, EURIBOR, etc.). CIP basis was close to zero prior to the Global Financial Crisis of 2007-2008.
Source: Bloomberg L.P.

usually a well-known standard, such as LIBOR for USD, and the fixed-rate coupon is the "price" of the swap. So, a trade of 1M USD for 5 years at a price of 2% would have the fixed-rate side receive 1% twice a year (since twice-yearly is the convention with USD bonds) while the variable-rate side would receive the LIBOR 3M rate four times a year. At the end of 5 years, both parties would each have to pay the other the principle of the bonds, 1M USD, but those amounts cancel out, so most interest rate swaps have only a "notional" principle. The 2% "price" for the interest rate swap, is known as the swap rate.

Figure 3.4: CIP basis using swap rates with 5-year horizon



Note: CIP basis is the difference between the return from investing in USD bonds and investing in local bonds. In this plot, the swap rates are used as the bonds' interest rates. Prior to 2008, the median spread from the largest CIP basis to the smallest was under 20bp. After 2012, the median spread exceeded 95bp.
Source: Bloomberg L.P.

Some researchers measure the CIP basis for swap rates by using a related product, the cross-currency basis swap. The cross-currency basis swap for EUR has 3 legs: a variable rate one in EUR (such as EURIBOR), a variable rate in the reference currency USD (such as LIBOR), and fixed-rate leg in EUR. It can be thought of as an EUR interest rate swap and a USD interest rate swap packaged together. The fixed-rate leg is the "price" of the basis swap and it is equal to the CIP basis using the swap rates. Researchers prefer the cross-currency basis swap because of this ease-of-measurement, because traders are not making a directional bet in either currency, and because a large volume is traded in the product, which results in accurate prices.

Figure 3.4 is a plot of CIP basis using swap rates with a 5-year horizon. Swap rates may have been used for CIP research, but there a number of issues which may prevent them being a good replacement for OIS and LIBOR 3M. This will be addressed in Section 5.1.

Chapter 4

CIP and Corporate Bonds

Covered interest parity has mostly been studied in relation to government bond rates and various bank borrowing rates, such as LIBOR 3M and the swap rate. Corporate bonds, in the U.S., are a market almost as big as Treasury bonds (9.7T USD vs. 11.8T USD). Liao[3] took a first step into this area by proposing that CIP holds for corporate bonds, when adjusted for maturity and other properties. In Liao's model, CIP is not enforced by banks performing arbitrage, but by firms choosing to issue bonds in the market with the lowest interest rates.

Liao verified his model by showing a strong correlation between CIP basis using swap rates and the "residualized credit spread differential". This section defines that term, explains its relationship with CIP basis, and explains how I calculated it (and how my calculation differed from Liao's).

4.1 Credit Spread Differential

This section defines the terms "credit spread" and "credit spread differential" for a single firm, so that Section 4.3 can define "residualized credit spread differential" for a set of firms.

A credit spread measures the price of risk using the difference between two rates. Liao uses the term "credit spread" to refer to the difference between corporate bond rates and the swap rate, which he uses as a reference rate:

$$cs_{f,EUR} = r_{f,EUR} - r_{swap,EUR} \tag{4.1}$$

where $cs_{f,EUR}$ is the credit spread for a firm f in the EUR market, $r_{f,EUR}$ is the rate for the firm's bonds in the EUR market, and $r_{swap,EUR}$ is the swap rate. Liao defined "credit spread differential" as:

$$c_{f,EUR} = (r_{f,EUR} - r_{swap,EUR}) - (r_{f,USD} - r_{swap,USD}) \tag{4.2}$$

where $c_{f,EUR}$ is the credit spread differential for a firm f for EUR in reference to USD. The credit spread differential $c_{f,EUR}$ measures the difference in the price of risk between the two currencies. If the value is positive, high-risk bonds will be cheaper (higher yield) in the local market and more expensive (lower yield) overseas. Thus, risk-taking investors will purchase in local markets and risk-providing corporations will issue bonds outside them. If the credit spread differential is negative, risk-taking investors will buy overseas and risk-providing corporations will issue natively.

In this thesis, the credit spread differential will always use USD as the reference currency. In this chapter, the CIP basis will be the 5-year CIP basis using the swap rate as the reference rate.

The credit spread differential is for a single firm, f. When investigating an aggregate measure, Liao found that simple averaging was insufficient. He produced the "residualized credit spread differential", which will be defined later in this chapter.

4.2 The Model

Liao's model is described in Appendix A. It was used without any modifications.

This chapter verifies the third prediction of the model. (See Section A.3 in Appendix A.) In the model, the representative firm always issues bonds in the cheapest market. As the representative firm issues more bonds, the prices of domestic and foreign corporate bonds move towards the same price (adjusted for FX). When the CIP basis is 0 for those corporate bonds, the credit spread differential and the CIP basis using swaps move equally in the same direction. Expressed as an equation:

$$lim_{D \to \infty} c - b = 0 \tag{4.3}$$

where D is the amount of debt issued, c is the credit spread differential, and b is the CIP basis using swap rates. In the following analysis, D is assumed to be sufficiently large that the prediction can be verified by measuring the correlation of c and b.

4.3 Liao's Analysis

Liao generated a single credit spread differential using the data from many firms. He did it by using a regression to predict the credit spread for each bond from each firm, and then using the fixed-effect estimate for currency as the credit spread in the credit spread differential formula. He called this the "residualized credit spread differential".

In Liao's regressions, the term S_{it} represents the credit spread for bond i and is the bond's yield minus the swap rate at time t. The swap rate was calculated from the exact duration of the bond at time t (e.g., 4.548 years) and was a linear interpolation of the published swap rates (e.g., 4-year and 5-year rates).[31]

Liao used the following cross-sectional regression:

$$S_{it} = \alpha_{ct} + \beta_{ft} + \gamma_{mt} + \delta_{rt} + \epsilon_{it} \tag{4.4}$$

where α_{ct}, β_{ft}, γ_{mt}, and δ_{rt} are fixed effects for currency c, firm f, maturity bucket m and credit rating bucket r. The maturity buckets were: 1 to 3 years, 3 to 7 years, 7 to 10 years, and >10 years. The ratings buckets were high (Moody's rating $\geq$ A) or low, with each bucket holding roughly the same number of bonds.

Liao calls $\hat{\alpha}_{ct}$ the "residualized credit spread" and estimates the credit spread differential for currency c with $\hat{\alpha}_{ct} - \hat{\alpha}_{USDt}$, which he calls the "residualized credit spread differential" (RCSD). The remainder of this analysis is comparing the RCSD with the CIP basis using swaps and measuring the correlation.[32]

4.4 Reproduction of Liao's Results

My reproduction of Liao's work differs mostly in the data used. I did not have Liao's resources and have a smaller data set: 17,000 bonds as compared to 35,000. (See Chapter 2 for details.)

The same regression was used, with a few adjustments to the data buckets.

$$S_{it} = \alpha_{ct} + \beta_{ft} + \gamma_{mt} + \delta_{rt} + \epsilon_{it} \tag{4.5}$$

γ_{mt} was the fixed effect for 4 maturity buckets (1 to 3 years, 3 to 7 years, 7 to 10 years, 10 to 20 years). The largest was capped at 20 years, since that was the longest-termed swap rate in my data set. δ_{rt} was the fixed effect for two ratings buckets, but, to ensure equal-sized buckets, the "high" bucket contains bonds with a combined credit rating[1] of at least an Aa3 from Moody's or an AA- from S&P.

When measuring correlation, RCSD is compared to CIP basis with a 5-year horizon. RCSD does not have a horizon. The regression formula in equation 4.4 assumes the fixed-effects for maturity does not depend on the currency, and so RCSD could be compared to CIP basis with any horizon. Liao's plots use the CIP basis with a 5-year horizon. I did not find Liao's rationale for the choice. 5-year corporate bonds are common in the data set and 5-year might be close to the median or mean corporate bond duration in

[1]Combined credit ratings are defined in Chapter 2.

the data set. This work uses a CIP basis with a 5-year horizon so that my results may be compared to Liao's.

Liao computed correlations and plotted graphs of RCSD and CIP basis for each currency. The same is done here. Table 4.1 has, for each currency, the correlation between the residual credit spread differential and the CIP basis using swap rates with a 5-year horizon. When Liao analyzed the currency, its correlation is also in the table. The table also contains the correlation for a pooled sample of the 9 currencies I studied and the 6 that Liao did.

Table 4.1: Correlation of RCSD with CIP basis using swaps

Currency	Correlation	Liao's Correlation
EUR	.85	.77
JPY	.57	.72
CHF	.67	.71
GBP	.18	.74
AUD	.47	.28
CAD	.19	.57
SEK	.53	N/A
NOK	.77	N/A
NZD	.53	N/A
all currencies	.68	.81

Note: Correlation of residualized credit spread difference with CIP basis using swap rates with a 5-year horizon. The row "all currencies" reflects a pooled sample containing the 9 currencies in my data and 6 currencies in Liao's. (Liao did not study SEK, NOK, nor NZD.)

Figures 4.1 to 4.9 show the residualized credit spread differential and CIP basis using swap rates for each currency. Where Liao studied the currency, the figure contains two panels, with Panel A contains my results and Panel B contains Liao's results. Panel B has been shifted horizontally to align the dates in the plots for easier comparison. Liao did not study SEK, NOK, and NZD, and for those currencies, there is no Panel B. The CIP basis has a 5-year horizon, to match what Liao chose. The error bars in all plots are the 95% confidence interval computed using robust standard errors clustered at the firm level.

In general, my plots of RCSD are similar to Liao's. Some features of Figures 4.1 to 4.9 are:

- There were dramatically fewer bond prices for the time from May 2002 to July 2005. In plots of EUR, JPY and CHF (in Figures 4.1 to 4.3), this is the likely cause of the higher standard errors in RCSD from mid-2002 to late 2004. For CAD, SEK, and NZD (Figures 4.6, 4.7, and 4.9), this is the likely cause for no value for RCSD for periods between early 2003 to late 2005. There were fewer than 900 price sample in each month from May 2002 to July 2005. (Every month in 2000 and 2001 exceeded 1,400 samples. As did every month after January 2006, excepting holidays. See Table 2.2.)

- For EUR in Figure 4.1, the value of RCSD is significantly below CIP basis for most of 2003. This could be due to the few price samples in the data set. The closest historical events are in 2002: EUR coins and notes were issued and Greece joined the Eurozone.

- In most plots, there is a steep drop in both RCSD and CIP basis in late 2008 and early 2009. This is related to the Global Financial Crisis and, for CIP basis, signals that it was more profitable to invest domestically than in USD. In November 2008, the U.S. Federal Reserve System started the quantitative easing later known as "QE1".

- For JPY (Figure 4.2), there was a rise in RCSD without a rise in CIP basis from mid-2009 to mid-2010. The Global Financial Crisis had a dramatic effect on Japan, but it rebounded with 4.2% growth in 2010, as compared to America's 2.5% and the E.U.'s 2.0%.

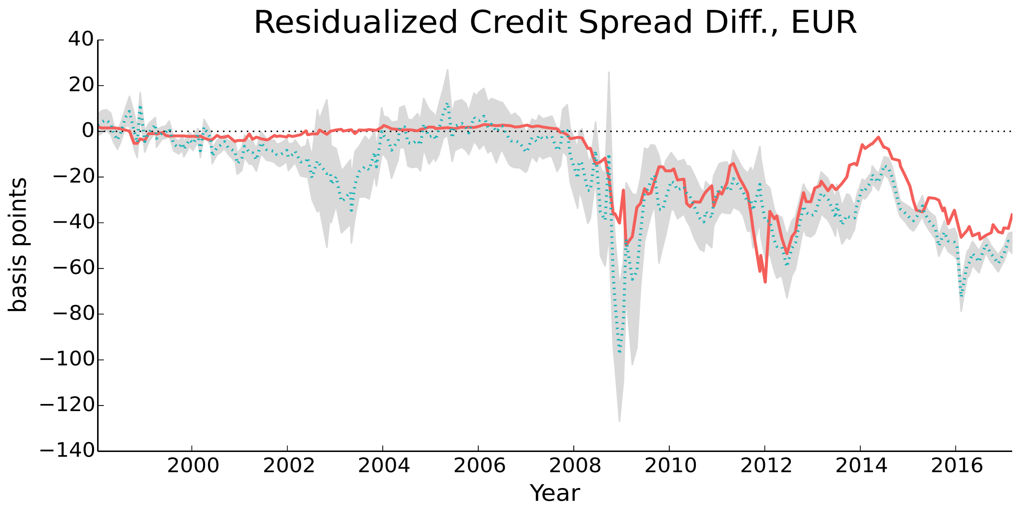
- For GBP (Figure 4.4), RCSD was significantly above CIP basis from late-2011 to mid-2013. During the same period, for NOK (Figure 4.8), RCSD was significantly below CIP basis. This is during the peak of the Euro debt crisis, where the yield for Greece's long-term debt went above 25% and Portugal's above 13%. The United Kingdom is part of the E.U., but does not use the Euro currency. Norway is not a member of the E.U., but is part of the European Economic Area, which has free movement of persons, goods, services, and capital (the "European Single Market").

- For some graphs, the CIP basis is significantly above or below the RCSD from 2013 onward. EUR, AUD, NOK has it above and JPY has it below.

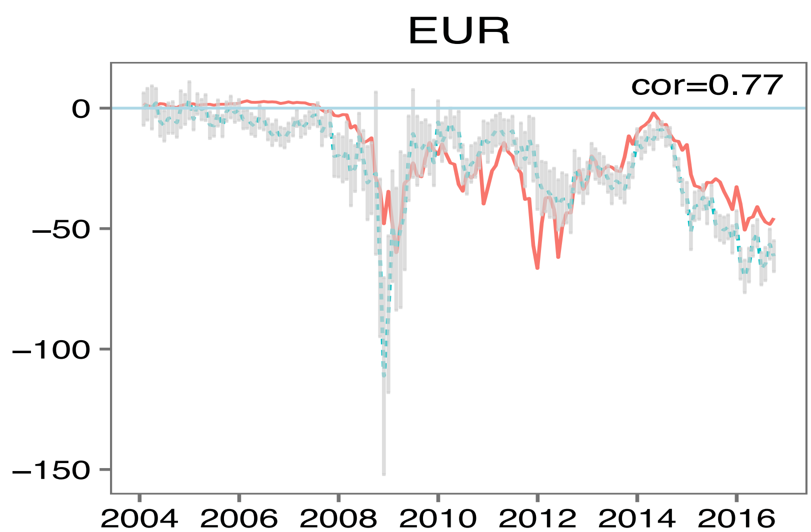
Figure 4.10 has comprehensive results, a plot of CIP basis against RCSD. Panel A contains my results and Panel B contains Liao's results. The slope of the trend line is .6390 and the r-squared is .4890. If CIP basis was 0 for the corporate bonds, the slope would be expected to be 1.

Figure 4.1: Residualized credit spread diff. of EUR

Panel A:



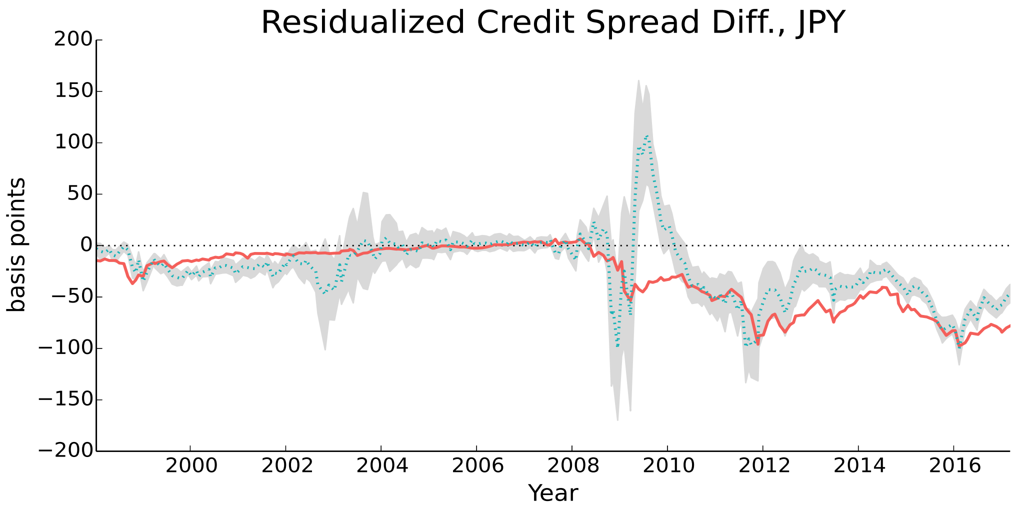
Panel B:



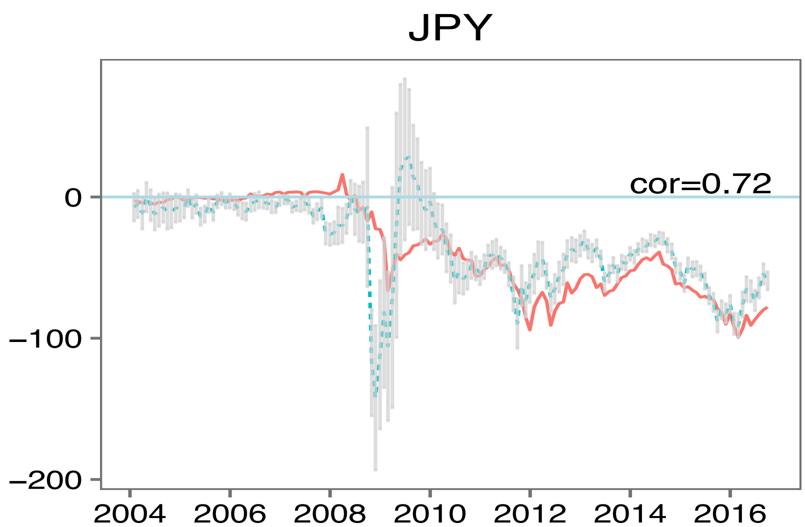
Note: Panel A is from this work and Panel B is from Liao's. Liao's plot has been shifted to the right in order to align the dates for easier comparison. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis using swaps with a 5-year horizon is in red (solid).
Source: (Panel B only) Liao(2016)[3]

Figure 4.2: Residualized credit spread diff. of JPY

Panel A:



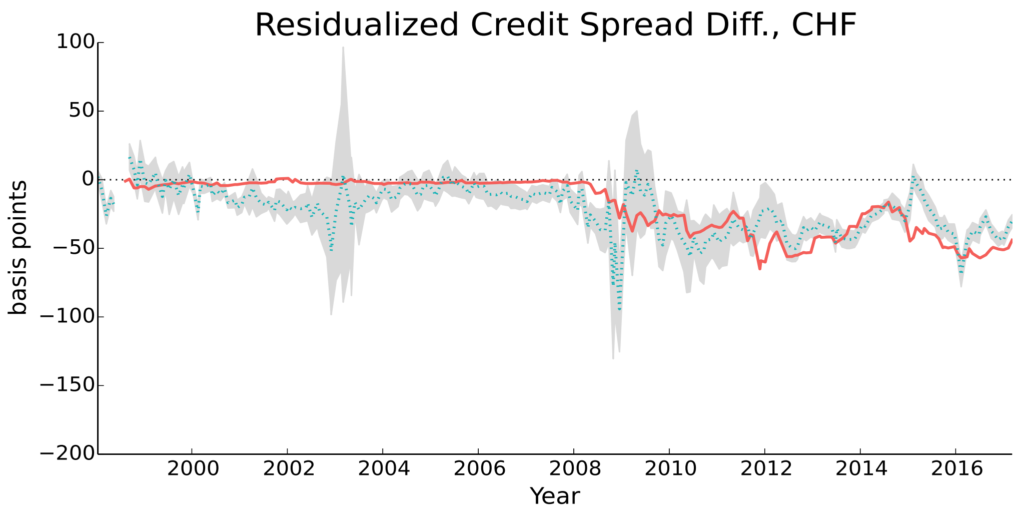
Panel B:



