Price discovery on traded inflation expectations: Does the financial crisis matter?

by

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Preliminary. Please do not quote.

Abstract:

We use a high frequency data set on inflation-indexed and nominal government bonds as well as inflation swaps to analyze the price discovery for break-even inflation rates (BEIR), eg inflation expectations plus risk and liquidity premia. For maturities up to 5 years new information comes from both, the swap and the bond market, whereas for longer time horizons the swap market increasingly loose ground in the euro area. In the US where the market volume of inflation-linked bonds is large the bond market dominates the price discovery process for all maturities. The severe financial crisis that spread out in Autumn 2008 drove a wedge between bond BEIR and swap BEIR in both currencies. Price discovery ceased to take part on the swap market. Disruptions coming from the short-end of the market even separated price formation on both markets for maturities of up to 6 years in the US. Whereas a heightened risk aversion generally obstructed trades on financial markets, contributions to price formation concentrated a lot more on the presumably safest financial instrument: government bonds.

Keywords: inflation-linked bonds, inflation swaps, price discovery, financial crisis
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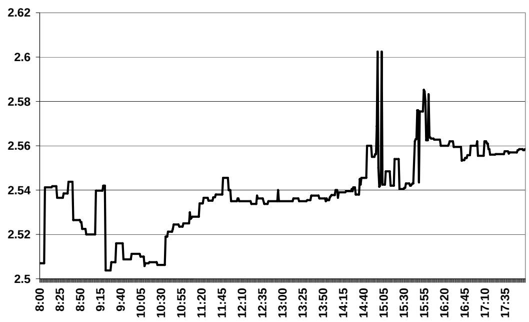
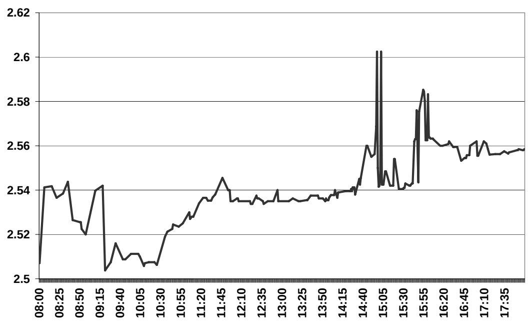
1 Introduction

Determining the correct level of long-term interest rates today or predicting short term interest rates in 2, 5 or 10 years requires an idea about future inflation and growth. Inflation expectations can be read from surveys of experts or inferred from market prices. In this paper we concentrate on markets for two claims which are directly inflation related: indexed bonds (and their nominal equivalents) and inflation swaps. Figure 1 shows that these instruments do indeed react on news concerning actual and future inflation rates although not necessarily to the same extent. To find out which market processes information about inflation more quickly and with more impact on long run equilibrium prices is the purpose of our paper. Knowing which market reflects inflation expectations timely is relevant both for financial practitioners and for central bankers.

To hedge unexpected changes in inflation rates in the distant future one can either take the inflation seller leg of an inflation swap or go long a nominal government bond and short an inflation-linked government bond of the same maturity. Instruments on both markets are actively traded and provide us with break-even inflation rates (BEIR), eg inflation expectations plus risk and liquidity premia. We are investigating the price discovery for these BEIR between the swap and the bond market implying that there exist an arbitrage relation.



(a) Bond BEIR



(b) Swap BEIR

Figure 1: Yield of inflation-indexed bond with maturity 2012 and 4 year inflation swap rate on 5 June 2008. President Trichet's remarks in the ECB press conference starting 2:30 p.m. were widely regarded as the turn in the euro interest rate cycle.

We measure the information flow via the relative share of each market price innovation contributions to a common efficient price. In econometric terms prices on both markets are cointegrated and there exists one common stochastic trend associated with the notion of the efficient price. The ratio of the adjustment coefficients of the vector error correction representation gives then an idea of the importance of a market for price discovery. For robustness both Hasbrouck information shares and Gonzalo Granger common factors are calculated. For the euro area only AAA rated government bonds issued by France and Germany are employed, in each case a pair of an inflation-indexed and a nominal bond. The linkers are indexed to the euro area harmonized index of consumer prices ex tobacco (HICPxT), the same reference as for the zero coupon inflation swaps. For the US sample we employ Treasury inflation-protected securities (TIPS) with residual maturities from 2 to 10 years as well as Treasury Notes (T-Notes) of the same maturities. The corresponding inflation swaps are linked to the US city average all items consumer price index for all urban consumers (CPI-U). We use a high frequency data set of the respective instruments at one-minute intervals. The inflation swap market is a relatively new market and, to the extent of our knowledge, price discovery has not been analyzed previously on an intra-day basis. The two sample periods range from May/June to August and from September to December 2008 which we label Summer and Autumn 2008 respectively. The employed periods contain both rising and declining inflation expectations, a turning point of monetary policy and the effects of a severe financial crisis.

We find that swap BEIR are typically higher than bond BEIR and attribute this to liquidity considerations and risk premia. Time series for both BEIR are cointegrated for all maturities in the euro area. For shorter maturities up to 5 years new information comes from both markets, whereas for horizons of 7 years and above the bond market increasingly leads the price discovery process. In the US where the market volume of TIPS is large compared to that of euro area issuers the bond market dominates the price discovery process for all maturities. Only for the shortest time horizon one third of price innovations comes from the swap market. Especially with longer maturities central government bonds are the benchmark for hedging inflation risk and for pricing inflation expectations. This result is much more pronounced during our crisis sample in Autumn 2008. US data shows that the bond and swap market are even separated for maturities of up to 6 years.

The reminder of the paper is organized as follows: The next Section gives an introduction of the respective markets where inflation expectations trade.

Section three contains a description of our data set. In Section four we explain the econometric method used and Section five shows the results of our analysis of price discovery for euro area and US data. The last Section concludes.

2 Two markets for trading inflation expectations

The desire to protect against inflation is a primary concern of every economic agent. The containment of rising prices has thus been the major reason for establishing independent central banks world-wide. Nevertheless, there might still be scope for trading inflation claims. From the point of view of public coffers, inflation-linked debt may contribute to lowering borrowing costs. Investors in a nominal bond demand an inflation risk premium on top of the real interest rate and expected inflation. If the markets do not systematically underestimate inflation - and there is no sensible reason for this given the history of upside surprises in the past fifty years - there is scope for lower borrowing cost with the government paying an explicit ex post inflation compensation. In this calculation the issuer saves the inflation risk premium. Furthermore, linkers can reduce borrowing costs if issuer and investors have divergent inflation expectations. A second line of argument is provided by Shiller (1993) who states that consumers need to protect themselves against macroeconomic shocks by being able to trade in securities indexed to macroeconomic variables. An inflation-indexed bond is exactly one of those instruments. In his view, governments should start issuing these securities, as the precursor in such a market will not be able to extract a rent covering development costs due to free riding of competitors (Campbell and Shiller 1996). A third, more technical, approach regards inflation simply as a specific stochastic process, which can be used as an underlying for a financial contract.

While the wish to hedge against inflation risk is evident, the potential suppliers of inflation protection cannot easily be identified. In a first instance these are governments. Shiller's argument of financial innovation as a public good and reduced borrowing cost by saving the inflation risk premium were already adopted above. A broader issuer base requires gains from trading inflation, therefore it would be necessary to identify market participants being "long" in inflation. Again, the first guess is governments. Income taxes and VAT are increasing with inflation. However, thwarting the progression from inflation is a standard reason for regularly undertaken reductions of income tax rates. Regarding expenditure, the payroll, which is an important part of any public budget, tends to rise in line with inflation. Furthermore, pension liabilities typically are positively related to inflation, either by direct indexation or through referencing it to the last wage before retirement.[2] Further potential suppliers of inflation are infrastructure ventures in the form of public private partnerships, eg toll roads or hospitals. Their income stream is regulated and in many cases linked to a price index. Moreover, large retailers are potential net suppliers of inflation, as their sales overlap widely with the baskets of commodities used for calculating price indices.

2.1 The inflation-indexed bond market

For all that reason the market for inflation-linked products has been established, with governments indeed paving the way for a broader market.[3] After pioneering UK, the US started to issue TIPS in early 1997. The US market is by far the largest one for inflation-protected bonds, with an amount outstanding worth US-$ 516 billion. TIPS issuance makes up more than 15% of overall Treasury notes and bond issuance.[4] Within the euro area France, Greece, Italy and Germany have indexed bonds outstanding. France is by far means the most active issuer here, sponsoring two programmes linking to the national CPI (ex tobacco) and the euro area HICPxT respectively. The combined amount outstanding is 137 billion euro. Germany has issued its first linker in 2006 and has in the meanwhile an amount outstanding of 22 billion euro.

Using nominal and inflation-indexed bond yields of the same maturity we can calculate BEIR. Starting from the Fisher equation which decomposes the nominal rate into the real rate and expected inflation we can infer the latter by subtracting real yields derived from inflation-linked bonds from nominal yields.[5] Yet, bond yields not only incorporate inflation and growth expectations. Investors require in addition compensation for unexpected inflation changes in nominal bonds and for illiquidity, default risk and other risk in nominal and inflation-protected bonds. The BEIR comprises everything that is not uniformly priced or not compensated on both, nominal and inflation-linked bond markets. To begin with, the BEIR contains inflation expectations among

[2]The pension effect on the inflation position of a government is not obvious per se, as a rising nominal discount factor reduces the present value of inflated future pension expenditures.

[3]See Campbell and Shiller (1996) for an overview of early linkers, including issues from emerging markets.

[4]As of January 2009.

[5]See Section four for a more formal representation.

financial market participants. Secondly, an inflation risk premium which reflects compensation the nominal bond holders require for unexpected inflation rate changes whereas the inflation-indexed bond holder is not exposed to that risk. Liquidity might be different on both markets. Nominal bond markets are larger in volume and might therefore be more liquid. To get exposure to a BEIR one must either go long a nominal bond and short an inflation-linked bond or vice versa. The cost of carry for both bonds is different and have therefore implications for the level of the BEIR. Delivery options for the futures market and other institutional features might drive bond yields on both markets further apart. Since we use pairwise government bonds from the same issuer, default risk is not an issue here.

2.2 The inflation swap market

Markets for inflation-linked derivatives have grown quickly in recent years. Their development has been complementary to those of inflation-indexed bonds. The most important segment of the inflation derivatives market are inflation swaps. These are traded in the over the counter market (OTC) by financial institutions, fund managers and corporate treasurers. The inflation swap is a bilateral contract which requires one party to the contract (the inflation receiver) to make predetermined fixed-rate payments in exchange for floating-rate payments linked to inflation from a second party (the inflation payer). The basic building block of inflation swap structures is the zero coupon (ZC) inflation swap. ZC means that payments are exchanged only on maturity, where maturities range from one year to over 30 years and, in general, are whole-year tenors.

Euro ZC swaps are linked to the same index as most bonds in the associated market. They pay the non seasonally adjusted euro zone HICPxT. The inflation index is subject to a lag of three month. Unlike inflation-linked bonds the reference price level for each day is not interpolated between two neighbouring months but changes at the end of the month. This involves jumps at the day of the change of the month especially for shorter maturities but has the advantage that a swap can be traded and unwound in the same month without incurring future inflation risk (an interpolated swap retains some inflation risk). US ZC swaps are linked to the non seasonal adjusted CPI-U and have an interpolated reference price level for each day as base as well as an indexation lag of three month. This closely aligns the swap market methodology with the bond market in the US.

Although a modest amount of inflation-linked trades have taken place in continental Europe since the early 1990s, euro inflation swap volumes boomed not before the early years of the new millennium (Dunbar 2003). The issuance of bonds linked to the euro zone HICPxT from the French and Italian government in 2001 and 2003 respectively supported the proliferation of the euro swap market. In 2007 the monthly notional amount traded in the euro inflation swap market stands at a two digit number of billion euros and is still one of the fastest growing OTC derivative contract. Unlike in the euro area the inflation swap market in the US developed while the inflation-linked bond market was already in existence for some years. In 2004 when TIPS issuance picked up US-CPI swaps became more popular as well. Yet, an estimated trading volume of US-$ 11 billion in 2007 is only minor compared to that of the inflation-indexed bond market (Peat and Segregeti 2008).

Just as with inflation-indexed bonds we can calculate a BEIR from inflation swaps. Far easier than with bonds, the zero coupon swap BEIR is typically the quoted rate the fixed rate agents are willing to pay in order to receive the cumulative rate of realized inflation during the life of the swap. Hence the swap BEIR will depend on expected inflation over the life of the swap as well as various risk premia. Again these premia comprise compensation for unexpected inflation rate changes and restrictions on the possibility to sell the swap contract at any time devoid of any deduction.