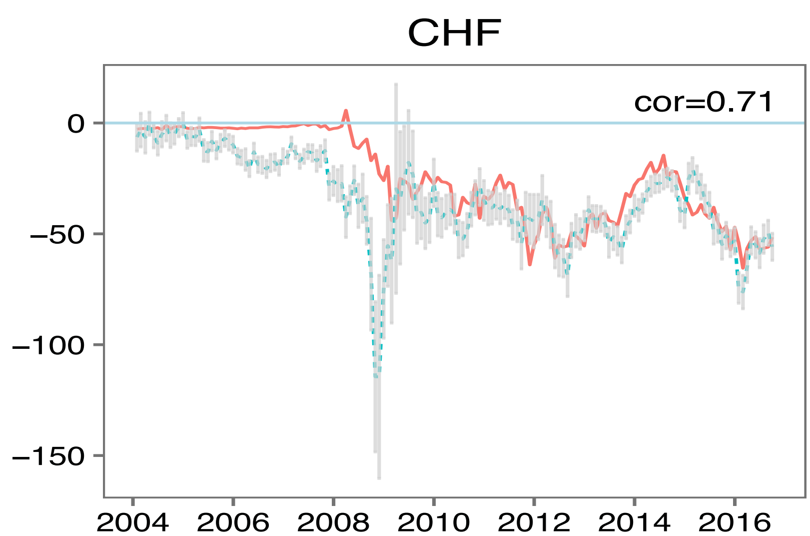
Note: Panel A is from this work and Panel B is from Liao's. Liao's plot has been shifted to the right in order to align the dates for easier comparison. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis using swaps with a 5-year horizon is in red (solid).
Source: (Panel B only) Liao(2016)[3]

Figure 4.3: Residualized credit spread diff. of CHF

Panel A:



Panel B:

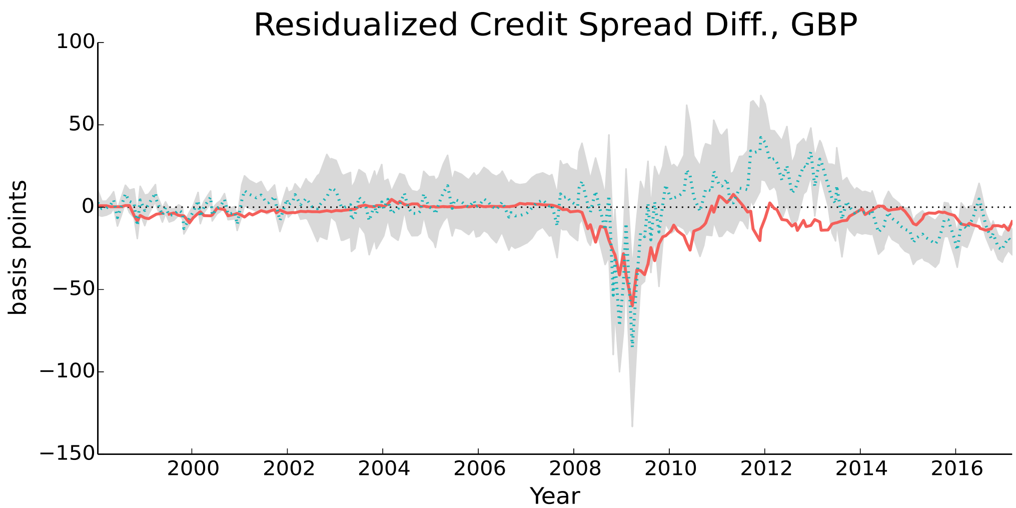


Note: Panel A is from this work and Panel B is from Liao's. Liao's plot has been shifted to the right in order to align the dates for easier comparison. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis using swaps with a 5-year horizon is in red (solid).

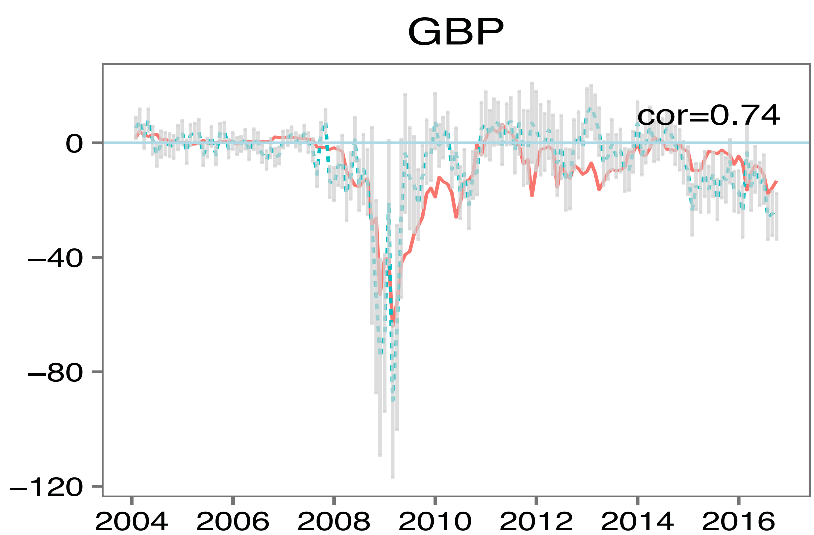
Source: (Panel B only) Liao(2016)[3]

Figure 4.4: Residualized credit spread diff. of GBP

Panel A:



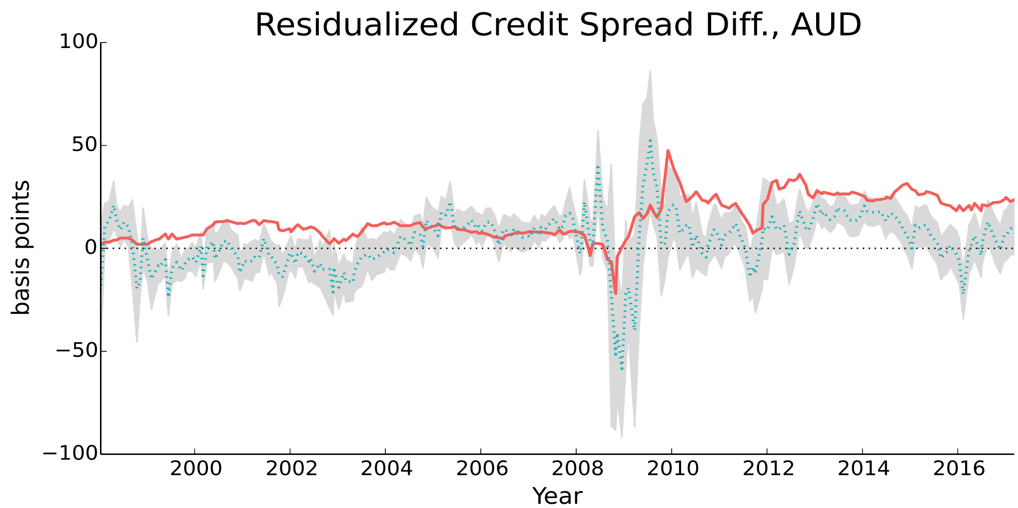
Panel B:



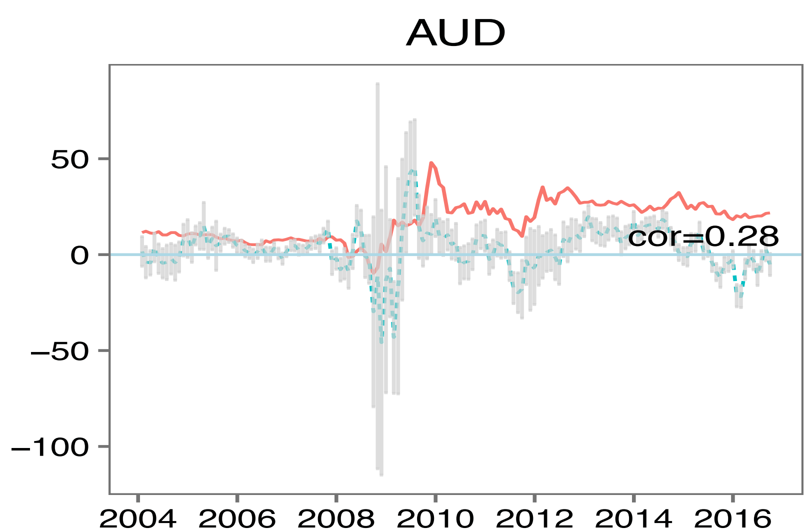
Note: Panel A is from this work and Panel B is from Liao's. Liao's plot has been shifted to the right in order to align the dates for easier comparison. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis using swaps with a 5-year horizon is in red (solid).
Source: (Panel B only) Liao(2016)[3]

Figure 4.5: Residualized credit spread diff. of AUD

Panel A:



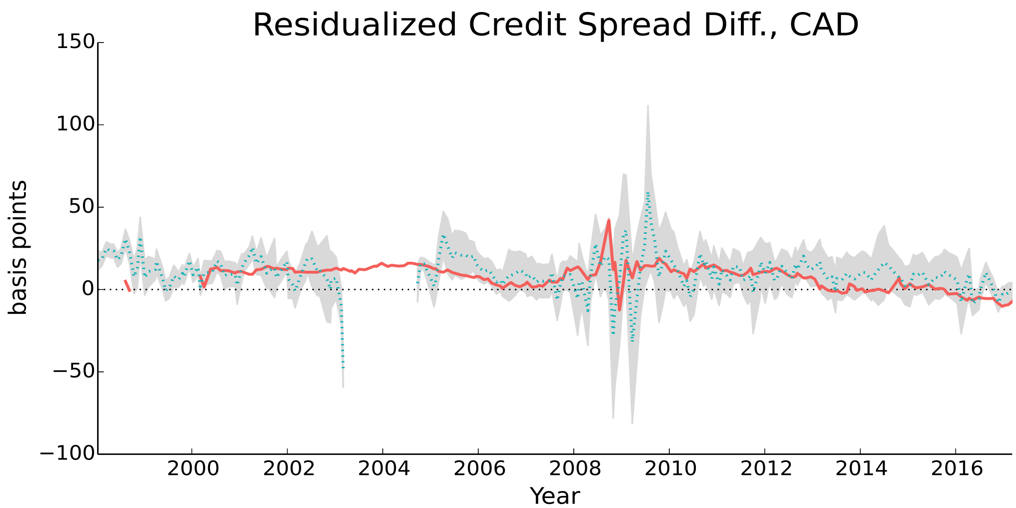
Panel B:



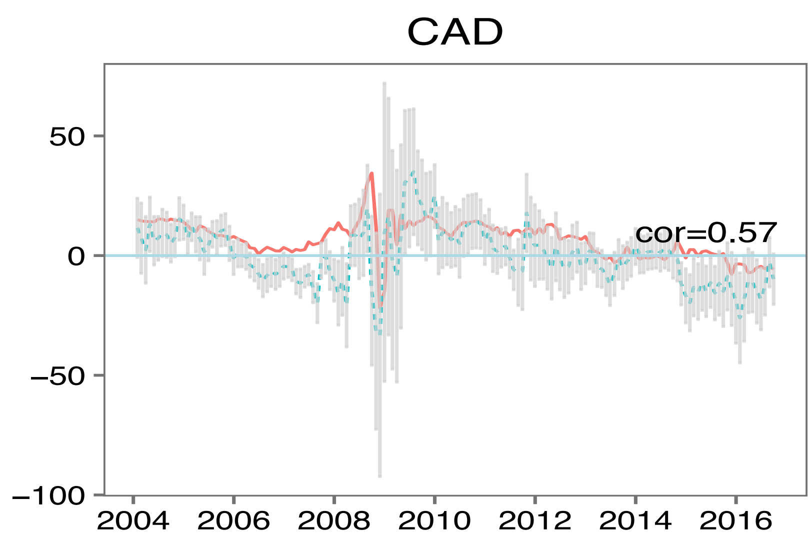
Note: Panel A is from this work and Panel B is from Liao's. Liao's plot has been shifted to the right in order to align the dates for easier comparison. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis using swaps with a 5-year horizon is in red (solid).
Source: (Panel B only) Liao(2016)[3]

Figure 4.6: Residualized credit spread diff. of CAD

Panel A:

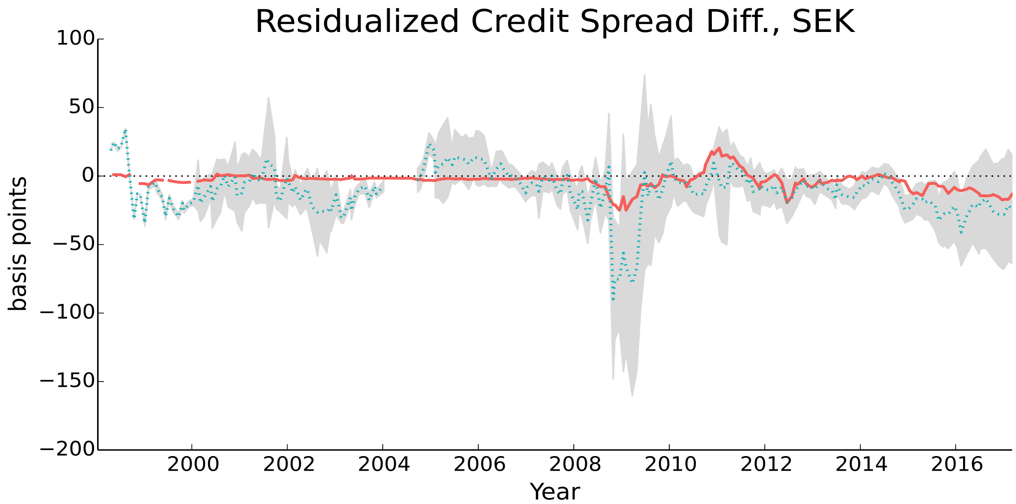


Panel B:



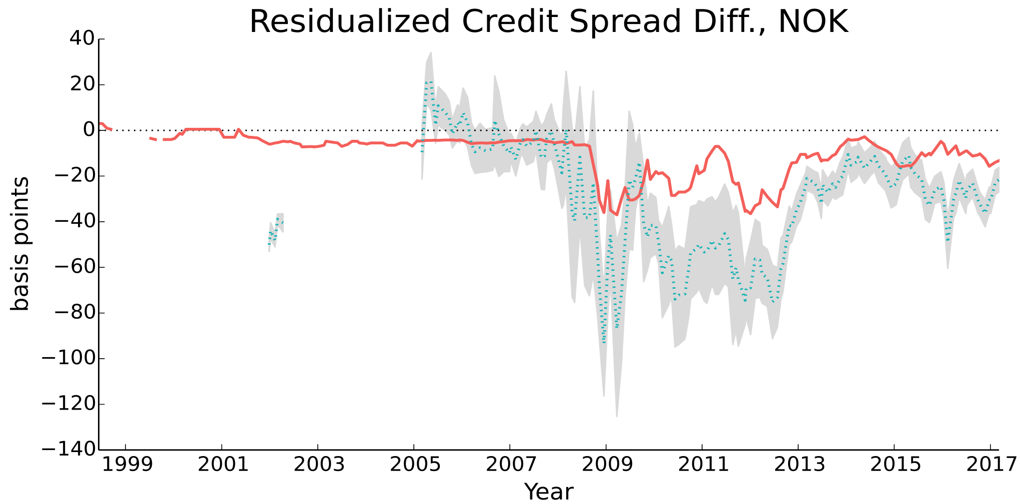
Note: Panel A is from this work and Panel B is from Liao's. Liao's plot has been shifted to the right in order to align the dates for easier comparison. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis using swaps with a 5-year horizon is in red (solid).
Source: (Panel B only) Liao(2016)[3]

Figure 4.7: Residualized credit spread diff. of SEK



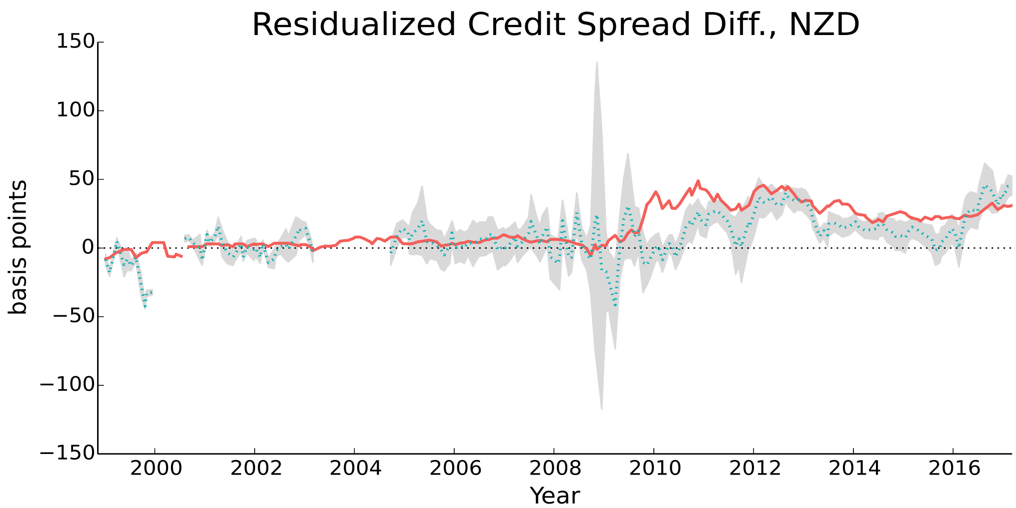
Note: The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid). There is no comparison with Liao[3], since Liao did not study this currency.

Figure 4.8: Residualized credit spread diff. of NOK



Note: The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid). There is no comparison with Liao[3], since Liao did not study this currency.

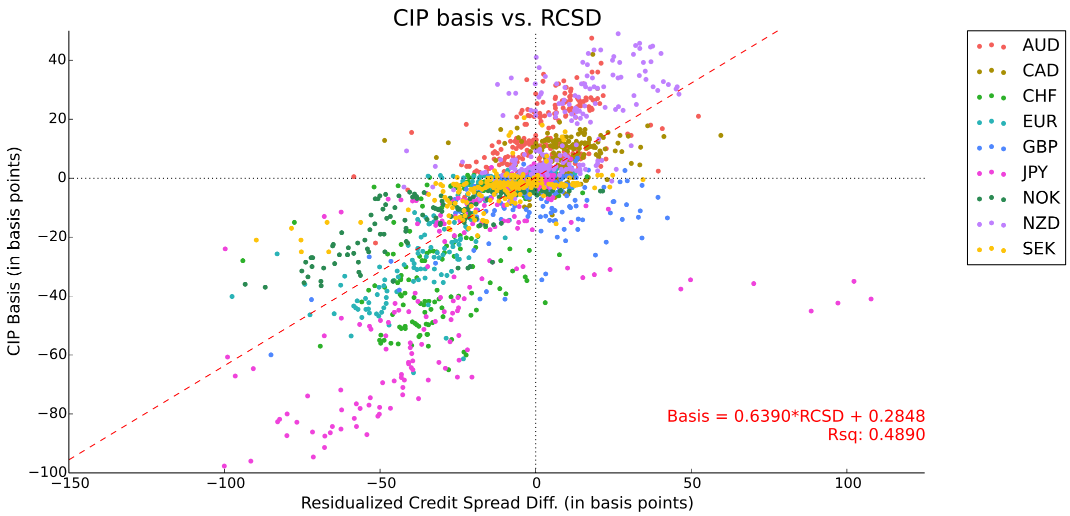
Figure 4.9: Residualized credit spread diff. of NZD



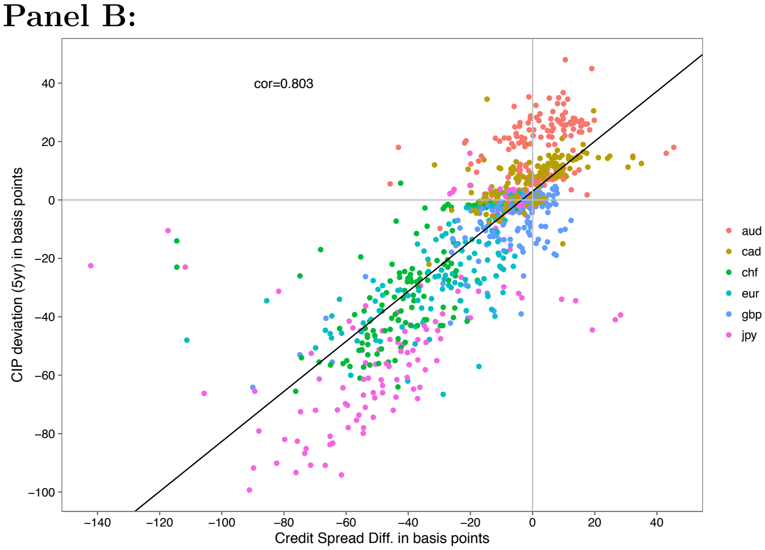
Note: The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid). There is no comparison with Liao[3], since Liao did not study this currency.