Compared to bond issues, inflation swaps are relatively new instruments which on the one hand hints to a low degree of liquidity of the market. The increasing volume of traded contracts which outvalue the outstanding amount of inflation-indexed linked bonds of the euro area as well as the lack of funding cost when entering a swap contract on the other hand may suggest a considerably high liquidity of inflation swaps. That notwithstanding market intelligence sometimes speaks of a lack of inflation payers resulting in inflation paid via swaps having a higher price than via bonds (Armann, Benaben, and Lambert (2005) and ECB (2006b)).

The swap BEIR may involve in addition a premium for counterparty risk. Payments are typically exchanged between two private corporations, mostly banks and broker firms but also hedge funds, insurers and other corporate companies. Therefore the degree of creditworthiness attached to that payments is typically lower than that of bonds issued by governments. Since the market trade mostly zero coupon swaps with payments only exchanged on maturity the counterparty risk especially for long term swaps could be prohibitively high. Collateralization tackles that problem and has become increasingly popular among OTC derivatives during the last years. The international swaps and derivatives association (ISDA) states that 66% of fixed income OTC derivatives were collateralized in 2008 compared to 48% in 2003 (ISDA 2005 and 2008).

2.3 Pricing and arbitrage

There exists a huge body of literature on how to extract inflation expectations out of financial market data. The literature is largely driven by staff members of investment banks and central banks. Whereas the former are more concerned with pricing and valuation of inflation-indexed bonds and derivatives for trading reasons (Armann (2008), Peat and Segregeti (2008) and Kerkhof (2005)) the latter focus more on pure long-term inflation expectations as indicator of credibility of their monetary policy (ECB (2006a), Hurd and Relleen (2006), Wright (2008) and Kim and Wright (2005)). Over the last fifteen years especially the search for measures of premia for inflation risk, liquidity and other risk which cloud inflation expectations proliferated. However, the price discovery process, i.e. the ”inflation discovery process”, on financial markets has been ignored so far. This paper tries to fill the gap.

We make use of the approximate arbitrage relationship that exists between bond BEIR and swap BEIR. Asset swaps are the instrument linking bond and swap prices. These swap a fixed investment, such as a bond with coupon payments, for a floating investment, such as Euribor plus a spread. While nominal asset swaps have been established for some time real or inflation-linked asset swaps have become popular only during the last five years. If bond BEIR is deemed too high an investor may find it worthwhile to enter into a real asset swap whereby he purchases an inflation-linked bond. This purchase can be funded at a repo rate.[6] Through the swap the investor pays inflation-indexed flows that are identical to those obtained from the bond and in return receives a floating rate, typically Euribor plus a spread (Sitbon and Pretet 2007). The investor has now an inflation-indexed bond from which he receives inflation and pays repo rates coupled with a swap contract through which he pays the same inflation flows and receives a floating rate plus a spread. As long as the floating rate plus the spread is higher than the repo rate plus the default risk coming from the swap (the government is assumed to be default-free) the investment is profitable. Where does the inflation swap step in? Both swap structures, the real asset swap and the inflation swap value inflation-linked

[6] A repo or repurchase transaction is a standard technique to finance purchases of financial instruments. The purchase of a government bond may be financed with borrowed money, where for the borrowed money the same bond is put up as collateral.

payments. The closing link is swapping back the fixed rate payments from the inflation swap and your floating rate payments from your real asset swap with a nominal interest rate swap.[7]

Of course, there are obstacles that hinder arbitrage. Transaction costs would be the most preeminent. Differences in market liquidity and in credit exposure have been discussed above. A simple lack of suitable assets or regulatory barriers for investors to engage in derivative instruments or shorten bonds may affect the balancing of pricing of inflation expectations with different instruments. Bond BEIR will inevitably incur repo cost, which in addition can be different for nominal and real bonds as nominal bonds have specialness options, eg coming from delivery in the future markets. Yet, if there is a liquid market for inflation-linked bonds and swaps neither real rates nor BEIR do not move far away from "fair value" for persistent periods as market participants arbitrage away any anomalies (Deacon, Derry, and Mirfendereski 2004).

3 Data

Our data-set contains real and nominal bonds, next to inflation swaps. To avoid biases in the euro area break even inflation rate, we concentrate on French and German bonds which all have a AAA rating. Furthermore, we focus on the harmonized euro area HICPxT as the relevant and comparable inflation measure, thus we remove bonds linked to the French national CPI from our sample.[8] In addition, we restrict the euro area sample to bonds with maturities of up to twelve years, as these are tenors for which inflation swaps are actively traded.[9] Altogether, six linkers remain in our sample, covering maturities of 2, 4, 5, 7, 8, and 12 years. Six suitable nominal bonds are selected to compute the BEIR (see Table A-1 in the Appendix for a list of bonds used). Inflation swaps with corresponding tenors are forming the alternative market for inflation. The US operates a more active issuing programme; thus we are able to investigate the term structure of BEIRs from 2 to 10 years for whole year tenors, for both the bond and the swap market (see Tables A-2 and A-3

[7]See Armann, Benaben, and Lambert (2005), p. 94 for a lucid treatment.

[8]All bonds are capital indexed, thus their notional is inflated with the change of the price index. Coupon and redemption payments are made on the adjusted notional. There is some protection against severe and persistent deflation, as redemption is never below the initial notional.

[9]As reported on Bloomberg. For longer horizons, eg the French bond expiring in 2040, we would need to interpolate between infrequently traded 30 and 40 year inflation swap rates, which is prone to errors.

in the Appendix).[10]

We obtain bid and ask prices for bonds as well as bid and ask rates for swaps, all on one minute intervals. Furthermore we receive the number of quote changes (ticks) in each minute, giving us some indication on the liquidity of the market. As we do not have transaction data, we use the midpoint of bid and ask quotes as the hypothetical transaction price or rate.[11] For the euro area, we use quotes between 9 a.m. and 6 p.m. as trading hardly takes place in the interim time. The Summer and Autumn data sets range from 5 May to 8 August 2008 and from 2 September to 8 December 2008 respectively. Each set spans 70 trading days. Given the adjustments described above, ca. 439,000 swap midpoints remain in our sample, as well as about 315,000 observations of nominal bond prices and 185,000 of indexed bonds (see Table A-4 in the Appendix). Claims on US inflation are traded more widely. Here quotes occur between 9 a.m. and midnight European Central Time. We obtain data for the Summer sample from 12 June 2008 to 13 August 2008 and for the Autumn period from 3 September 2008 to 9 December 2008. Here we finally assemble a total of approximately 520,000 quotes for the nine nominal bonds, 324,000 for the inflation-indexed bonds and 858,000 quotes of the matching inflation swaps (see Table A-5 in the Appendix). Prices are carried forward until a new quote comes to pass. All data is taken from Bloomberg.

Bond prices are transformed into yields. We use the yield to maturity or redemption yield concept to calculate bond yields from our price data. The bond yields are therefore systematically slightly undervalued compared to the zero coupon yields coming from our inflation swap data.[12]

The prices for the bond data reflect a decreasing time to maturity whereas our inflation swaps are daily quoted whole year tenors over the whole lifetime of our sample. For comparability reasons we adjust the yields of the bond to reflect whole year tenors as well. We used daily estimates of term structures of nominal and real bonds to increase (decrease) the yields of our bonds from the remaining time to maturity to whole year tenors. Times to maturity other than whole years involve seasonality effects for inflation-linked bonds because these are linked to non-seasonally adjusted inflation indices. This influences the level of BEIR across the year. In the euro area consumer prices are typically

[10] All bonds except the 5 year tenors are off-the-run.

[11] Intervals with only either a bid or an ask entry are eliminated.

[12] Calculating true zero coupon yields for our high frequency bond price data is nearly impossible, as necessary interpolations are prone to contaminate the marginal price change of a single bond.

low in January and high in April.[13] These are indeed the reference month for inflation compensation of German respectively French bonds. Investors buying bonds at any other time during the year adjust the price according to the lower (higher) actual non-seasonally adjusted inflation rates and therefore over- (under)estimate the bond yield and the BEIR respectively. We adjust for seasonality via daily seasonal factors extrapolated from monthly seasonally adjusted and non-seasonally adjusted CPI data.[14] The same adjustments are performed on US data. Due to the biannual coupon payments of the US bonds, the issue of seasonality is less virulent in this sample.

The respective competitive market are comprised of six inflation swaps for the euro area and nine for the US with tenors equivalent to the bond BEIR. Since we consider only swaps with full year tenors we neither need to make maturity nor seasonality corrections.

4 Price discovery: Measurement method

If both the swap and the bond market price inflation expectation plus risk premia equally, bond BEIR and swap BEIR of the same maturity should be similar. Subject to the arbitrage imperfections noted above the difference between the two measures - here called the basis - should be nonzero. Nevertheless a positive (negative) mean of the basis would imply that there are irrevocable costs attached to the investment that makes the hedging of inflation exposure more costly (more attractive) in one market.

The basis for a given tenor, t, is defined as:

$$basis_t = swapBEIR_t - bondBEIR_t, \tag{1}$$

where:

$$bondBEIR_t = \left[\left(\frac{1+y_t^n}{1+y_t^r} - 1 \right) * 100 \right], \tag{2}$$

and y_t^n and y_t^r are the yields of the nominal respectively real bond.

In the BEIR implicit inflation expectations are traded in the swap and the bond market. Price discovery is the process by which prices embed new information in either one or both of the two markets. Arbitrage implies that prices cannot wander apart too far. In econometric terms, prices are cointegrated

[13] For an explanation and visualization of seasonality in CPI see for example Peat and Segregeti 2008, p. 183ff.

[14] See Eijsing, Garcia, and Werner (2007) for further explanations of the adjustment method.

I(1) variables which means that the price series show one or more common stochastic factors. If we assume that there is one cointegration relation only and therefore one common factor, we can thus term this factor the implicit efficient price. It is this price driven by new information which is the source of the permanent movement in the prices of both markets. The price discovery can be analyzed with two alternative concepts both relying on common factor models, Hasbrouck's information shares (Hasbrouck 1995) and Gonzalo and Granger's contributions to the common factor (Gonzalo and Granger 1995).[15] Whereas Hasbrouck defines price discovery in terms of the variance of all innovations in a vector error correction model (VECM) to the common factor Gonzalo Granger involves only permanent shocks where each markets contribution to the common factor is defined to be a function of only the error correction coefficient in a VECM. Hasbrouck information shares use contemporaneous correlations between price innovations in both markets as much as the variance of these innovations whereas Gonzalo Granger does not. To see the difference more clearly assume that the swap market's price responds to deviations from the bond market's price described by the error correction term, but the bond market does not respond to deviations from the swap market. With the Gonzalo Granger method price discovery only occurs in the bond market. In contrast if we further assume that the price innovations are correlated across both markets the Hasbrouck metric suggest that both markets contribute to price discovery because of this correlation. In the following we compute both measures.

If the two prices are $I(1)$, cointegrated and have the r^{th} order vector autoregression representation,

$$p_t \;=\; \Theta_1 p_{t-1} + \cdots + \Theta_r p_{t-r} + \varepsilon_t, \tag{3}$$

where $p_t = (p_{1,t}, p_{2,t})'$. It follows that the returns,

$$\Delta p_t \;=\; \begin{bmatrix} p_{1,t} - p_{1,t-1} \\ p_{2,t} - p_{2,t-1} \end{bmatrix}, \tag{4}$$

evolve according to the Engle and Granger (1987) representation theorem in a bivariate equilibrium correction process

$$\Delta p_t \;=\; \alpha z_{t-1} + A_1 \Delta p_{t-1} + \cdots + A_r \Delta p_{t-r-1} + \varepsilon_t, \tag{5}$$

[15]See Hasbrouck (1995), Baillie et al. (2002), Mizrach and Neely (2007) or Grammig and Peters (2008) for derivations and a discussion of both measures.

where z_{t-1} is the error correction term and ε_t is a zero-mean vector of serially uncorrelated innovations. z_t is a vector of differences in prices between markets and because swap BEIR are not directly comparable to bond BEIR includes coefficient β_2, that adjusts for daily changes in the basis and a constant c:

$$z_{t-1} = [p_{1,t-1} - \beta_2 p_{2,t-1} - c] \tag{6}$$

$$z_{t-1} = \beta' p_{t-1}.$$

Therefore the cointegration vector is $\beta = (1, -\beta_2, c)'$ or if you assume that the arbitrage relation holds up to a time invariable amount of transaction costs $\beta = (1, -1, c)'$. The coefficient α reveals the speed with which deviations between the prices in different markets are corrected. Other things equal, a larger α_1 indicates a greater speed of correction to the price in market 2 and less price discovery in market 1.