Figure 4.10: CIP basis vs. RCSD

Panel A:



Panel B:



Note: Plots of CIP basis against residualized credit spread differential, for all currencies. Panel A is from this work and Panel B is from Liao's. The red-dashed trend line in Panel A is from a linear regression. Liao did not document what the black line was in his plot.
Source: (Panel B only) Liao(2016)[3]

Chapter 5

Extensions

Two new studies were done using corporate bonds. First, I reperformed Liao's analysis, except using government bond rates as the reference interest rate instead of swap rates. Second, I estimated CIP basis using corporate bond rates and compared the result to that gotten using government and swap rates.

5.1 Alternative Interest Rate

Liao's study, as well as others in the field, uses the swap rate instead of a government bond rate to compute the CIP basis. This section presents reasons why this may not be good practice and then reproduces the results of Chapter 4 using government bond rates as the reference rate.

5.1.1 Reasons Not To Use the Swap Rate

Swap rates are convenient to gather and use in calculations of CIP basis, but there are a number of reasons why swap rates may not be appropriate. Two reasons are presented in this subsection. The first applies to all bank borrowing rates (i.e., including LIBOR and OIS), and not just the swap rate.

CIP requires the bonds involved to have the exact same risk. Banks from different countries have different default risks and the bank borrowing rates (OIS and interbank loans) will reflect those different risks. While the financial systems of countries are linked, they do not move identically. If a trader goes long USD LIBOR and short EURIBOR, they are not left with zero risk.

Experimentally, Frenkel and Levich[30] found that CIP basis calculated with interbank loan rates was generally closer to zero than when CIP basis was calculated with government bills. This may be because banks are more likely to increase borrowing (i.e., go short) in order to exploit currency prices than governments are. But if that condition held before the crisis, it does not necessarily mean it will hold during the crisis.[1]

The second reason not to use swap rates is that swaps are not bonds. Treasury notes, OIS and LIBOR are all loans for a fixed amount of money, but an interest rate swap is a contract for an exchange of floating payments.

Unlike the market for U.S. Treasuries, where customers are trying to buy bonds, the market for interest rates swaps has customers who are trying to buy a contract, most often to be part of a portfolio with other securities (e.g., to hedge risk). Because the customers are interested in particular portfolios, not the contract by itself, it is not clear from the contract's definition what the price in the market should be. In fact, the prices of interest rate swaps

[1] In fact, Frenkel and Levich chose to measure CIP basis during a calm period: "The empirical analysis covers the period between January 1962 and November 1967. The choice of the period was determined by our preference for a relatively "quiet period" which was terminated by the British devaluation."[30]

have been studied[33] because, since 2009, the 20Y swap rate has spent most of its time below the 20Y U.S. Treasury bond rate, which many found to be unexpected. (See Figure 5.1.)

The interest rate swap is equivalent to exchanging a fixed-rate bond for a variable-rate one. For USD swaps, the variable-rate bond uses the LIBOR 3M rate and, for EUR swaps, the variable-rate bond uses EURIBOR 3M. Other authors measure CIP basis by the difference between the USD and EUR interest rate swap rates, which means they are measuring the difference between payments of LIBOR 3M and EURIBOR 3M. It is not obvious why these should have equal risk or even have equally priced risk. This argument is strengthened by larger spreads between OIS and the interbank loan rate since the crisis.[2, 4]

Multiple papers in the CIP field use swap rates for their long-term rates. Borio et al.[4] use them. Others use a variant, the "cross-currency basis swap", which is two interest rate swaps packaged together. Those appear in Liao[3], Du, et al.[2] and Avdjiev et al.[7].

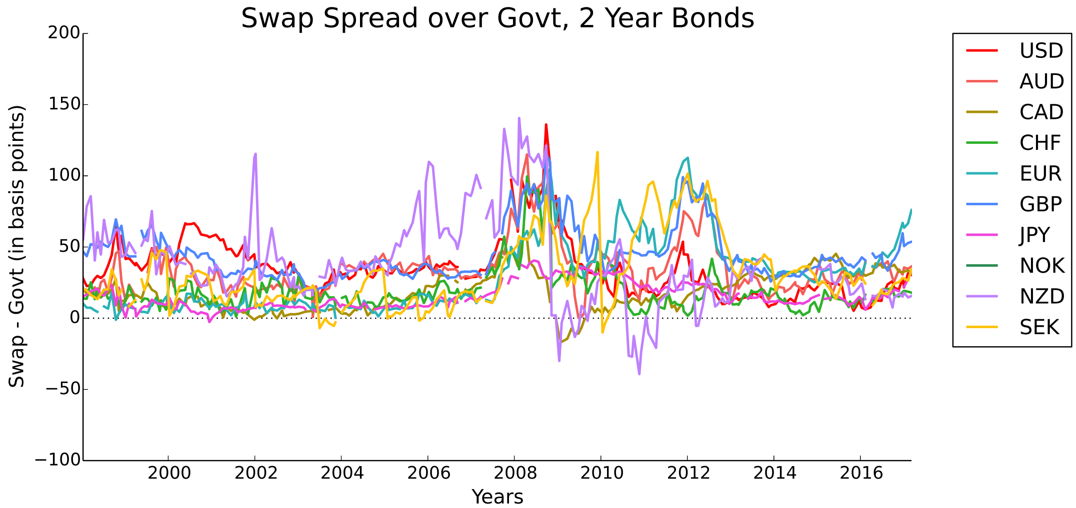
5.1.2 Results Using Government Bond Rates

I reproduced Liao's work using government bond rates, instead of the swap rates. In this section, I describe the changes to the analysis and the results.

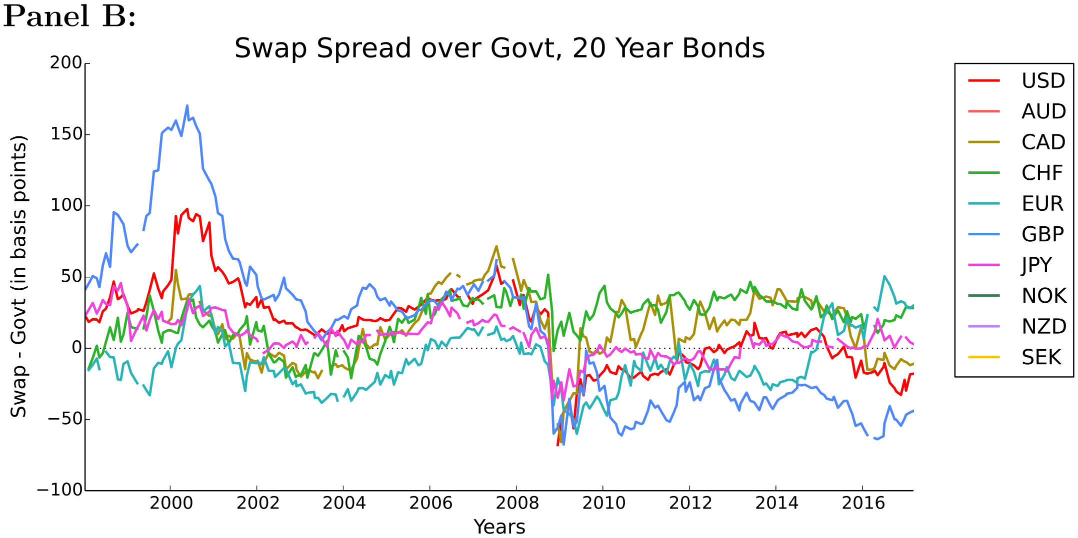
The set of bond prices used is not exactly the same as in the previous chapter's study. The regression requires the spread of the bond rate over the

Figure 5.1: Spread of swap rate over the government rate

Panel A:



Panel B:



Note: The swap rate minus the rate on government bonds, over time. Panel A uses 2 year bonds; Panel B uses 20 year bonds. For shorter terms, the swap rate behaves like a bank borrowing rate, staying a small amount above the government rate. And during the crisis, when banks were under distress, the spread rose. However, for longer terms, the swap rate does not behave like a bank borrowing rate. It went below the government rate and, during the crisis, it dropped rather than rose.
Source: Central banks, Bloomberg L.P.

reference interest rate. In the previous section, the reference rate was the swap rate and, in this section, it is the government rate. When the reference rate for a particular date does not exist, the data sample was dropped. Missing swap rates happened occasionally, with no particular pattern. With government rates, it was more systematic. (See Table 5.1.) For example, AUD and NZD do not have 20 year bonds; their maximum is 10 years. So, for those currencies, only data within 10 years of the measured date was used.

Table 5.1: Maturities priced by central banks

Currency	1-year bond	2Y	3Y	5Y	7Y	10Y	20Y
USD	Y	Y	Y	Y	Y	Y	Y
EUR	Y	Y	Y	Y	Y	Y	Y
JPY	Y	Y	Y	Y	Y	Y	Y
CHF	Y	Y	Y	Y	Y	Y	Y
GBP	Y	Y	Y	Y	Y	Y	Y
AUD		Y	Y	Y		Y	
CAD	Y	Y	Y	Y	Y	Y	Y
SEK	Y	Y		Y	Y	Y	
NOK	Y		Y	Y		Y	
NZD	Y	Y		Y		Y	

Note: Central banks estimate prices for their country's bonds in the secondary market. 'Y' indicates that the maturity is priced by the central bank.
Source: Central banks

The goal of replacing swap rates with government rates was to obtain greater accuracy, not to improve the correlation. But the correlations of the pooled sample did improve from 68% to 82%. Table 5.2 has separate correlations for each currency.

Table 5.2: Correlation of RCSD with CIP basis using govt. rates

Currency	Govt. Correlation	Swap Correlation	Liao's Correlation
EUR	.85	.85	.77
JPY	.44	.57	.72
CHF	.45	.67	.71
GBP	.56	.18	.74
AUD	.91	.47	.28
CAD	.90	.19	.57
SEK	.82	.53	N/A
NOK	.87	.77	N/A
NZD	.79	.53	N/A
all currencies	.82	.68	.81

Note: Correlation of RCSD with CIP basis using government bond rates with a 5-year horizon. The row "all currencies" reflects a pooled sample containing the 9 currencies in my data and 6 currencies in Liao's. (Liao did not study SEK, NOK, nor NZD.)

Figures 5.2 to 5.10 show the residualized credit spread differential and CIP basis using government rates in Panel A and swap rates in Panel B. The CIP basis has a 5-year horizon. The error bars in all plots are the 95% confidence interval computed using robust standard errors clustered at the firm level.

In general, the separation of RCSD and CIP basis is similar between the pairs of plots. Some features of Figures 5.2 to 5.10 are:

- In all plots using government rates, the CIP basis from 1998 to 2007 is farther from the x-axis when using government rates than when using swap rates. Swap rates are generally within 30bp of the x-axis, while government rates can exceed 60bp, such as with EUR in 1999. The distance between CIP basis and RCSD seems similar to the plots using swap rates.

- Just as with the swap rate data, there were dramatically fewer bond prices for the time from May 2002 to July 2005. In plots of EUR, JPY and CHF (Figures 5.2 to 5.4), this is the likely cause of the higher standard errors in RCSD from mid-2002 to late 2004. For CAD, SEK, and NZD (Figures 5.7, 5.8, and 5.10), this is the likely reason why no value for RCSD was able to be computed for periods between early 2003 to late 2005. There were fewer than 900 price sample in each month from May 2002 to July 2005. (Every month in 2000 and 2001 exceeded 1,300 samples. As did every month after January 2006, excepting holidays. See Table 2.2.)

- Just as with the swap rate data, for EUR in Figures 5.2, the value of RCSD is significantly below CIP basis for most of 2003. This could be due to the few price samples in the data set. The closest historical events are in 2002: EUR coins and notes were issued and Greece joined the Eurozone.

- Just as with the swap rate data, in most plots there is a steep drop in both RCSD and CIP basis in late 2008 and early 2009. This is related to the Global Financial Crisis and, for CIP basis, signals that it was more profitable to invest domestically than in the U.S. In November 2008, the U.S. Federal Reserve System started the quantitative easing later known as "QE1".

- Just as with the swap rate data, for JPY (Figure 5.3), there was a rise in RCSD without a rise in CIP basis from mid-2009 to mid-2010. The Global Financial Crisis had a dramatic effect on Japan, but it rebounded with 4.2% growth in 2010, as compared to America's 2.5% and the E.U.'s 2.0%.

- Just as with the swap rate data, for GBP (Figure 5.5), RCSD was significantly above CIP basis from late-2011 to mid-2013. During the same period, for NOK (Figure 5.9), RCSD was significantly below CIP basis. This is during the peak of the Euro debt crisis, where the yield for Greece's long-term debt went above 25% and Portugal's above 13%. The United Kingdom is part of the E.U., but does not use the Euro currency. Norway is not a member of the E.U., but is part of the European Economic Area, which has free movement of persons, goods, services, and capital (the "European Single Market").

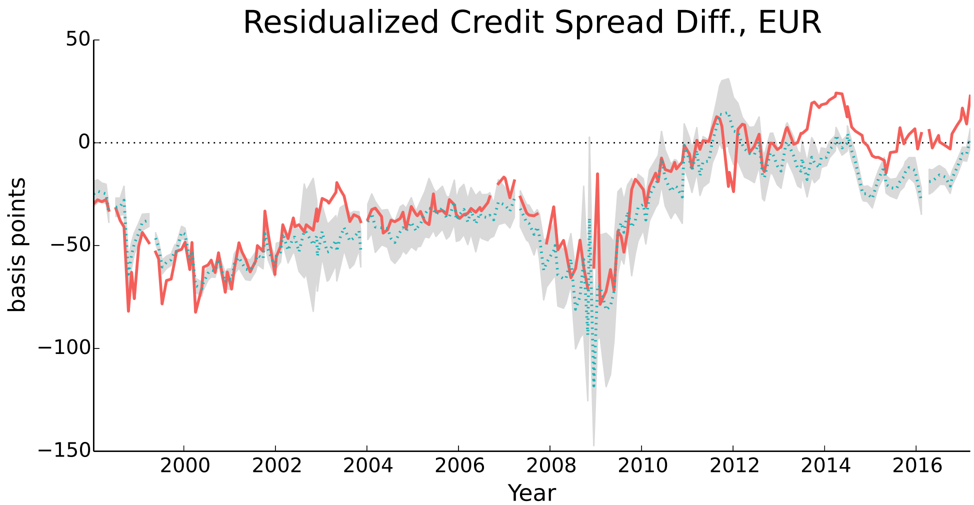
- Just as with the swap rate data, for some graphs, the CIP basis is significantly above or below the RCSD from 2013 onward. EUR, AUD, NOK has it above and JPY has it below.

Figure 5.11 has comprehensive results, a plot of CIP basis against RCSD. Panel A contains results using government rates as the reference rate and Panel B contains results using swap rates.

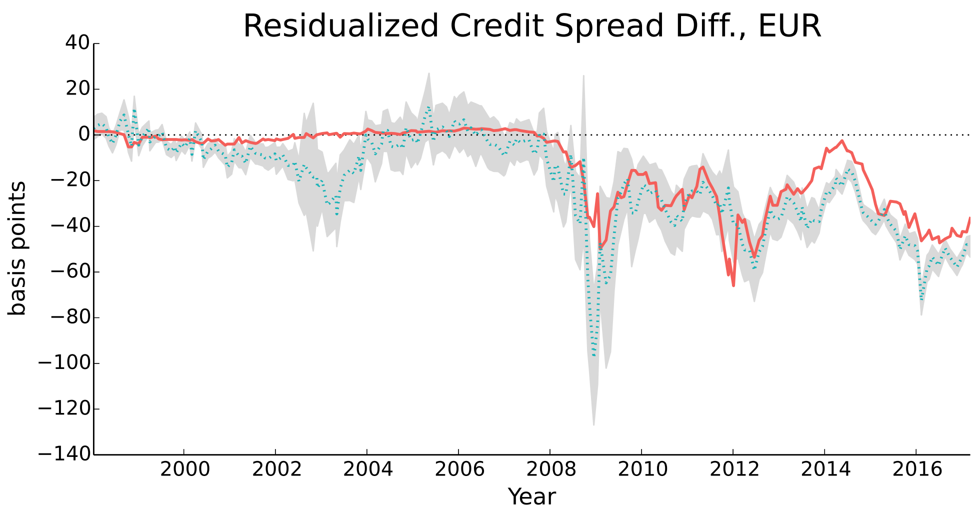
Government rates were used to get better accuracy, not a higher correlation. But the correlation did improve and the trend line in Figure 5.11 improves as well. The slope is closer to 1 (from .6390 to .9039) and a higher r-squared (from .4890 to .7222).

Figure 5.2: Residualized credit spread diff. of EUR

Panel A:



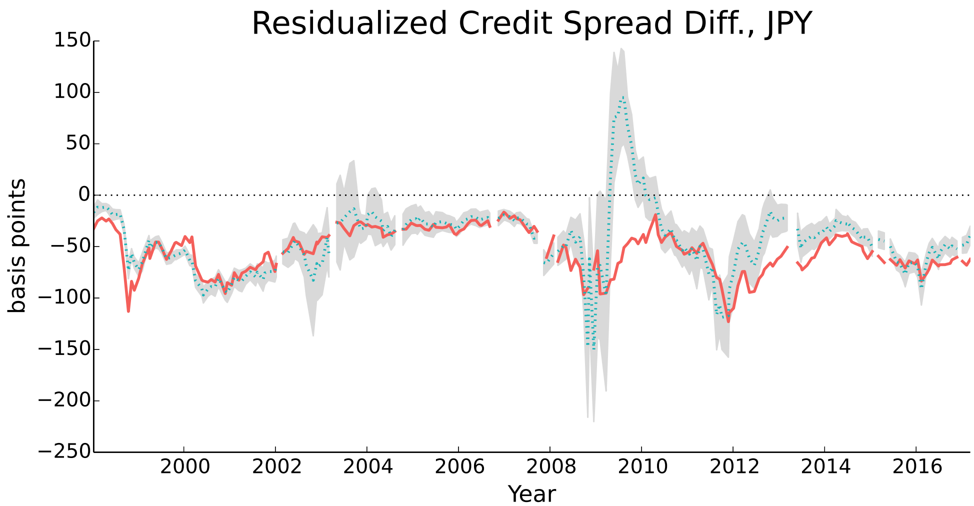
Panel B:



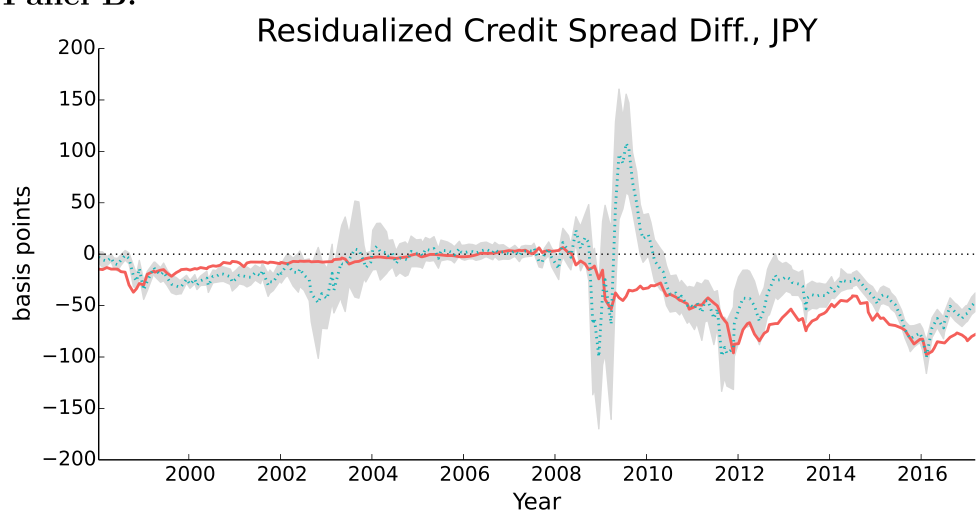
Note: Panel A uses government rates and Panel B uses swaps. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid).
Source: Central banks, Bloomberg L.P.