Following the (Stock and Watson 1988) permanent-transitory decomposition Hasbrouck (1995) transforms equation (3) into a vector moving average (VMA) representation and its integrated form,

$$p_t = \Psi(1) \sum_{s=1}^{t} \varepsilon_s + \Psi^*(L)\varepsilon_t, \tag{7}$$

where $\Psi^*(L)$ is a matrixpolynomial in the lag operator, L. $\Psi(1)$ represents the permanent effect of the shockvector on all the cointegrated security prices, with $\Psi(1)\varepsilon_t$ being the long run impact of an innovation in t. Under the assumption of a single common factor the long run multipliers $\Psi(1)$ can be provided in the error correction framework as Baillie et al. (2002) show.

$$\Psi(1) = \beta_\perp \pi \alpha'_\perp \tag{8}$$

$$\Psi(1) = \pi \begin{bmatrix} \gamma_1 & \gamma_2 \\ \gamma_1 & \gamma_2 \end{bmatrix}.$$

Since we assumed a single common factor π is a scalar and $\beta_\perp$ and $\alpha_\perp$ are the orthogonal complements of the original parameter vectors in (3) and (4). Because the prices are cointegrated each error term must have the same long run impact on prices. This means that all the rows in (6) are identical. If the covariance matrix Ω of the residuals ε_t is diagonal, i.e. the contemporaneous correlation of the residuals is zero, the information share of market 1 is defined by:

$$S_1 = \frac{\gamma_1^2 \sigma_1^2}{\gamma_1^2 \sigma_1^2 + \gamma_2^2 \sigma_2^2}. \tag{9}$$

If there is correlation between the error terms, i.e. $\rho \neq 0$, Hasbrouck (1995) suggest a Choleski factorization of the covariance matrix such that $\Omega = MM'$, where M is a lower triangular matrix.[16] The Hasbrouck information shares for market 1 and 2 are then defined as:

$$H_1 = \frac{(\gamma_1 m_{11} + \gamma_2 m_{12})^2}{(\gamma_1 m_{11} + \gamma_2 m_{12})^2 + (\gamma_2 m_{22})^2}, \tag{10}$$

$$H_2 = \frac{(\gamma_2 m_{22})^2}{(\gamma_1 m_{11} + \gamma_2 m_{12})^2 + (\gamma_2 m_{22})^2}. \tag{11}$$

That is market 1 information share is the proportion of the variance in the common factor that is attributable to shocks in market 1. The factorization imposes a greater information share on the first price (unless $m_{12} = 0$). Therefore upper (lower) bounds of information shares are calculated when market 1 is first (second) in the ordering of the variables for the factorization. In the following we calculate midpoints of the upper and lower bounds of the Hasbrouck shares induced by the different orderings of the variables.

An alternative measure for price discovery is based on the Gonzalo and Granger (1995) decomposition of the price vector into a permanent, g_t, and a transitory, f_t, component,

$$p_t = \theta_1 g_t + \theta_2 f_t, \tag{12}$$

where the permanent component is a linear combination of the prices in the two different markets, $g_t = \Gamma p_t$, i.e. Γ is the common factor coefficient vector. The additional identifying restriction that f_t does not Granger-cause g_t implies that $\theta_1 = \beta_\perp \alpha'_\perp = (\gamma_1, \gamma_2)'$. The weights given to price discovery are then defined as:

$$GG_1 = \frac{\gamma_1}{\gamma_1 + \gamma_2}. \tag{13}$$

5 Price discovery in the euro area and the US

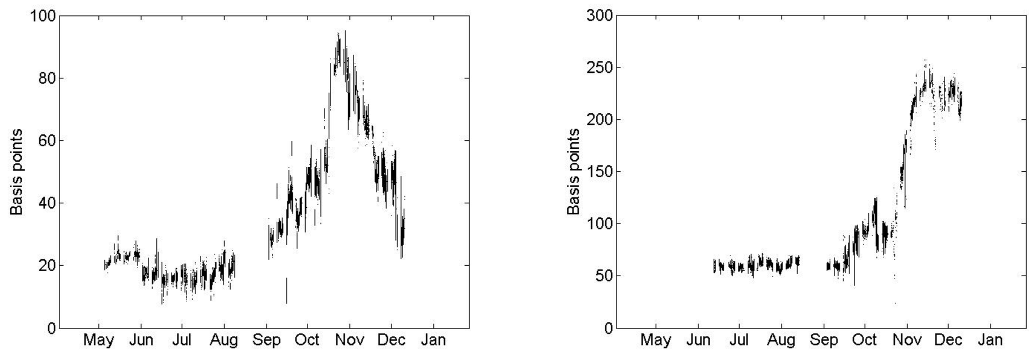
Since our data sets span each only 70 - for the US one only 45 - trading days the use of cointegration techniques which target long run equilibria might appear inappropriate. Yet, we are investigating an (near) arbitrage relationship on

[16] The covariance matrix is $\Omega = \begin{bmatrix} \sigma_1^2 & \rho\sigma_1\sigma_2 \\ \rho\sigma_1\sigma_2 & \sigma_2^2 \end{bmatrix}$ and the lower triangular matrix is $M = \begin{bmatrix} m_{11} & 0 \\ m_{12} & m_{22} \end{bmatrix} = \begin{bmatrix} \sigma_1 & 0 \\ \rho\sigma_2 & \sigma_2(1-\rho^2)^{1/2} \end{bmatrix}$

a financial market, where corrections to deviations from equilibrium could be effected instantaneously or in our case every minute. Therefore we expect the half live of deviations to be short-lived. Indeed, the average half live of a deviation across all maturities and both markets is around 3 $^1/_2$ hours in the euro area and 7 $^1/_2$ hours in the US in Summer 2008. If we set the length of our data set in relation to this average half life as is proposed by Hakkio and Rush (1991) we get a ratio of 190 or 94 respectively. Studies testing for purchasing power parity where cointegration is routinely applied featuring half lives of three to five years (Rogoff 1996). They would need over 300 years of data to match a ratio of 100. However, the half live of deviations increases to over 40 hours for euro area data and over 120 hours in the US in our extreme crisis sample in Autumn 2008 implying a ratio of the length of the data set to the average half live of 16 or 6 respectively. This gives a first hint that trades and the adjustment to a common efficient price were distinctly slower during the financial turmoil period.

In the remainder of this Section we start with laying out price discovery, first in the comparatively "calm" period of Summer and subsequently in the "hot crisis" phase of Autumn 2008. Price discovery with forward rates is presented in the last Subsection.

5.1 Summer 2008: The baseline scenario



(a) Basis euro area

(b) Basis US

Figure 2: Basis for tenor 7 years.

Data for swaps and bonds show that the basis is significantly positive (see Figure 2 and Table 1). For all maturities - except the shortest in the US - the basis is meaningfully greater than zero implying that the BEIR derived from swaps lies unanimously over the bond BEIR. One part of this difference stems

Table 1: Average of difference between swap BEIR and bond BEIR

Euro area		
	Summer 08	*Autumn 08*
	Basis points	
2 year swap-bond BEIR	37.9	45.2
4 year swap-bond BEIR	30.7	49.2
5 year swap-bond BEIR	36.7	68.5
7 year swap-bond BEIR	23.4	55.8
8 year swap-bond BEIR	24.2	61.5
12 year swap-bond BEIR	19.8	53.9
US		
	Summer 08	*Autumn 08*
	Basis points	
2 year swap-bond BEIR	-3.1	125.9
3 year swap-bond BEIR	14.8	147.5
4 year swap-bond BEIR	25.0	115.6
5 year swap-bond BEIR	32.3	76.6
6 year swap-bond BEIR	64.9	147.0
7 year swap-bond BEIR	66.2	129.7
8 year swap-bond BEIR	53.2	105.4
9 year swap-bond BEIR	48.9	92.2
10 year swap-bond BEIR	45.5	94.9

from our use of yield to maturity (YTM) yields for bonds versus zero coupon yields (ZCY) for swaps. If the yield curve does not run completely flat, as is the case in our sample, YTM are lower compared to ZCY. When comparing ZCY for both swap and bond BEIR using a data set with daily frequency we see that a significant and positive basis persists although it is on average around 8 basis points smaller than that of our high frequency data set. This is in line with previous literature assessing the higher swap yield to liquidity considerations and other risk premia (Armann, Benaben, and Lambert (2005) and Deacon, Derry, and Mirfendereski (2004)).

We performed unit root tests for all time series and could not reject the null at conventional test sizes using the Augmented Dickey Fuller test. We determined the lag order of the unrestricted vector auto regression (VAR) following the Schwarz information criterion. Since the criterion required at most 15 lags, i.e. 15 minutes, we suspected that overnight returns did not play a prominent role in our estimations which would be the case if market prices jumped a lot between market close and opening on the next day.[17] This implies that swaps and bonds are hardly traded outside the peak trading hours ranging from 8 a.m. to 6 p.m. in the euro area and from 9 a.m. to midnight in the US, which we cover in our sample. Indeed our raw data set which comprises transactions during a full 24-hours a day shows nearly no trading activity in the interim time.

We report Johansen trace statistics for the determination of the number of cointegration vectors in Tables A-8 and A-9 in the Appendix. The pairs of all swap and bond BEIR for all maturities exhibit one cointegration relation and therefore one common trend. As has been discussed before, markets price BEIR entirely equally only if the unity cointegration vector $[1, -1]$ applies. Yet, swap BEIR nearly always exhibit higher liquidity and risk premia than bond BEIR. To cover this difference, we included a constant in our cointegration vector. In the euro area only shorter maturities, 2 and 4 years, comply with the restriction of a common price up to a constant amount. For the US this is the case for 2, 7, and 8 years. For other (longer) maturities at least one market exhibit time-varying nontransient factors in its price that might be due to nonstationary liquidity differentials on both markets.

The Hasbrouck information share midpoints show that for tenors of 2 to 5 years price discovery on inflation expectations is nearly evenly split in the euro area (see Table 2).[18] Yet, the bond market leads as shares are still significantly different from equality.[19] At longer maturities, this changes dramatically. Regarding average inflation expectations over 8 years, nearly no price discovery takes place in the swap market. This result is confirmed by the Gonzalo Granger contributions to the common factor which are reported in the same table.[20] One interpretation of that result is that especially for longer maturities protection against unexpected inflation rate deviations is virtually only provided by central governments. Financial institutions, brokers and corporate treasurers which act as inflation taker on the swap market are cagey when

[17]Reestimation of the VECM and the Hasbrouck information shares with the overnight returns substituted with the mean return of the following day showed virtually no influence on the parameters. We thank Franziska Julia Peter and Joachim Grammig for performing the estimation using their Gauss procedures.

[18]See Table A-10 in the Appendix for upper and lower bounds of the Hasbrouck information share measure.

[19]Wald tests on the equality of the ratio of adjustment coefficients or the ratio of the γ respectively are rejected at conventional test sizes.

[20]As discussed before, the divergence of both measures is greater when either the correlation of the residuals or their variances differ significantly.

Table 2: Contributions to price discovery in the euro area

	Hasbrouck inform. shares		*Gonzalo Granger*	
	Summer 08	*Autumn 08*	*Summer 08*	*Autumn 08*
2 year swap BEIR	0.46	0.09	0.29	0.09
2 year bond BEIR	0.54	0.91	0.71	0.91
4 year swap BEIR	0.44	0.05	0.32	0.08
4 year bond BEIR	0.56	0.95	0.68	0.92
5 year swap BEIR	0.44	0.06	0.28	0.08
5 year bond BEIR	0.56	0.94	0.72	0.92
7 year swap BEIR	0.30	0.05	0.22	0.07
7 year bond BEIR	0.70	0.95	0.78	0.93
8 year swap BEIR	0.09	0.04	0.08	0.05
8 year bond BEIR	0.91	0.96	0.92	0.95
12 year swap BEIR	0.34	0.02	0.28	0.04
12 year bond BEIR	0.66	0.98	0.72	0.96

Note: Midpoints of Hasbrouck information shares are reported. Lower and upper bounds can be found in Table A-10 in the Appendix. Where appropriate according to the results in Table A-8 the restriction of an unity vector is imposed.

taking inflation risk in their books that is priced differently to the government bond market.

We motivated our use of an US data set with the different structure of markets for tradable inflation expectations in the euro area and the US. This prior of a larger and more liquid inflation-linked bond market over a less established inflation swap market can be recovered in the results. Hasbrouck information share midpoints and Gonzalo Granger contributions show a clear lead of the bond market in our baseline scenario (see Table 3). Only for the shortest maturity the swap market contributes less than one third to the price discovery process. Most likely the volume of the respective market does play a role in the determination where price information is processed firstly.