Figure 5.3: Residualized credit spread diff. of JPY

Panel A:



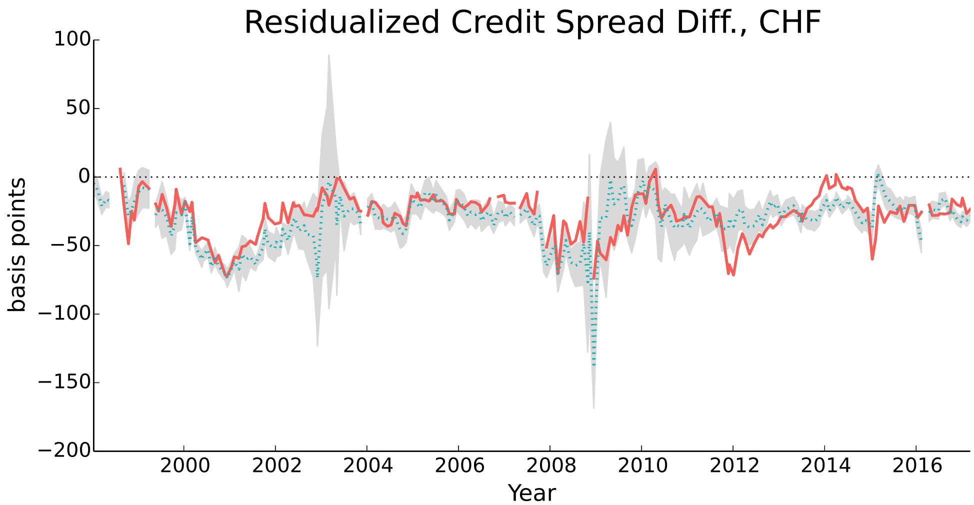
Panel B:



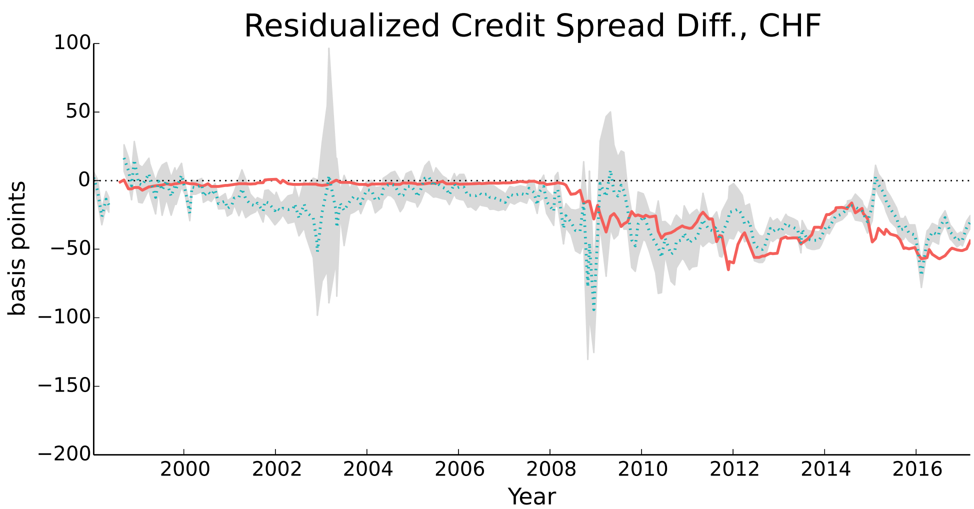
Note: Panel A uses government rates and Panel B uses swaps. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid).
Source: Central banks, Bloomberg L.P.

Figure 5.4: Residualized credit spread diff. of CHF

Panel A:



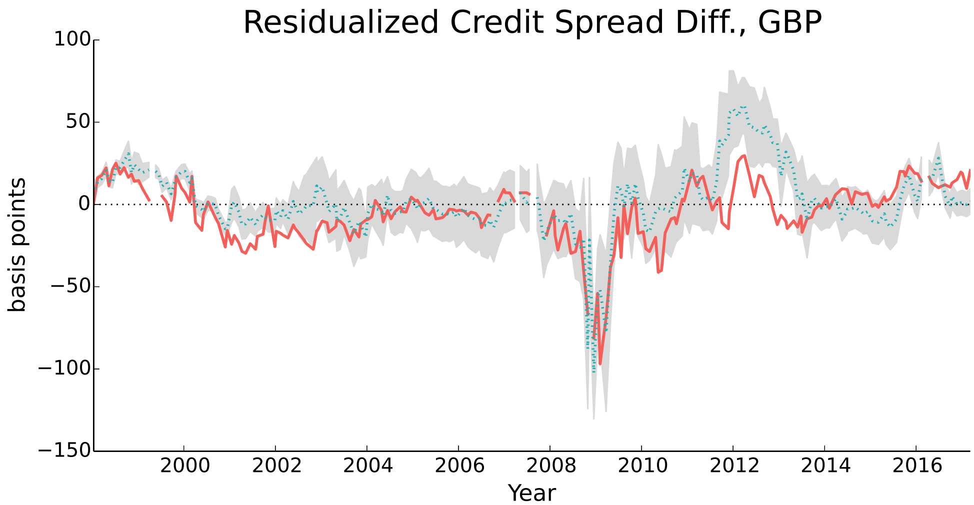
Panel B:



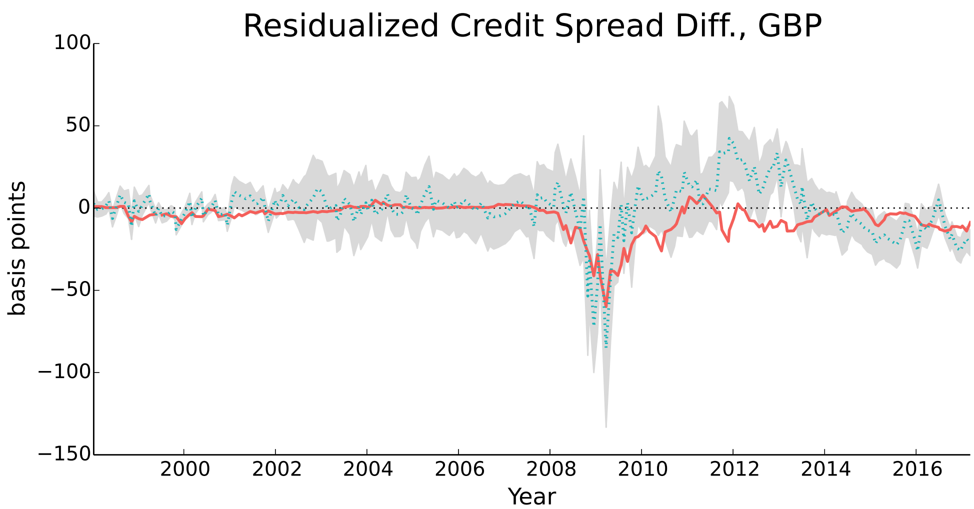
Note: Panel A uses government rates and Panel B uses swaps. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid).
Source: Central banks, Bloomberg L.P.

Figure 5.5: Residualized credit spread diff. of GBP

Panel A:



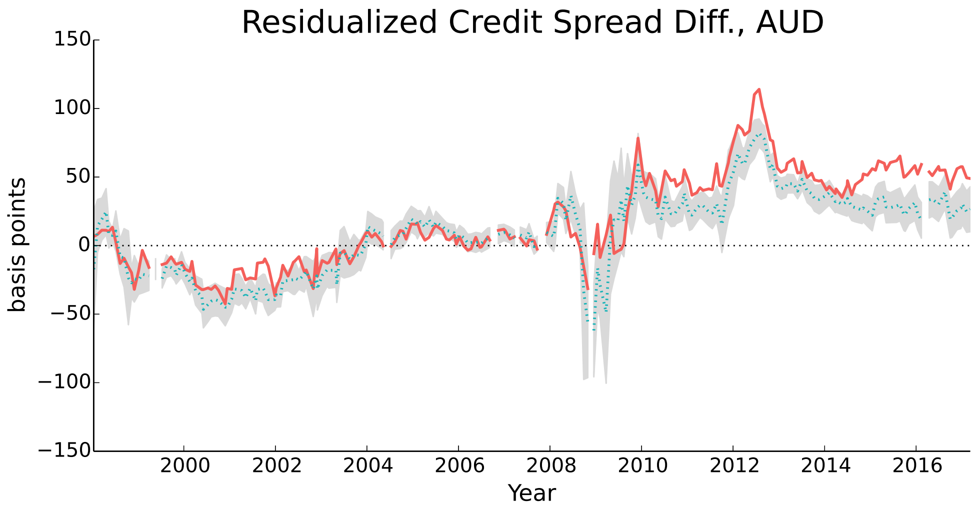
Panel B:



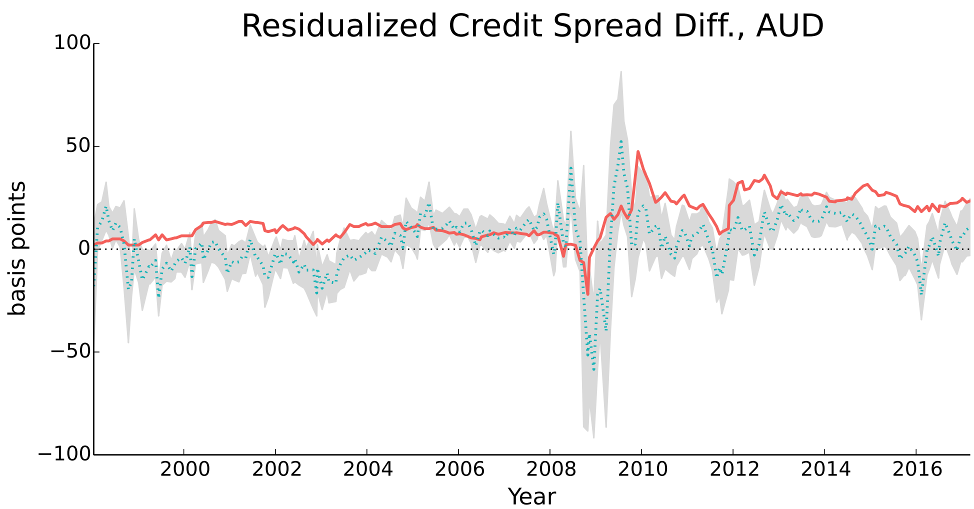
Note: Panel A uses government rates and Panel B uses swaps. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid).
Source: Central banks, Bloomberg L.P.

Figure 5.6: Residualized credit spread diff. of AUD

Panel A:



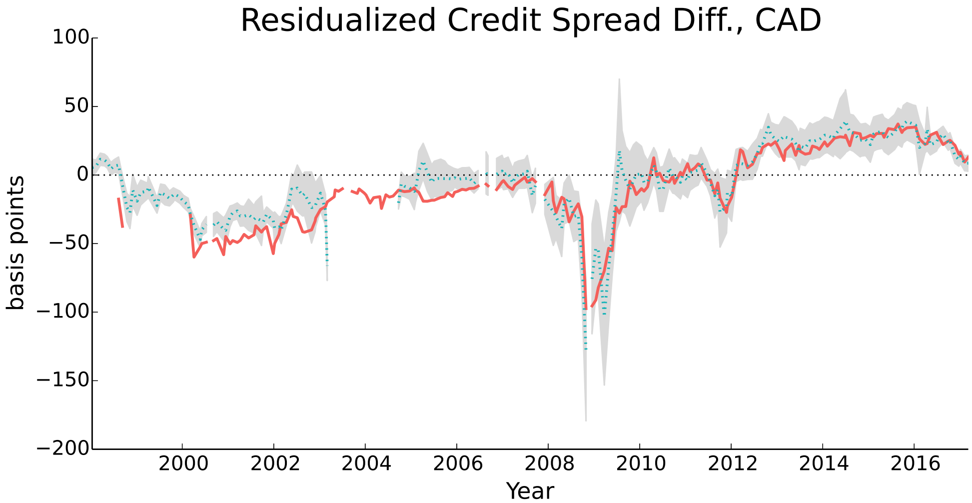
Panel B:



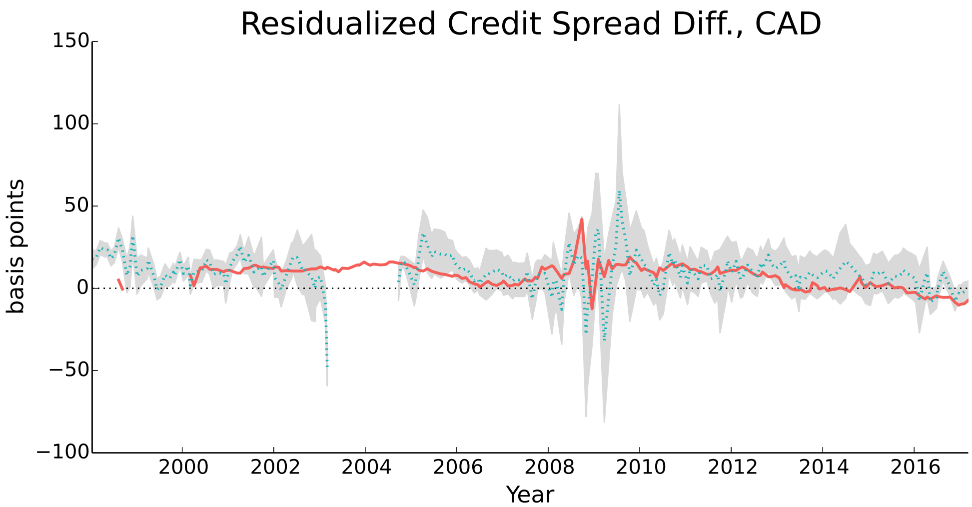
Note: Panel A uses government rates and Panel B uses swaps. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid).
Source: Central banks, Bloomberg L.P.

Figure 5.7: Residualized credit spread diff. of CAD

Panel A:



Panel B:

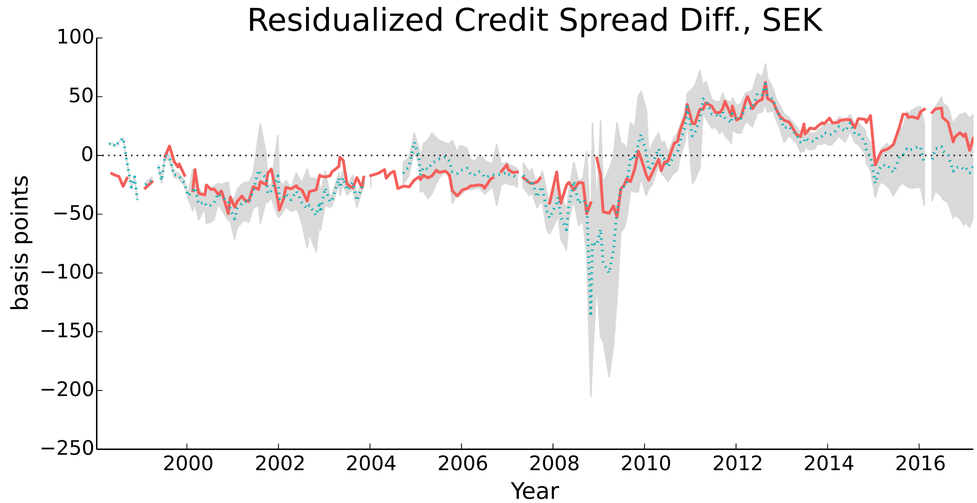


Note: Panel A uses government rates and Panel B uses swaps. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid).

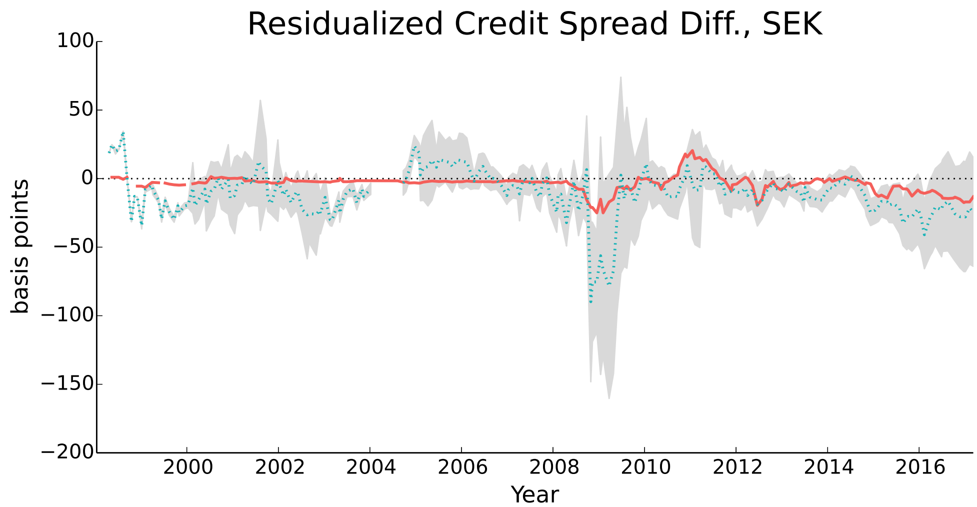
Source: Central banks, Bloomberg L.P.

Figure 5.8: Residualized credit spread diff. of SEK

Panel A:



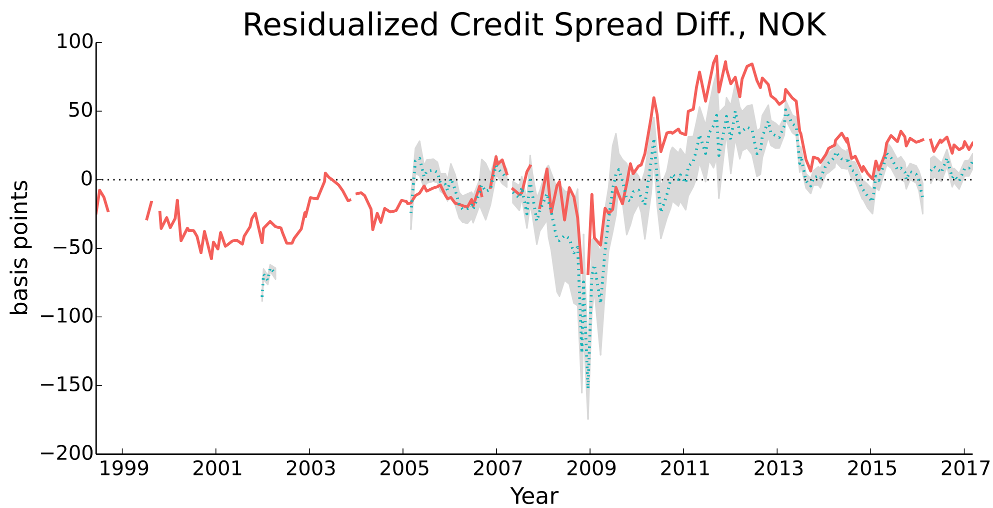
Panel B:



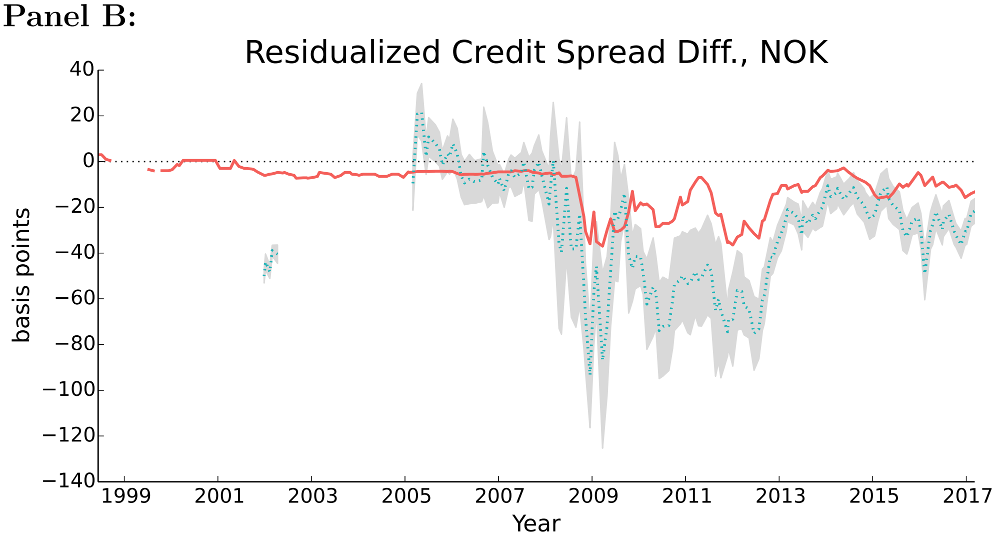
Note: Panel A uses government rates and Panel B uses swaps. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid).
Source: Central banks, Bloomberg L.P.