5.2 Price discovery in times of extreme financial crisis

In Autumn 2008 a fully-fledged financial crisis propagated through the financial system as well as the real economy and left inter alia the US and the euro area in a recession at the year-end. The turmoil on the financial markets went along with bigger amplitudes for price changes of financial instruments. The increased variability showed up in both, the bond and the swap market

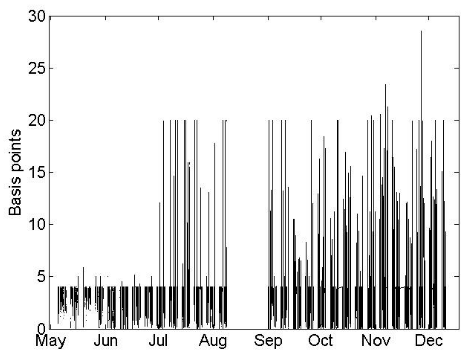
Table 3: Contributions to price discovery in the US

	Hasbrouck inform. shares		*Gonzalo Granger*	
	Summer 08	*Autumn 08*	*Summer 08*	*Autumn 08*
2 year swap BEIR	0.27		0.14	
2 year bond BEIR	0.73		0.86	
3 year swap BEIR	0.12		0.06	
3 year bond BEIR	0.88		0.94	
4 year swap BEIR	0.13		0.06	
4 year bond BEIR	0.87		0.94	
5 year swap BEIR	0.11	0.07	0.04	0.04
5 year bond BEIR	0.89	0.93	0.96	0.96
6 year swap BEIR	0.18		0.10	
6 year bond BEIR	0.92		0.90	
7 year swap BEIR	0.09	0.08	0.02	0.03
7 year bond BEIR	0.91	0.92	0.98	0.97
8 year swap BEIR	0.04	0.04	0.00	0.03
8 year bond BEIR	0.96	0.96	1.00	0.97
9 year swap BEIR	0.04	0.03	0.02	0.04
9 year bond BEIR	0.96	0.97	0.98	0.96
10 year swap BEIR	0.04	0.04	0.01	0.02
10 year bond BEIR	0.96	0.96	0.99	0.98

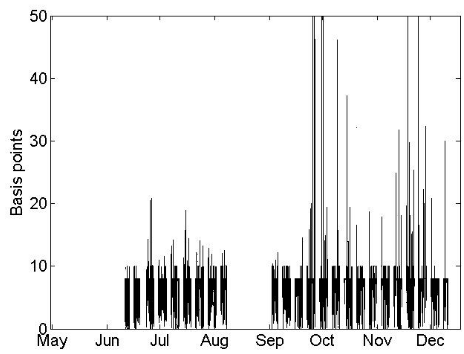
Note: Hasbrouck midpoints, lower and upper bounds can be found in Table A-11 in the Appendix. Blank spaces indicate no cointegration relation. Where appropriate according to the results in Table A-9 the restriction of an unity vector is imposed.

(see Tables A-6 and A-7 in the Appendix). Standard deviations for bond and swap prices nearly quadrupled in the euro area and blew up tenfold in the US. Furthermore, the price distribution exhibited a significant lower kurtosis, eg prices were more splattered away from the mean. The higher variability was more contained for longer maturities as short term markets were firstly and persistently disrupted during the financial crisis. The mean of BEIR decreased considerably for all maturities and it even went negative. Again the development was more pronounced in the US where the mean of the BEIR decreased far more from partly over 3 percentage points to negative values of partly over one percentage point for short to medium maturities. The lower inflation expectations incorporated in the BEIR are in line with an upcoming negative economic outlook and falling energy and commodity prices which brought down actual inflation rates and inflation expectations in surveys. Nevertheless it might be partly driven by the liquidity drain stemming from the withdrawal of risky assets and the search for highest-quality collateral which affected foremost nominal government bonds. The liquidity differential between nominal and real government bonds widened and bond BEIR fell consequently.

The crisis involved a significant increase of risk aversion from the part of investors and consequently affected various financial instruments and markets differently. The difference between swap and bond BEIR, the basis, raised considerably since September 2008 (see Table 1). The wedge between the swap and the bond market in the US broadened up to the point where one would expect that both markets do not exhibit a near arbitrage relationship any longer. Market participants described that especially after one of the bigger traders, Lehman Brothers, filed for bankruptcy on 14 September 2008 a new kind of risk came to the fore. The default-to-replacement risk contains both, costs incurred by replacing the swap contract with new counterparties and costs of - not collateralized - price movements after a default (WatsonWyatt 2008). Pricing this default-to-replacement risk induced higher risk premia on inflation swaps even if they were fully collateralized. Government bonds were valued more by the investors thus exhibiting higher prices and lower yields as well as lower BEIR compared to swaps.



(a) Euro area



(b) US

Figure 3: Bid-ask spread for 7 year inflation swaps.

Apart from that newly marked kind of risk the elevated basis naturally lead to the question why it was not arbitraged away. Three factors might have hampered the smoothing out of price differences: increased transaction costs, liquidity constrained dealers and interest rate uncertainty. Firstly, trades have become more costly due to increased bid-ask spreads. The increase was pronounced with inflation swaps in particular (see Figure 3). Even though the mean of the overall tight bid-ask spread was higher by only half a basis point in our crisis sample, variation picked up dramatically. A spread of 20 basis points which was not unusual in November and December for some trading hours made relative value trades prohibitively costly. Furthermore, spreads went up for bond trading as well. On the bond market the spread increase was more pronounced for inflation-linked compared to nominal bonds.[21] While the absolute rise of the spread which is normally contained within one basis point for this liquid market was small in numbers it was twice as high on the inflation-indexed compared to the nominal bond market. In accordance to that trading volumes of inflation-linked bonds on electronic platforms, eg EuroMTS, decreased. For the TIPS market a more than doubled spread as well as a reluctance to trade inflation-linked bonds were reported (Madar, Rodrigues, and Steinberg (2009)). This development strengthened the liquidity differential between real and nominal bonds and and could have therefore brought down bond BEIR further. Secondly, some of the most active traders, eg banks and hedge funds, faced liquidity and financing constraints. With a diminishing capital basis caused by huge write-offs, banks were forced to reduce both portfolio holdings and capital allocated to their trading desks. Hedge funds, a classic class of arbitrageurs, faced significant withdrawals from their customers admit bad performance. Furthermore, banks were less willing to finance highly leveraged operations. Thus, banks, hedge funds and other dealers could hardly invest in buying "cheap" bonds and reselling the inflation-linked cash flow in a likewise disturbed swap market. Finally, increased interest rate uncertainty which showed up in the high implied volatility of options on bond futures might also have hampered gap offsetting trades, as it became more probable that rates would alter significantly during the transaction time necessary to initiate, calculate, fund and execute an arbitrage deal. Yet it was not just demand that dried up considerably. The supply side suffered comparably since fewer people were willing to pay inflation or long-end rates.

Not surprisingly the disturbances affected the pricing of the different financial market instruments. Price discovery nearly ceased to take part on the swap market from September to December 2008 in the euro area (see Table 2).[22] In the shortest maturity segment just under one tenth of information relevant for

[21]Data from Bloomberg show that for one big trader spreads for linkers quadrupled whereas the ones for nominal government bonds only doubled in Autumn compared to the first half of the year.