Figure 5.9: Residualized credit spread diff. of NOK

Panel A:



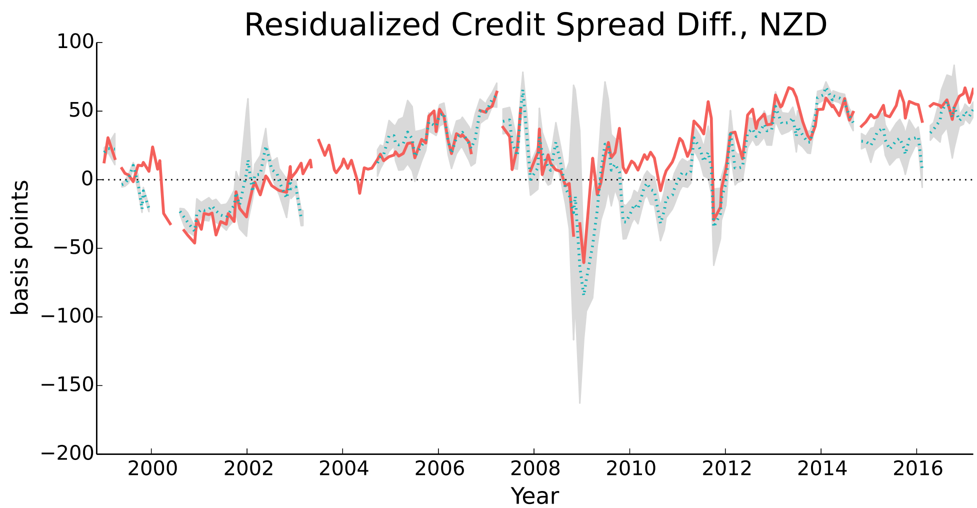
Panel B:



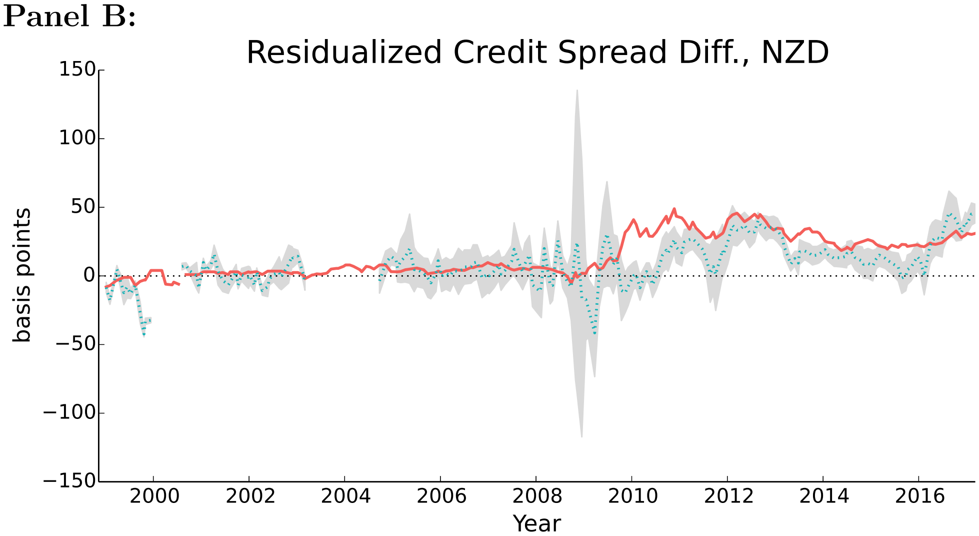
Note: Panel A uses government rates and Panel B uses swaps. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid).
Source: Central banks, Bloomberg L.P.

Figure 5.10: Residualized credit spread diff. of NZD

Panel A:



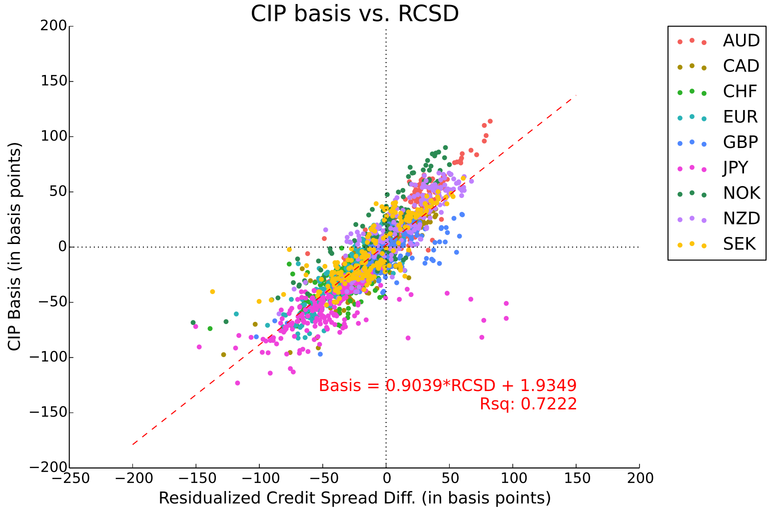
Panel B:



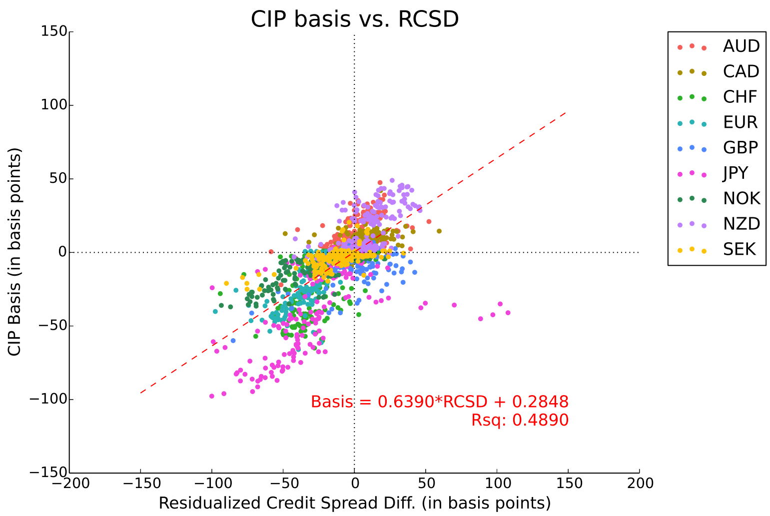
Note: Panel A uses government rates and Panel B uses swaps. The RCSD is plotted in blue (dotted) with the 95% confidence interval in gray. CIP basis is in red (solid).
Source: Central banks, Bloomberg L.P.

Figure 5.11: CIP basis vs. RCSD

Panel A:



Panel B:



Note: Plots of CIP basis against residualized credit spread differential. Panel A is with government bonds yields as the reference rate; Panel B with swap rates. The red-dashed trend line in both plots comes from a linear regression. Using government rates results in a slope that is closer to 1 and a higher r-squared.
Source: Central banks, Bloomberg L.P.

5.2 Measuring Corporate CIP Basis

So far, this work has measured CIP basis using swap rates and government bond rates. In this section, I present a different approach: using corporate bond prices. First, the model used for the measurement is described and its assumptions are discussed. Next, details are discussed which are necessary for applying the model to real data. Then, the model is compared and contrasted with Liao's regressions and work by Du et al. Lastly, the results are plotted and compared to CIP basis data gathered from swaps and government rates.

5.2.1 Corporate Bonds for CIP

Measuring CIP basis requires bonds, issued in different currencies, with the exact same risk. Government bonds can be used only if we assume that they are all risk-free. This is a plausible assumption, but a questionable one since only 3 of the 10 governments (Germany, Switzerland, and Norway) were top-rated by all three major credit rating agencies (S&P, Moody's, Fitch) for the period of this study, from Jan. 1998 to March 2017.[25] Swap rates, as detailed in Section 5.1.1, are not bonds and do not have the same risk. However, corporate bonds issued by the same firm in multiple countries should have similar risks.

Bonds issued by the same firm in multiple countries are not identical. Their prices can be affected when they are traded in different markets, with different ticksizes and different bid-ask spreads. Financial markets can differ because of each country's policy on inflation. In the case of default, depending on how bonds are issued, different countries have different courts and legal policies. Some countries might bailout native firms, but not foreign firms. And large international defaults can become political events.

Corporate bonds also differ in their attributes. A corporation can issue bonds with different maturities, different coupons, etc. In this section, I assume that the risk of a corporate bond does not depend on the currency it is issued in. However, bonds with different maturities will be allowed to have different levels of risk. That risk will be accounted for, when bond prices are used to measure CIP basis.

5.2.2 Model

The model assumes that there are many corporations, each with bonds giving a (potentially) different measure of corporate CIP basis. To resolve these different values, the model presumes there is a "true" CIP basis and there is some error in each measurement. Below, I'll present the model for a bond's yield, the model's assumptions, and then justify that the model accurately reflects the definition of CIP basis.

The model is defined in terms of a bond's yield so that CIP basis will be consistent when there are more than 2 currencies. The bond's yield is:

$$y_{f,c} = \log\left(\frac{S_{c,USD}}{F_{c,USD}}\right) - b_c + \zeta_f + \epsilon_{f,c} \tag{5.1}$$

where $y_{f,c}$ is the yield of a bond from firm f in currency c, $S_{c,USD}$ is the spot exchange rate for currency c in USD, $F_{c,USD}$ is the forward exchange rate, b_c is the CIP basis for currency c with USD as the reference currency, and ζ_f is the true yield for a bond from firm f in USD. Recall that CIP basis is in relation to a specific time horizon, such as 5 years, so the forward's delivery date and bond's maturity must share that same horizon.

The assumptions for this model are that $\epsilon_{f,c}$ are i.i.d., that $\mathbb{E}[\epsilon_{f,c}] = 0$, and that $\mathrm{Var}(\epsilon_{f,c}) = \sigma^2_{f,c}$. For yields, $y_{f,c}$ are i.i.d. and $\mathbb{E}\,|y_{f,c}|$ is finite. For ζ_f, I assume $\mathbb{E}[\zeta_f]$ is finite and that $\mathbb{E}[\zeta_f]$ does not change if the set of firms is restricted by the currencies in which the firms issue bonds.

These assumptions are not ideal, but are practical. The $\epsilon_{f,c}$ terms represent the error of pricing the bonds by the market. Assuming the firms' errors are uncorrelated between firms is unrealistic in practice, since there exists sectors in which firms' revenues are correlated. Nonetheless, many other stock and bond analyses make (or accept) the assumption that different firms have unrelated profitability, as is done here.

There is potential for selection bias in the model, since firms use bond yields to decide in which currencies to issue bonds. Bonds might not exist in currencies with high yields because firms choose the currency with the lowest yield in which to issue. This effect is lessened by using prices from the secondary market.

The selection bias does not affect ζ_f directly, but may do so indirectly. There is no direct effect because a firm's profit from issuing a bond overseas is affected by the CIP basis, b_c, and not by its true yield in USD, ζ_f. That is because, in the model, the true yield has the same effect on all markets. There is an indirect effect because larger firms are more likely to have a low ζ_f and more likely to have lower overhead for issuing overseas bonds. Thus, there might be correlation between issuance and ζ_f. Since the data is limited to bond issues of 150M USD (or equivalent), I assume all firms issuing are large and the selection bias does not affect ζ_f.

For this model, its estimate of CIP basis can be computed by averaging and its result is consistent with the definition of CIP basis. To derive this, take the mean of the yield over firms 1 to ϕ to get:

$$\frac{\sum_{f=1}^{\phi} y_{f,c}}{\phi} = \log\left(\frac{S_{c,USD}}{F_{c,USD}}\right) - \hat{b}_c + \frac{\sum_{f=1}^{\phi} \zeta_f}{\phi} + \frac{\sum_{f=1}^{\phi} \epsilon_{f,c}}{\phi} \tag{5.2}$$

Letting ϕ go to infinity, by the Law of Large Numbers, we get:

$$\mathbb{E}[y_{f,c}] = \log\left(\frac{S_{c,USD}}{F_{c,USD}}\right) - \hat{b}_c + \mathbb{E}[\zeta_f] + \mathbb{E}[\epsilon_{f,c}] \tag{5.3}$$

Using the assumption $\mathbb{E}[\epsilon_{f,c}] = 0$ and solving for $\hat{b}_c$ we get:

$$\hat{b}_c = \log\left(\frac{S_{c,USD}}{F_{c,USD}}\right) + \mathbb{E}[\zeta_f] - \mathbb{E}[y_{f,c}] \tag{5.4}$$

Now, if c is USD, there is no exchange of currencies and the CIP basis is by definition 0, yielding:

$$\mathbb{E}[\zeta_f] = \mathbb{E}[y_{f,USD}] \tag{5.5}$$

Using equation (5.5) to substitute $\mathbb{E}[\zeta_f]$ in equation (5.4), we get:

$$\hat{b}_c = \log\left(\frac{S_{c,USD}}{F_{c,USD}}\right) + \mathbb{E}[y_{f,USD}] - \mathbb{E}[y_{f,c}] \tag{5.6}$$

Using the approximations $e^x \approx 1 + x$ and $\log(1 + x) \approx x$ for small x, we get:

$$\hat{b}_c \approx \frac{S_{c,USD}}{F_{c,USD}}(1 + \mathbb{E}[y_{f,USD}]) - (1 + \mathbb{E}[y_{f,c}]) \tag{5.7}$$

Which is analogous to the definition of CIP basis:

$$b_c = \frac{S_{c,USD}}{F_{c,USD}}(1 + r_{USD}) - (1 + r_c) \tag{5.8}$$

The model has been presented and justified to represent the definition of CIP basis. Next, I'll go into the details of applying the model to real-world aspects of the data.

5.2.3 Adjusting Yields

The model in equation (5.1) assumes that every firm has multiple bonds that mature exactly with the CIP basis's horizon. That is, when calculating the CIP Basis with a 5-year horizon, the bonds all mature in exactly 5 years. This is rarely the case. When analyzing the data, the bond yields must be adjusted so that they estimate the yield of a 5-year bond, even if they happen to be a 4- or 6-year bond.

The adjustment is done by calculating the spread of the corporate bond over a government bond and then applying that spread to a government bond with the horizon's maturity. For example, if we want the yield of a corporate bond with a maturity of 5 years in EUR, but have a bond with a maturity of 4 years, we start by finding the yield of a government bond of 4 years. If none exists, we do a linear interpolation of the yield from the nearest government bonds, in this case, the 3- and 5-year German bund. If the estimated 4-year German bund has a yield of 1.0% and the 4-year corporate bond has a yield of 3.2%, we subtract to get the spread of 2.2%. To get our estimate of the 5-year corporate bond rate, we add that spread to the rate of the 5-year German bund. If that was 1.1%, the estimated corporate rate would be 1.1% + 2.2% = 3.3%.

In the following discussion, the term "adjusted yield" refers to a bond's yield that has been adjusted by this process to reflect a maturity equal to the CIP's horizon. It should be obvious that the maturity cannot be adjusted too far without a loss of quality to the estimate. When targeting a CIP with a 5-year horizon, only bonds with a remaining maturity between 3 years and 7 years were used.

This adjustment includes an additional source of error that comes from the government rates. The government rates are estimates themselves. They are assembled by the central banks from secondary market prices for government bonds. That means, the 5-year government rate may be an estimate from government bonds that themselves have maturities shorter or longer than 5-years. In the process of adjusting corporate yields, the government rate is both added and subtracted and the rates chosen are close in maturity, so its effect should be small.

5.2.4 Multiple-bond Model

The model in equation 5.1 assumes that firms issue at most one bond per currency, but in reality, there may be many. In this section, the single-bond model is modified. The important change is that errors are allowed to be correlated for bonds that share the same currency and firm.

The model for a bond's yield becomes:

$$y_{f,c,i} = \log\left(\frac{S_{c,USD}}{F_{c,USD}}\right) - b_{c,USD} + \zeta_f + \epsilon_{f,c,i} \tag{5.9}$$

where $y_{f,c,i}$ is the yield of bond i from firm f in currency c. The terms $S_{c,USD}$, $F_{c,USD}$, $b_{c,USD}$, and ζ_f remain unchanged. The error term $\epsilon_{f,c,i}$ is now also indexed by the bond identifier i. As in the original model, the CIP basis is in relation to a specific time horizon, such as 5 years, so the future and every bond's maturity must share that horizon.

Assumptions for the model include that $\epsilon_{f,c,i}$ are i.i.d. and that $\mathbb{E}[\epsilon_{f,c,i}] = 0$. The assumption that changes for $\epsilon_{f,c,i}$ is that $\mathbb{E}(\epsilon_{f,c,i}\epsilon_{f',c',i'}) = \sigma^2_{f,c}\,\mathbb{1}(f = f' \wedge c = c')$. That is, errors are correlated for the same firm and currency. The remaining assumptions are unchanged: For yields, $y_{f,c}$ are i.i.d. and $\mathbb{E}\,|y_{f,c}|$ is finite. For ζ_f, we assume $\mathbb{E}[\zeta_f]$ is finite and that $\mathbb{E}[\zeta_f]$ does not change if we restrict the set of firms by the currencies in which they issue bonds.

This multi-bond model is solved by averaging, similarly to the single-bond model. The model only differs in calculating the error term, where this multi-bond model uses robust clustered standard errors, clustering on the firm.

5.2.5 Comparison to Liao's Regression

The regression equation (5.9) looks similar to Liao's equation (4.4), so it is important to highlight the differences between this work and Liao's.

First, my regression is a measurement of a general property: CIP basis. The result of the measurement has a number of applications. Liao's regression result is one step in verifying a model. He is estimating the credit spread differential and then using the correlation of that estimate with CIP basis (using swap rates) to verify his model.

Second, my regression is derived from the formula for CIP basis. Liao's regression appears to originate from an industry practice, "matrix pricing", to approximate the credit spread. His paper states, "This method of attribution is analogous to the standard industry practice of matrix pricing in which a bond with unknown prices is assessed against other bonds with similar maturity and rating." The subsection where the regression is explained is entitled "Matrix pricing of corporate credit" and I could find nothing further about other origins of the regression formula.

Third, my regression has a specific time horizon. If that horizon is 5 years, the delivery dates of forwards are in 5 years and the yields of bonds are adjusted to 5-year maturities. Liao's regression operates on all maturities at once. He uses maturity buckets, so a 4-year bond is treated exactly the same as a 6-year, because they are in the same bucket. The maturity buckets are not indexed by currency, so the spread between short-term bonds of different currencies must be the same as the spread between long-term bonds of the same currencies.

Fourth, the set of assumptions is different. My analysis assumes that the spread between a 4-year and a 5-year government bond is nearly the same as between a 4-year and 5-year corporate bond, in the same currency. Liao's regression assumes that the spread for maturity does not depend on the currency. It also assumes that the spread for rating does not depend on the currency, nor on the maturity. Notice that my regression does not rely on a bond's rating, since the firms attributes are already assumed to be in the ζ_f term.

There are similarities. Liao defines "net deviation" as equal to the residual credit spread differential minus the CIP basis using swaps.[2] That value is very similar to the CIP basis using corporate bonds. (See Appendix B.) Liao assumes that net deviation should be close to 0, and converts that into a test that the credit spread differential and CIP in swap rates have a high correlation. However, net deviation is not CIP basis. It does not have a horizon and it assumes maturity's effect on yield is the same for all currencies.

To conclude, my regression computes CIP basis from corporate bonds. While it is similar to Liao's "net deviation", it is different in purpose, assumptions, and value.

[2]Page 29 of Liao[3] describes an improvement to the calculation of net deviation. Instead of computing RCSD by regression and then subtracting CIP basis, the value for CIP basis is moved into the regression and the horizon of the CIP basis is selected to match the maturity of the bond. This does not change any of the arguments made in this section.

5.2.6 Comparison to Du et al.

Du et al. also measured CIP basis using corporate bonds. Their most detailed analysis uses bonds from a single bank. There is also summary data from measuring CIP using bonds from supranational institutions, banks, and non-financial firms. The details below are based on their paper and its Online Appendix.[3]

Du et al.'s work on corporate bonds centered on measuring CIP basis using bonds from a single firm: the German bank Kreditanstalt fü Wiederaufbau (KfW).[2] The bank had a AAA rating and is owned by the German government "with all its liabilities fully backed by the German government".[2] They analyzed bonds in the following currencies: USD, EUR, JPY, CHF, and AUD.

The analysis used spreads over the swap rate for USD. For KfW's bonds in USD, the "z-spread" was the bond's yield minus the swap rate. For KfW's other bonds, the z-spread was the bond's yield minus both the swap rate and minus the rate of the cross-currency basis swap. The cross-currency basis swap rate is equal to CIP basis using swap rates and was used to account for the currency conversion. For a bond, Du et al. defined the "KfW basis" as the difference between the bond's z-spread and z-spread of a USD bond of similar maturity.

[3]The Online Appendix was downloaded on 10 November 2017. On 16 November 2017, the authors were working on a revision to it.[34]

Du et al. computed an aggregate KfW basis for a currency, say EUR. The first step was to group all EUR and USD bonds by maturity year. Second, the KfW basis was computed for all pairs of EUR and USD bonds with the same maturity. Third, the value was averaged within each maturity group. Lastly, the average was computed across all maturities.[34] Thus, the value Du et al. quantified and plotted was an average of CIP basis across all horizons.

Plots of the aggregate KfW basis show some correlation with CIP basis using 3-M LIBOR. For CHF and JPY, the aggregate KfW basis is always within 20bp of the 3-M LIBOR. For times after the crisis, the aggregate KfW basis for all 4 currencies is generally closer to 0 than CIP basis using 3-M LIBOR.

The authors determined that costs for the arbitrage trade were around 20 basis point and that CIP basis for the JPY, EUR, and CHF exceeded that margin for 75%, 50% and 30% of the period from 1 Jan. 2009 to 31 Aug. 2016.

KfW is a large issuer with 370B USD (equivalent) of bonds outstanding. However, the amount issued in both CHF and JPY was less than 5B USD (equivalent). The authors concluded "liquidity differential can be a potential factor in explaining the positive profits of going long in the more illiquid yen and Swiss franc KfW bonds and shorting the more liquid dollar KfW bonds.". But they also concluded that liquidity issues could not explain the positive spread between the USD and EUR bonds.

In addition to the analysis on KfW, Du et al. analyzed bonds from

16 banks and financial companies, using data gathered from Bloomberg. The method was, presumably, the same as with KfW.

The aggregate CIP basis was computed separately for each institution. Each company's aggregate CIP basis reacted differently. In 2009, one firm had an aggregate CIP basis above 150bp in AUD, while another had an aggregate CIP basis below -300bp. All four currencies had dates in 2009 where the top and bottom firm in aggregate CIP basis were at least 400bp apart. The plots of aggregate CIP basis were continuous; this effect did not seem to result from noise. The firms that had extreme values for aggregate CIP basis in one currency did not necessarily have extreme values in another currency.

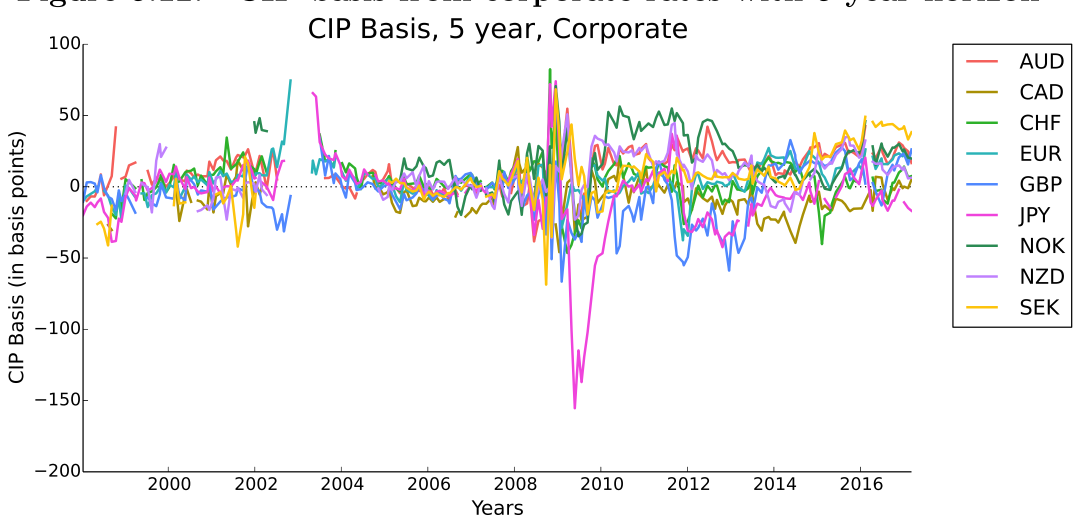
The values plotted were aggregate CIP basis, which means they were an average of CIP basis at different maturities. The maturities were not weighted evenly, because the analysis could only weight a maturity for which the firm had issued a bond and that bond had prices on Bloomberg. Also, the firms were all financial firms. Other firms look to them to take the other side of currency transactions. It should not be surprising that one or another might have difficulty borrowing in AUD if its clients had left it with a large position. Unlike with KfW, Du et al. did not comment on issues related to the liquidity of each firm in each currency.

Du et al. provides an interesting look at CIP basis for individual firms. Since individual firms only issue a few bonds, the calculation of CIP basis requires some form of aggregation across maturities to produce a meaningful number.

5.2.7 Results

Figure 5.12 contains a plot of the CIP basis inferred from corporate bond prices, for a 5-year horizon. Figure 5.13 has the max CIP basis spread for a 5-year horizon using swap, government and corporate rates. The abnormally low value for max CIP basis spread using corporate rates on 28 March 2016 is an Easter Monday, where 7 countries government rates were unavailable.

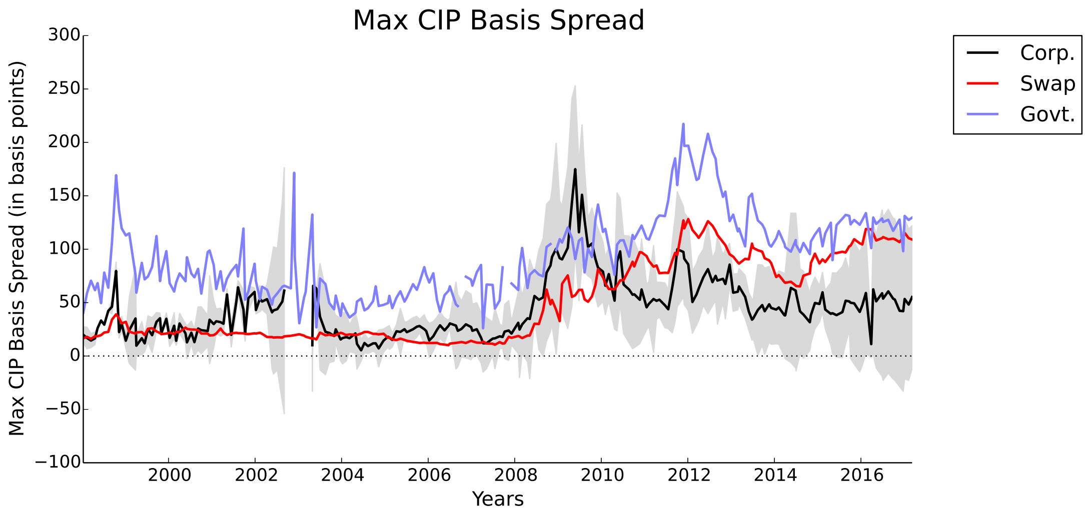
Figure 5.12: CIP basis from corporate rates with 5-year horizon



Note: CIP basis values inferred from a corporate bond rates, using a 5-year horizon.

For the period from Oct. 2002 to Aug. 2004, the max CIP basis spread using corporate rates has large errors — and even no value at all — as a result of having few price samples in the data set. The regression for CIP (equation (5.9)) requirements that the bond's maturity be "close in time" to the horizon. For the 5-year horizon, that was chosen to be 3 to 7 years from maturity. In each of the Oct. 2002 to Aug. 2004 time periods, there were

Figure 5.13: Max CIP basis spread



Note: Maximum CIP basis spread for 3 different ways of calculating CIP basis. The gray region is the 95% confidence interval for max CIP basis spread using corporate rates. The max CIP basis spread is the return an arbitrageur would get when trading without leverage. The abnormally low value for max CIP basis using corporate rates on 28 March 2016 is an Easter Monday, where 7 countries government rates were unavailable.
Source: Central banks, Bloomberg L.P.

fewer than 200 price samples that met that requirement. For January 2003, there were none. Other dates outside this time periods, barring holidays, had 350 to 2100 price samples.

From January 1998 (the start of the study) to December 2007, max CIP basis spread for the swap rate is almost flat. It spends 90% of its time between 10 and 25bp, with a median of 19.5. The max CIP basis spread using government rates spends 90% of its time between 38 and 92bp, with a median of 56.5. Max CIP basis spread using corporate rates spends 90% of its time between 5 and 61bp, with a median of 23.3. The spread using corporate rates spends much of its time close to the spread using swap rates, which at that time period was the metric for measuring CIP. The major departure from the swap rate during that time period is the Oct. 2002 to Aug. 2004 time period, which is associated with less data and higher error bounds.

From February 2009 to October 2009, max CIP basis spread is highest when computed with corporate bond rates, but this period also has larger error. The spike is caused by a large negative movement by JPY, as seen in Figure 5.12. This spike coincided with large swings in Japanese GDP. This spike is only seen in CIP basis calculated with corporate bonds and not when it is calculated with either government bonds nor swap contracts.

From Mid-2011 to the end of 2012, all measures of max CIP basis spread show a peak. This is during the height of the European debt crisis. For CIP basis using corporate bonds, the lowest currency is usually GBP and the highest is NOK, both European Single Market currencies. CIP basis using government bonds has JPY as its lowest and NOK as its highest. CIP basis using swap rates has NZD as its highest and JPY as its lowest.

From January 2013 to March 2017 (the end of the study), the median value of max CIP basis spread using swap rates is 96.4bp, up from 19.5bp during the 1998 to 2007 time period. For government bonds, the median spread is 116bp, up from 56.5bp. This is the problem that lead researchers to study CIP basis: a large bank should trade well before the spread gets to 96.4 or 116 basis points. However, when measured using corporate rates, the median spread is 48.0 basis points. This is roughly twice what it was before the crisis (23.3bp), but it is below the 60bp which is the believed trading threshold for banks.

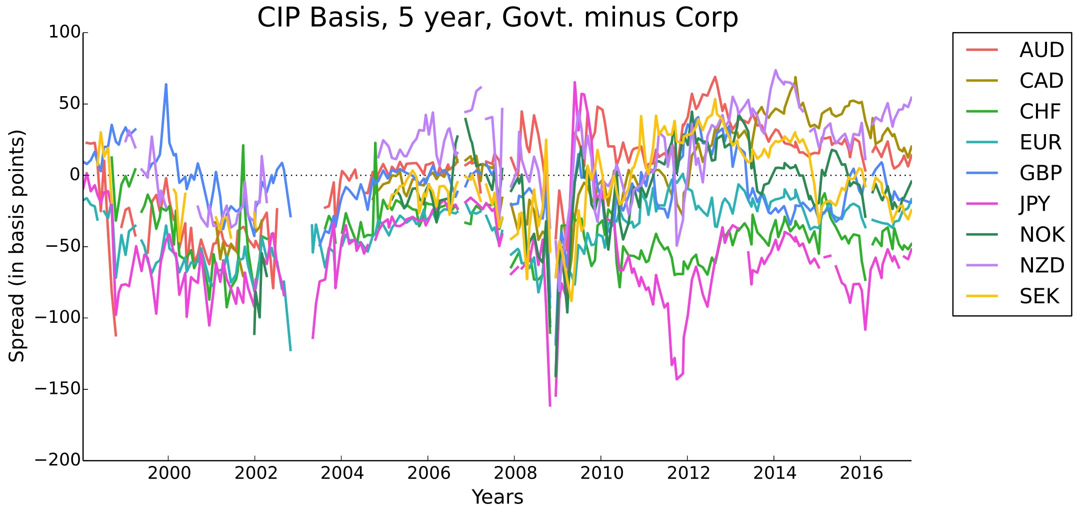
CIP basis requires bonds of the same risk. Corporate bonds from the same corporation are not identical but do have largely similar risk. Government bonds do not have the same risk and, if that difference is significant, it can explain why the max CIP basis spread is, in general, larger when calculated using the government bonds than when calculated using corporate bonds.

The behavior of max CIP basis spread with swaps is harder to explain. The plots of the spread of the swap over government bonds in Figure 5.1 show that the behavior of swaps changed during the crisis. After the crisis, long-term swap rates moved with government rates. This might explain why max CIP basis spread for swap rates follows the movement of max CIP basis spread for government rates.

If CIP basis using corporate bonds is an accurate measure of CIP basis, then subtracting it from CIP basis using government bonds would produce the price of risk associated with each government's bonds. This is plotted in Figure 5.14. For completeness, the CIP basis using swaps minus the CIP basis using corporate bonds is plotted in Figure 5.15.

Notable events in Figure 5.14 are that USD (represented by the x-axis) has the highest risk bond from April 2000 to April 2002, which coincides with the March 2001 to Nov. 2001 recession in the U.S., and from October 2008 to

Figure 5.14: CIP basis using govt. minus CIP basis using corp.



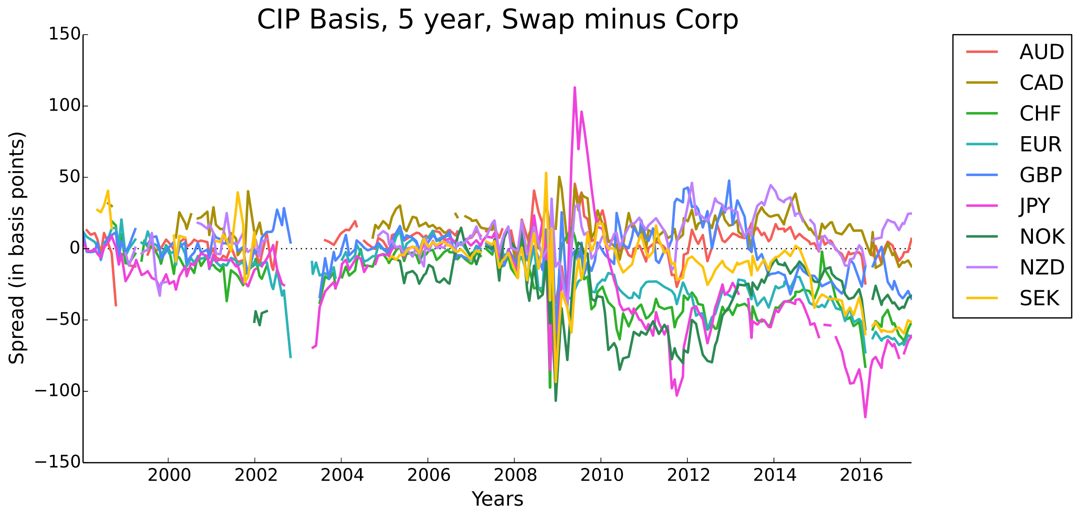
Note: CIP basis using government rates minus the CIP basis using corporate bond rates. If CIP basis using corporate bonds is accurate, then this plot shows the price of risk for each government bond, relative to that in USD government bonds.
Source: Central banks, Bloomberg L.P.

March 2009, which contains the November 2008 start of quantitative easing. JPY usually has the lowest price of risk, which is not easily explained since Japan's debt-to-GDP ratio is high for most of the time period. But from April 2009 to October 2009, Japan has the highest price of risk, as it GDP fell and was predicted to fall at an annualized rate of -9%.[35]

Figures 5.16 through 5.24 plot the CIP basis using corporate rates over time for each currency. Also plotted are the CIP basis using swaps and CIP basis using government rates. Some features of these figures are:

- In all plots, CIP basis using corporate rates shows higher standard errors or gaps from Oct. 2002 to Aug. 2004. This is because there were fewer

Figure 5.15: CIP basis using swaps minus CIP basis using corp.



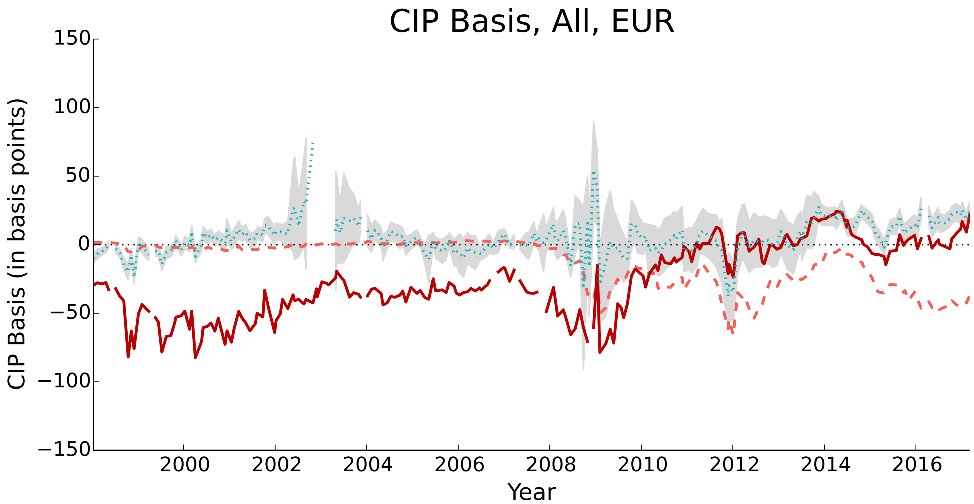
Note: CIP basis using swap rates minus the CIP basis using corporate bond rates. If CIP basis using corporate bonds is accurate, then this plot shows the price of risk in swap rates, relative to that in USD swap rates.
Source: Bloomberg L.P.

price samples in the data set.

- For JPY in Figure 5.17, the CIP basis using corporate rates was a significantly not equal to 0 for all of 2009 and for most of 2012 and 2013. Japan had a large swing downward in GDP in 2009. But 2012 and 2013 were part of an expansionary period for the Japanese economy. Neither seems associated with quantitative easing events, which were announced on Oct. 2010, Aug. 2011, Apr. 2013, and Oct. 2014.

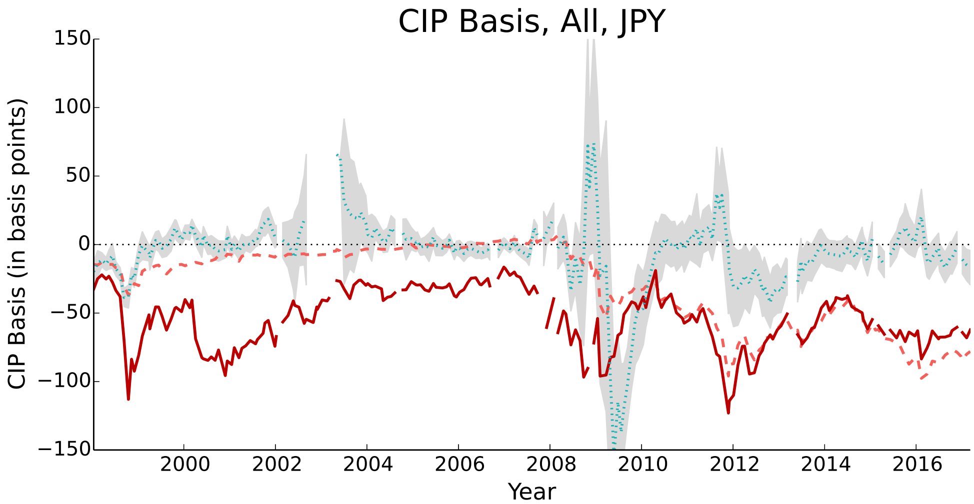
- For most of the time period from Jan. 2010 to the end of the study (March 2017), AUD stays significantly above zero. Its estimate ranges from 8 to 43bp, with a median of 22bp.

Figure 5.16: CIP basis for EUR with 5-year horizon



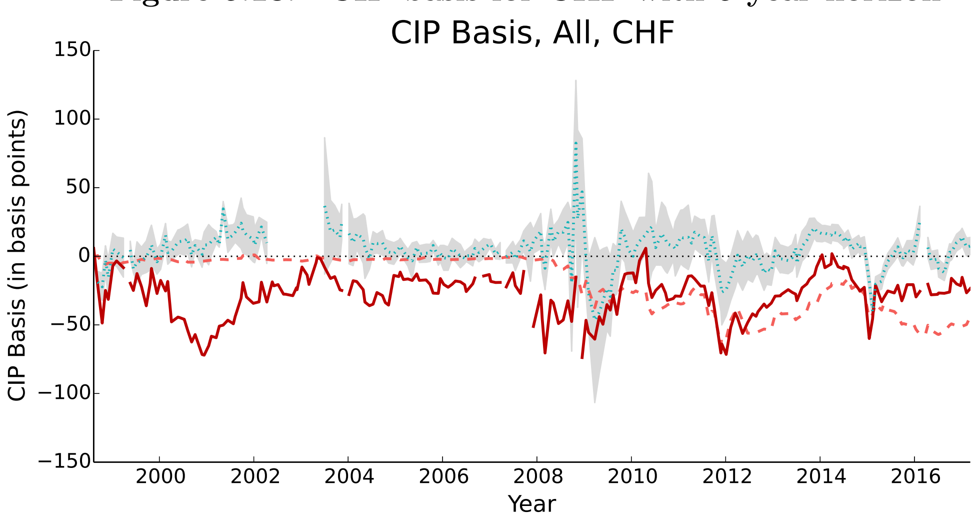
Note: CIP basis values inferred from corporate bond rates are in blue (dotted), with 95% confidence interval from clustered standard error in gray. The CIP basis calculated from government bond rates are in red (solid). The CIP basis using swaps rates is in orange (dashed).
Source: Central banks, Bloomberg L.P.

Figure 5.17: CIP basis for JPY with 5-year horizon



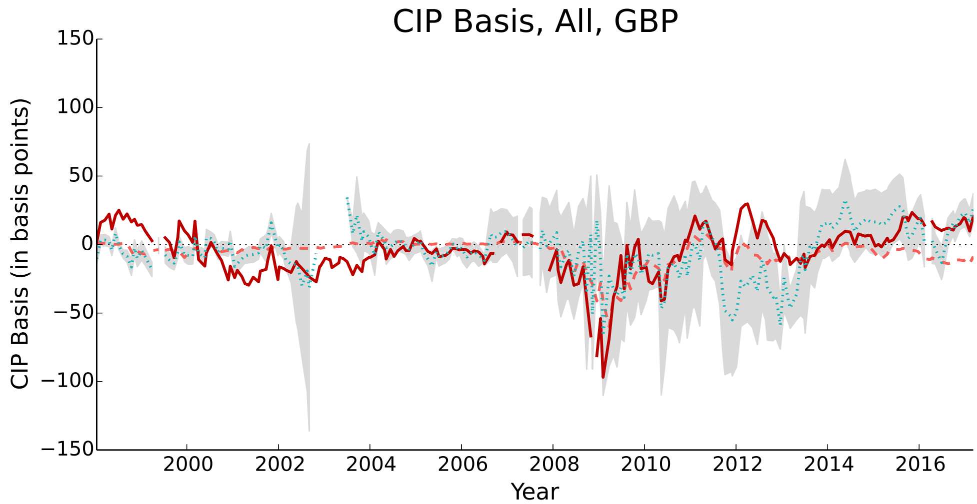
Note: CIP basis using corporate rates in blue (dotted) with 95% conf. int. in gray, using government rates in red (solid), and using swap rates in orange (dashed). Source: Central banks, Bloomberg L.P.

Figure 5.18: CIP basis for CHF with 5-year horizon



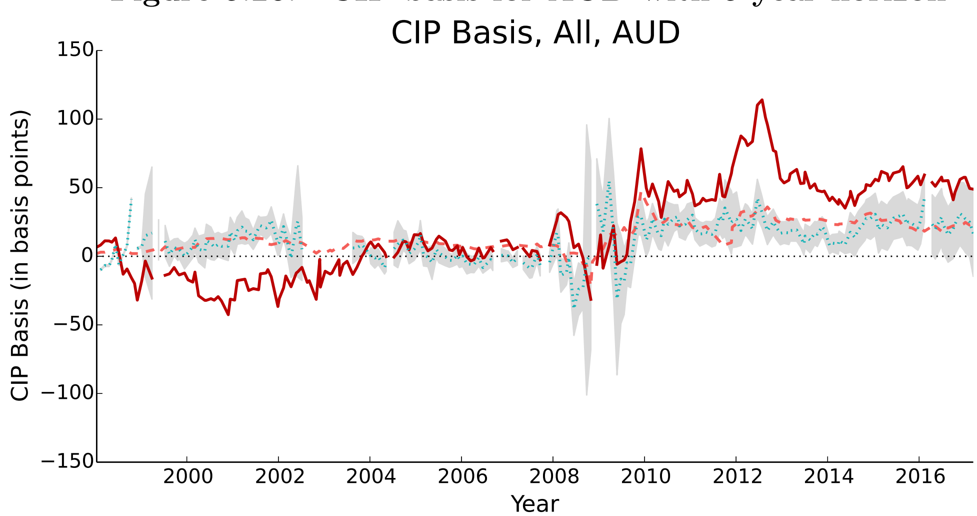
Note: CIP basis using corporate rates in blue (dotted) with 95% conf. int. in gray, using government rates in red (solid), and using swap rates in orange (dashed). Source: Central banks, Bloomberg L.P.

Figure 5.19: CIP basis for GBP with 5-year horizon



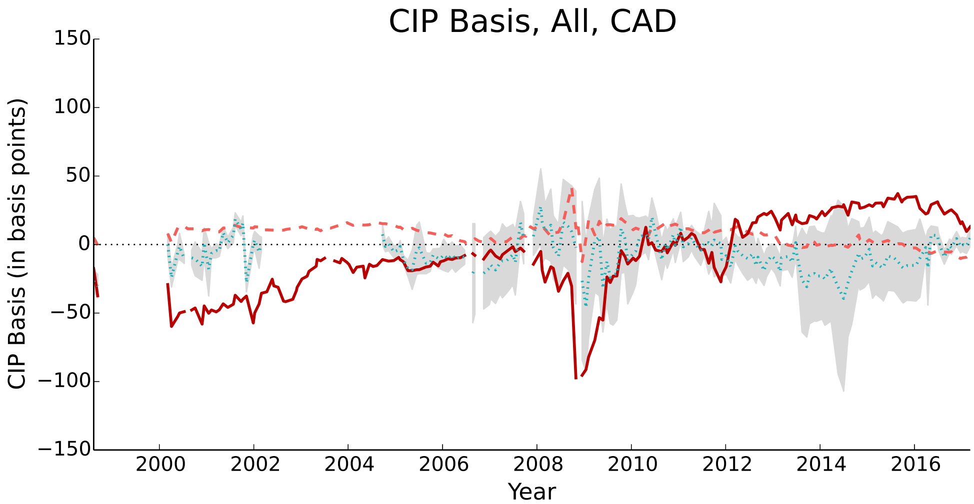
Note: CIP basis using corporate rates in blue (dotted) with 95% conf. int. in gray, using government rates in red (solid), and using swap rates in orange (dashed). Source: Central banks, Bloomberg L.P.

Figure 5.20: CIP basis for AUD with 5-year horizon



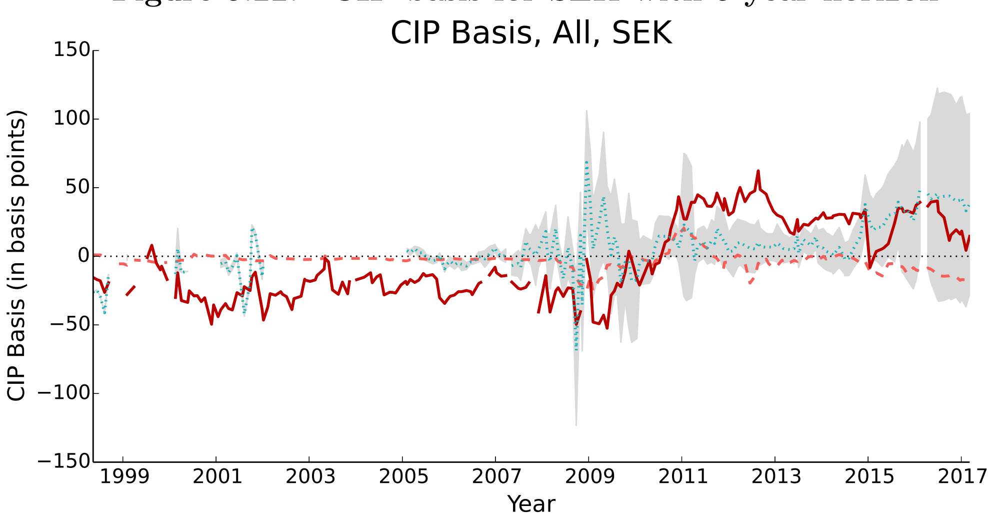
Note: CIP basis using corporate rates in blue (dotted) with 95% conf. int. in gray, using government rates in red (solid), and using swap rates in orange (dashed). Source: Central banks, Bloomberg L.P.

Figure 5.21: CIP basis for CAD with 5-year horizon



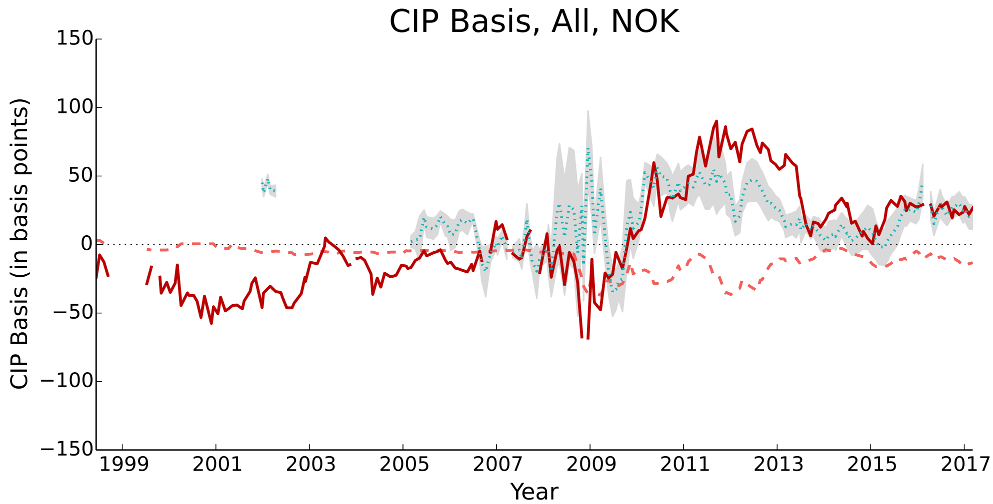
Note: CIP basis using corporate rates in blue (dotted) with 95% conf. int. in gray, using government rates in red (solid), and using swap rates in orange (dashed). Source: Central banks, Bloomberg L.P.

Figure 5.22: CIP basis for SEK with 5-year horizon



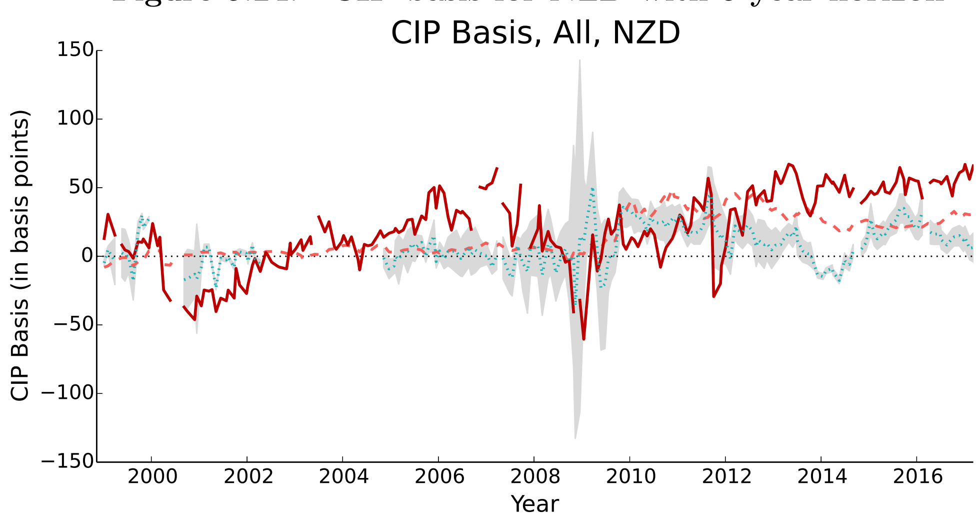
Note: CIP basis using corporate rates in blue (dotted) with 95% conf. int. in gray, using government rates in red (solid), and using swap rates in orange (dashed). Source: Central banks, Bloomberg L.P.

Figure 5.23: CIP basis for NOK with 5-year horizon



Note: CIP basis using corporate rates in blue (dotted) with 95% conf. int. in gray, using government rates in red (solid), and using swap rates in orange (dashed). Source: Central banks, Bloomberg L.P.

Figure 5.24: CIP basis for NZD with 5-year horizon



Note: CIP basis using corporate rates in blue (dotted) with 95% conf. int. in gray, using government rates in red (solid), and using swap rates in orange (dashed). Source: Central banks, Bloomberg L.P.

Chapter 6

Conclusion

This work explored covered interest parity on long-term horizons using rates from government bonds, swaps, and over 17,000 international corporate bonds. The major result of Liao[3] was reproduced and then extended to cover 6 more years and 3 more currencies. Liao's result used swap rates as the reference rates. These were argued to be poorly suited for CIP basis since they contain risk, being based on bank borrowing rates, and are variable contracts not bonds. The major result of Liao was then reevaluated using government bond rates. The correlation of RCSD with CIP basis improved when using government rates.

The CIP basis was then estimated using a regression on corporate bonds. Prior to the crisis, the max CIP basis spread using corporate rates was of a similar scale to max CIP basis spread using swap rates, which is considered the reference measure for that time period. After 2012, the median value for max CIP basis spread using corporate rates was 48bp, which was less than half the max CIP basis spread using government rates or swap rates. The value was also of the correct scale for the threshold where banks would perform the arbitrage trade. Thus, CIP basis using corporate rates seems to be behaving as we would expect CIP basis to behave. Future work on long-term CIP basis should include corporate rates and possibly prefer their results to CIP basis calculated using swap or government rates.

Appendices

Appendix A

Liao's Model

Liao's model is based around a firm issuing debt in either a domestic or foreign market. A company wishing to raise 1B USD can raise it domestically by just issuing a bond. Raising the money overseas is more complicated. The firm must issue 900 EUR worth of bonds, then exchange the proceeds for 1B USD, and also hedge its EUR/USD exposure by buying an FX forward.

A.1 Model Overview

The model has four markets: a USD (domestic) debt market, a EUR (foreign) debt market, an FX spot market and an FX forward market. The model has 4 actors: the representative firm issuing debt, an investor who buys exclusively USD debt, a similar investor in EUR debt, and an FX arbitrageur. The investors have downward sloping demand curves. The FX arbitrageur has a downward sloping demand curve for FX positions.

The actions of the representative firm connects the prices in all the markets. The firm determines the amount to issue domestically based on the domestic investor's demand curve. The quantity issued overseas depends on the FX spot price, the foreign investor's demand curve, and the FX arbitrageur's demand for risk in FX forwards. Minimizing the firm's costs produces the amount issued domestic and overseas. Qualitatively, if the CIP basis b_{EUR} is positive, the firm is more likely to issue foreign debt. If the credit spread difference is positive, the firm is more likely to issue domestically.

Liao allows for two kinds of exogenous shocks. "Credit demand shocks" affect the demand by one investor, irrespective of the other investor. An example might be a central bank purchasing debt in their local market. The other kind of shock is a "CIP shock", where the FX forward market moves irrespective of the FX spot market. An example is a new regulation that requires insurance companies to hedge their FX exposure.

A.2 Model Equations

I'll now cover the equations governing the actors in the model.

The **representative firm** must raise a fixed amount of debt D, but has the choice of how much to raise in each currency. Letting μ be the share raised in USD gives us the condition:

$$\min_{\mu\in[0,1]} \; \mu(1 + r_{corp,USD}) + (1-\mu)\frac{F}{S}(1 + r_{corp,EUR}) \tag{AA.1}$$

which becomes

$$\begin{aligned}&\min_{\mu\in[0,1]} \; \mu(\frac{S}{F}(1 + r_{corp,USD}) - (1 + r_{corp,EUR}))\\ &\min_{\mu\in[0,1]} \; \mu(b_{EUR} + \frac{S}{F}(r_{corp,USD} - r_{swap,USD}) - (r_{corp,EUR} - r_{swap,EUR}))\end{aligned}$$

And if $\frac{S}{F} \approx 1$ we can get

$$\min_{\mu \in [0,1]} \ \mu(b_{EUR} - c_{EUR}) \tag{AA.2}$$

Where b_{EUR} is the CIP basis using the swap rate and c_{EUR} is the credit spread difference. If $b_{EUR} > c_{EUR}$, then the representative firm gets all of its funds domestically. If $b_{EUR} < c_{EUR}$, then all from overseas.

The **USD investor** only buys USD-denominated bonds. They borrow at the swap rate $r_{swap,USD}$ and buy bonds with promised yield Y_{USD}. The bond has π chance of default, in which case it pays L. The payoff's variance V should be $\pi(1-\pi)(Y+L)^2$ but the quadratic term makes the equations complicated and, for tractability, V is assumed to be an exogenous constant. The investor's appetite for risk is a mean-variance trade-off with tolerance τ. Choosing investment amount X_{USD} solves the following:

$$\max_{X_{USD}} X_{USD}((1-\pi)Y_{USD} - \pi L - r_{swap,USD}) - \frac{1}{2\tau} X_{USD}^2 V \tag{AA.3}$$

which results in

$$X_{USD} = \frac{\tau}{V}((1-\pi)Y_{USD} - \pi L - r_{swap,USD}) \tag{AA.4}$$

The **EUR investor** is similar. It is worth noting that probability of default π, payout in default L, variance V, and risk tolerance τ are exactly the same as the USD investors. The governing equation is:

$$X_{EUR} = \frac{\tau}{V}((1-\pi)Y_{EUR} - \pi L - r_{swap,EUR}) \tag{AA.5}$$

The **FX arbitrageur** has wealth W in EUR. They can devote this wealth either to CIP arbitrage or to an alternative investment that pays $f(I)$, where I the amount invested. The CIP arbitrage pays $sb_{swap,EUR}$ where s is the size of the position. The arbitrageur's wealth is not decreased by the size of the CIP arbitrage position, but by the "haircut" $\gamma|s|$. In REPO, the haircut is the portion of risk that the borrower is forced to retain and is inversely related to leverage. The arbitrageur chooses s to solve:

$$\max_{s} \; sb_{swap,EUR} + f(W - \gamma|s|) \tag{AA.6}$$

The result, when solved for b, is $b = \text{sign}[s]\gamma f'(W - \gamma|s|)$. If the alternative investment is quadratic with $f(I) = \phi_0 I - \frac{1}{2}\phi I^2$, then we have

$$b = \text{sign}[s]\gamma(\phi_0 - \phi W + \phi\gamma|s|) \tag{AA.7}$$

The **market clearing condition** for bond markets is that supply matches demand. Liao, at this point, introduces the exogenous bond demand shock ϵ_c, which might represent demand for bonds from a central bank.

$$X_{USD} = \mu D \tag{AA.8}$$

$$X_{EUR} + \epsilon_c = (1 - \mu)D \tag{AA.9}$$

In **equilibrium**, the CIP basis and credit spread difference control the behavior of the representative firm. The equation for the CIP basis is:

$$b_{EUR} = -\gamma^2(D(1 - \mu) + \epsilon_b) \tag{AA.10}$$

where ϵ_b represents exogenous hedging demand. As the haircut γ gets smaller (which is equivalent to higher leverage), the CIP deviations get smaller. The other factor represents the net demand for hedging.

For credit spread, the identity $Y_{EUR} - Y_{USD} = c + (r_{EUR} - r_{USD})$ and a first-order approximation of π at 0 produces the equation:

$$c_{EUR} = \frac{V}{\tau}((1 - 2\mu)D - \epsilon_c) \tag{AA.11}$$

The factor V/τ is the elasticity of bond demand and is the ratio of volatility to risk tolerance. The other factor represents the net supply of bonds in EUR over USD.

These CIP basis and credit spread then govern the behavior of the representative firm:

$$\mu = \begin{cases} 1 & : \quad b_{EUR} > c_{EUR} \\ 0 & : \quad b_{EUR} < c_{EUR} \end{cases} \tag{AA.12}$$

A.3 Liao's Predictions

Liao made four predictions. First, if there is a pricing violation in one market (FX or credit), it can spill into the other market. In the model we see that $\epsilon_c \uparrow$ results in $c \downarrow$ and $\mu \uparrow$ and then $b \downarrow$. Similarly, if $\epsilon_b \uparrow$, then $b \downarrow$ and $\mu \downarrow$ resulting in $c \downarrow$. Thus, for either kind of shock, b and c move in the same direction. So, the first prediction is that b and c respond in the same direction.

The second prediction is that costs affect where bonds get issued. If $(c - b) \downarrow$ then $\mu \downarrow$. Here, $c - b$ is the net deviation in cost between issuing in EUR and USD.

The third prediction is that increasing the amount issued will decrease the deviations. Specifically, $\frac{\partial |c-b|}{\partial D} < 0$ and $\lim_{D \to \infty} c - b = 0$.

The last prediction is that the absolute value of both c and b react similarly to many changes in parameters. If the haircut γ increases, both increase. If the investors risk tolerance τ increases, both increase. If the bond's variance V increases, both increase.

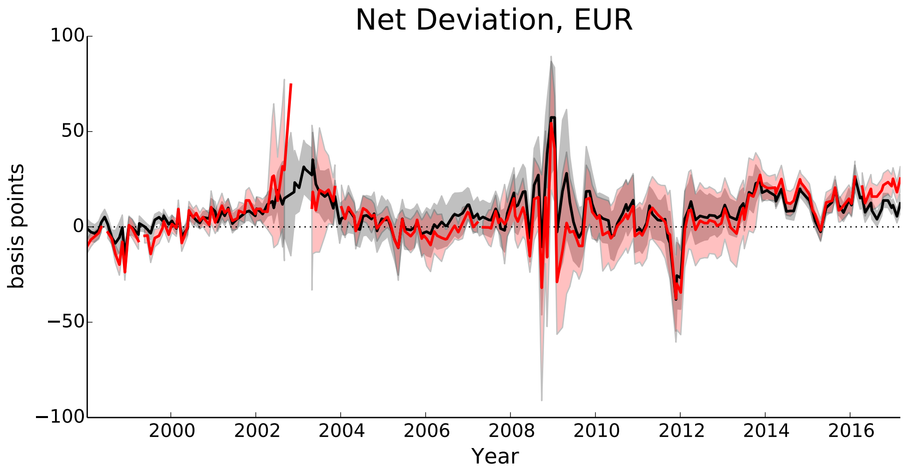
Appendix B

Liao's Net Deviation

Liao's regression on corporate bonds to compute "net deviation" is similar to mine to compute CIP basis. (Compare equations (4.4) and (5.9).) This appendix presents plots of the 9 currencies comparing the results in Figures B.1 through B.9.

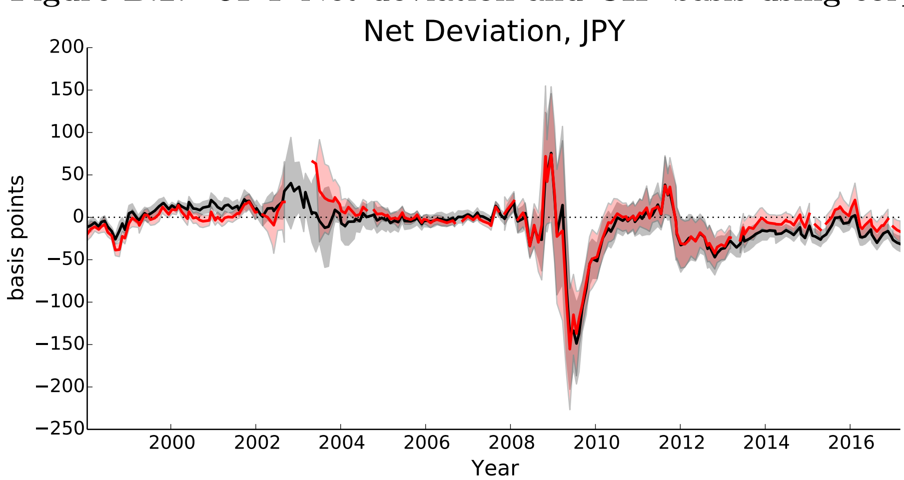
For this section, I use Liao's first definition of net deviation, which is the residualized credit spread difference (RCSD) minus the CIP basis. The CIP basis here is the 5-year CIP basis. Both the RCSD and CIP bases are computed using swap rates. I did not use Liao's refined definition on page 29 of his paper[3] where the value for CIP basis is moved into the regression and the horizon of the CIP basis is selected to match the maturity of the bond.

Figure B.1: EUR Net deviation and CIP basis using corp. bonds



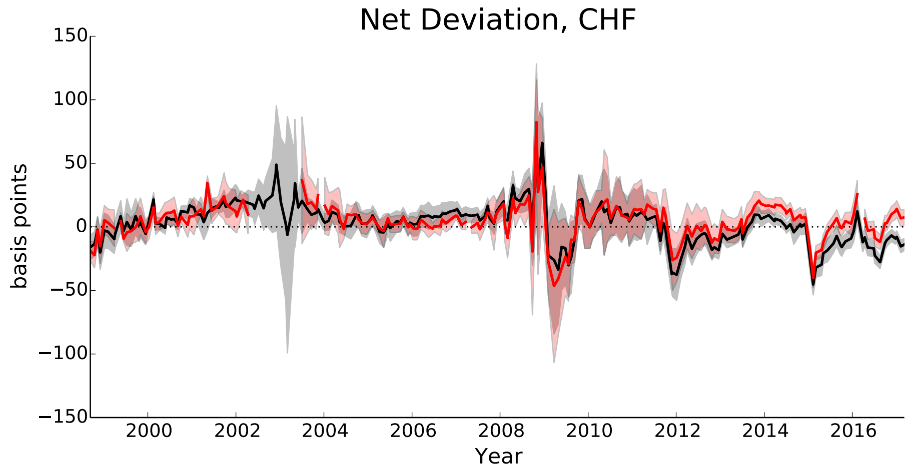
Note: Black is the net deviation (RCSD minus CIP basis); gray is the 95% conf. int. from clustered standard errors. Red is the CIP basis using corporate bonds with a 5-year horizon; pink is the 95% conf. int. from clustered standard errors. Source: Bloomberg L.P.

Figure B.2: JPY Net deviation and CIP basis using corp. bonds



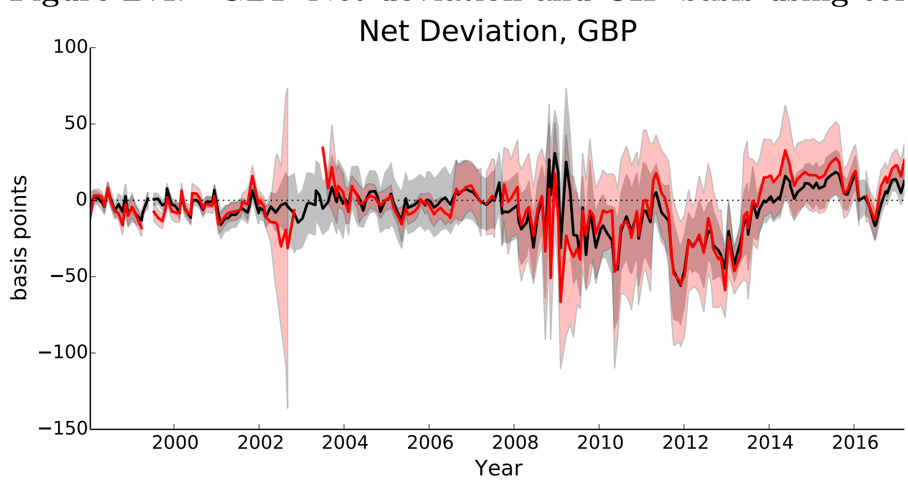
Note: Black is the net deviation (RCSD minus CIP basis); gray is the 95% conf. int. from clustered standard errors. Red is the CIP basis using corporate bonds with a 5-year horizon; pink is the 95% conf. int. from clustered standard errors. Source: Bloomberg L.P.

Figure B.3: CHF Net deviation and CIP basis using corp. bonds



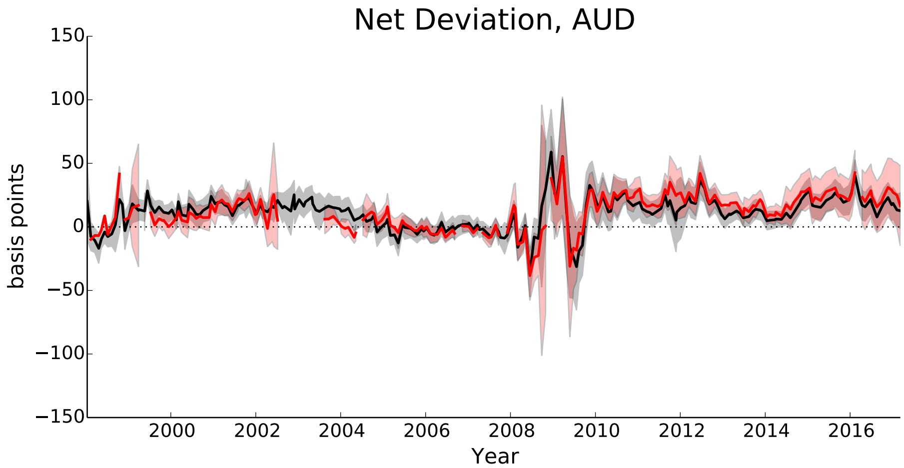
Note: Black is the net deviation (RCSD minus CIP basis); gray is the 95% conf. int. from clustered standard errors. Red is the CIP basis using corporate bonds with a 5-year horizon; pink is the 95% conf. int. from clustered standard errors. Source: Bloomberg L.P.

Figure B.4: GBP Net deviation and CIP basis using corp. bonds



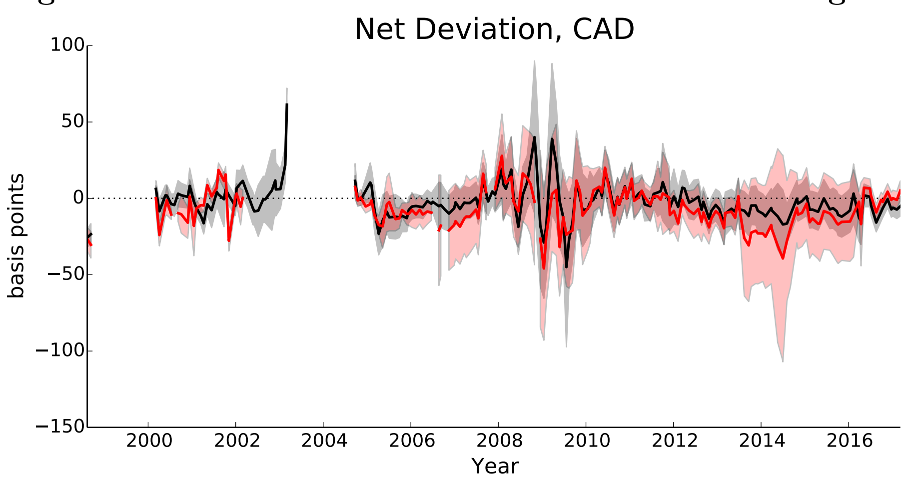
Note: Black is the net deviation (RCSD minus CIP basis); gray is the 95% conf. int. from clustered standard errors. Red is the CIP basis using corporate bonds with a 5-year horizon; pink is the 95% conf. int. from clustered standard errors. Source: Bloomberg L.P.

Figure B.5: AUD Net deviation and CIP basis using corp. bonds



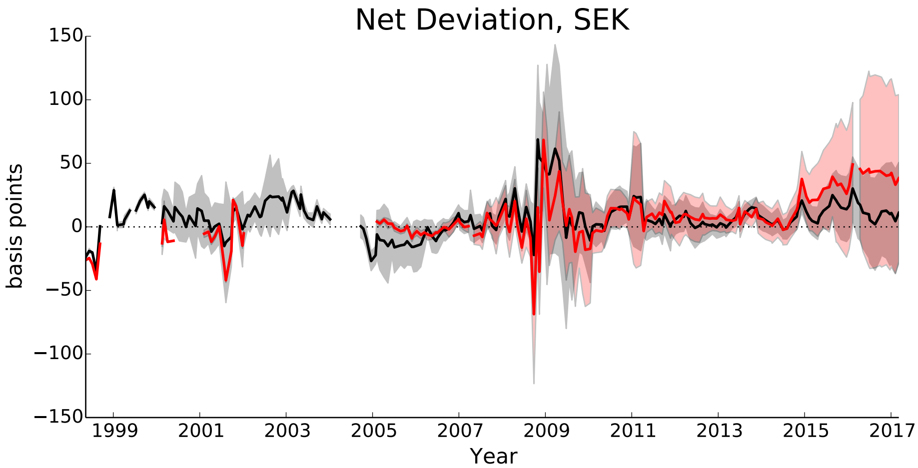
Note: Black is the net deviation (RCSD minus CIP basis); gray is the 95% conf. int. from clustered standard errors. Red is the CIP basis using corporate bonds with a 5-year horizon; pink is the 95% conf. int. from clustered standard errors. Source: Bloomberg L.P.

Figure B.6: CAD Net deviation and CIP basis using corp. bonds



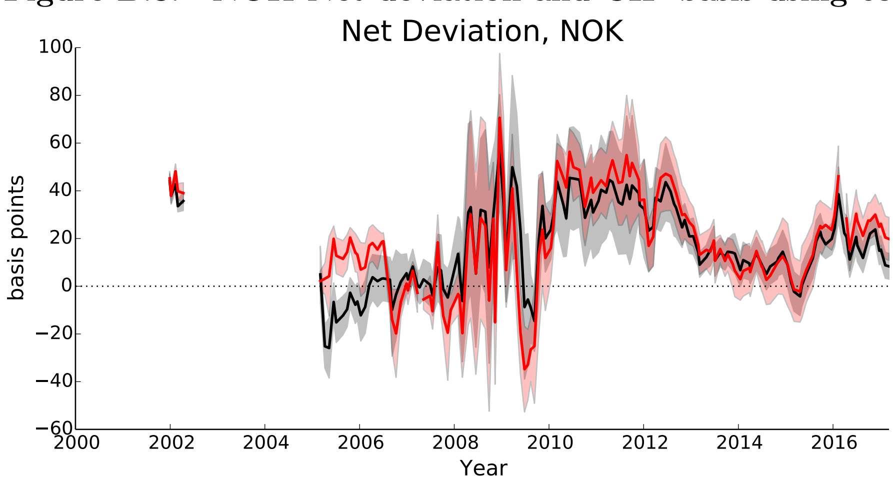
Note: Black is the net deviation (RCSD minus CIP basis); gray is the 95% conf. int. from clustered standard errors. Red is the CIP basis using corporate bonds with a 5-year horizon; pink is the 95% conf. int. from clustered standard errors. Source: Bloomberg L.P.

Figure B.7: SEK Net deviation and CIP basis using corp. bonds



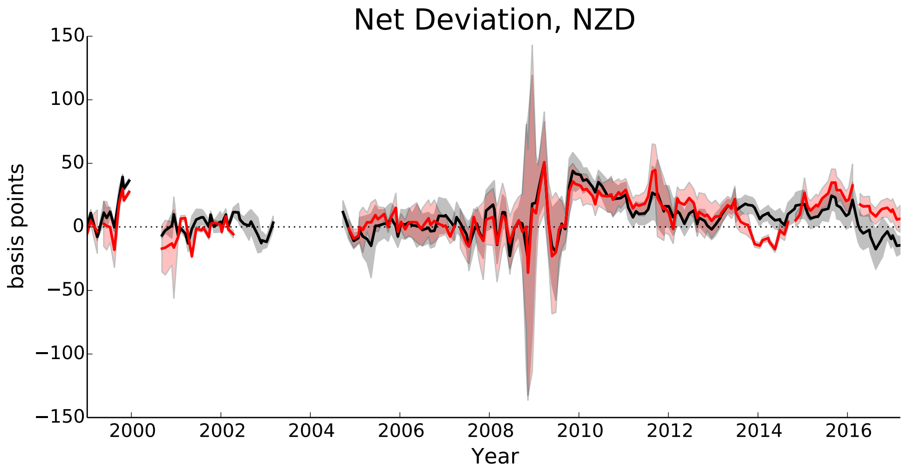
Note: Black is the net deviation (RCSD minus CIP basis); gray is the 95% conf. int. from clustered standard errors. Red is the CIP basis using corporate bonds with a 5-year horizon; pink is the 95% conf. int. from clustered standard errors. Source: Bloomberg L.P.

Figure B.8: NOK Net deviation and CIP basis using corp. bonds



Note: Black is the net deviation (RCSD minus CIP basis); gray is the 95% conf. int. from clustered standard errors. Red is the CIP basis using corporate bonds with a 5-year horizon; pink is the 95% conf. int. from clustered standard errors. Source: Bloomberg L.P.

Figure B.9: NZD Net deviation and CIP basis using corp. bonds



Note: Black is the net deviation (RCSD minus CIP basis); gray is the 95% conf. int. from clustered standard errors. Red is the CIP basis using corporate bonds with a 5-year horizon; pink is the 95% conf. int. from clustered standard errors.

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Vita

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