[22]We performed unit root tests for all series. The number of lags recommended by the Schwarz information criterion did not exceed 15 or 22 lags where a number of intermediate lags were excluded. Johansons trace statistics for the number of cointegration vectors are reported in Table A-8 in the Appendix.

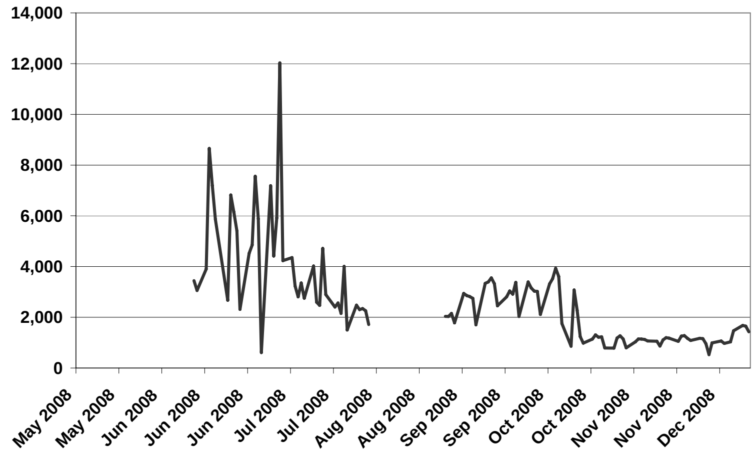


Figure 4: US Inflation Swaps: number of daily quotes, tenor 2 years.

pricing was processed first in the swap market. In all other maturities pricing virtually only took part with government bonds. Likelihood ratio tests of the variables for the cointegration vector showed weak exogeneity for bond BEIR with maturities above two years. This adds to the interpretation of the swap market has become nearly an appendix to the government bond market when it comes to price inflation expectations.

What happened in the US in Autumn 2008 can be depicted as the collapse of an integrated market for inflation expectations. Technically we were not able to find a cointegration relation between the swap and the bond market for maturities of 2, 3, 4, and 6 years (see Table A-9 in the Appendix). Economically speaking arbitrage did not prevent markets from developing in completely different directions. The first explanation for this is the increase in transaction costs due to liquidity and financial constraints. This led to a downturn in trades and for the inflation swap market even the number of quotes during a day decreased dramatically for shorter maturities (see Figure 4). Secondly, a feature that can be seen as unique for the US is that the pronounced deflationary expectations hampered relative value trades in BEIR. Whereas it is generally possible to trade inflation swaps on negative BEIR - the cash flows for fixed and variable rate payers are reversed - inflation-linked bonds safeguard investors against deflationary deductions which are above the coupon payments since the principle is always repaid at a 100 percent. Like an embedded option premia this feature only steps in in the case of extreme deflation expectations and therefore its value is time variable. That notwithstanding as in the euro area the liquidity differential between nominal and real bonds widened in the US as well and therefore led to lower bond BEIR.

For maturities of 5, 7 years, and above we found a cointegration relation and the information shares showed a complete concentration of the price discovery on the government bond market. The confidence withdrawal of investors hindered the exchange of financial flows not only on the short term money market segment but on longer-term financial markets as well. Solely the comparable safest instrument, government bonds, seemed to be still accepted by investors.

5.3 Price discovery with forward rates

Since it is clear that both the swap and the bond market are affected by idiosyncratic liquidity risk, market risk and demand factors it might be helpful to look at cointegration and price discovery for BEIR forward rates derived from BEIR spot rates. As long as the market specific factor influence all maturities to the same extent they cancel out when computing forward rates. We calculated 5 year forwards starting in 2 years and starting in 5 or 7 years for both markets and both periods. The series turned out to be stationary in the euro area in the Summer sample, so no cointegration analysis was executed. For the Autumn period we calculated Hasbrouck info shares and Gonzalo Granger contributions to the common factor. For the 5 year forward starting in 2 years both measures were slightly higher than those for the 5 year spot rate in the euro area. Nevertheless the swap market accounted for less than one fifth of price discovery. This is far lower than the info shares computed using the spot rate in the Summer period. Two interpretations might result from this finding. It corroborates our interpretation that the crisis infected the short-term segment of the market differently from long-end rates and it shows that apart from idiosyncratic factors prevailing on both markets, the government bond market clearly dominates price discovery for traded long-term inflation expectations.

Calculating forward BEIR from US data shows that price discovery is even in the baseline scenario quantitatively more concentrated on the bond market. For the crisis data sample we find a cointegration relationship among the 5 year forward bond and swap BEIR starting in 2 and 5 years.[23] This might imply that what breaks the cointegration relation is somehow contained in liquidity differentials across maturities of the same market.

[23] As a caveat note that unit root tests with forward swap rates are rejected in the majority of cases which is not surprisingly as forward rates are calculated as differences of spot rates.

6 Conclusions

Using a high frequency data set on inflation-indexed as well as nominal bonds and inflation swaps we were able to analyze the price discovery for BEIR implicit in the mentioned financial instruments. News affecting inflation expectations incorporated in the BEIR are slightly quicker processed on bond markets for maturities up to 5 years in the euro area. For longer maturities bond markets increasingly lead the price discovery process. These results are somewhat dependent on the structure eg the volume and liquidity of the respective markets. For the US where the TIPS market is large in absolute volume and compared to overall Treasury issuance the bond market clearly determine the price formation for all time horizons.

During Autumn of 2008 the turmoil in the financial systems worldwide amplified and pricing on financial markets became seriously disturbed. The dramatic decrease of the part of price discovery that took place on the swap market illustrates the severe dysfunction of the normally smooth working derivative market especially in the short to medium term. Increasing bid-ask spreads - more pronounced with derivatives - hampered arbitrage between the bond and the swap market. BEIR were therefore more driven apart than during our baseline sample in Summer 2008. Disruptions coming from the short-end of the market even led to a collapse of the integration of the two markets where inflation expectations trade. Whereas a heightened risk aversion generally obstructed trades on financial markets, contributions to price formation concentrated a lot more on the safest financial instrument: government bonds.

That notwithstanding BEIR are generally priced higher on the swap market. We attribute this mostly to liquidity and risk premia. The difference between instruments on both markets is furthermore not constant but display time variation. We proposed the default-to-replacement risk and embedded put options in inflation-linked bonds that safeguard against a loss in an extreme deflationary setting as two features driving this time variability without formally testing them. Since idiosyncratic liquidity and risk premia are difficult to quantify it might be a promising starting point for further research to relate changes in the liquidity premia to aggregate liquidity conditions.

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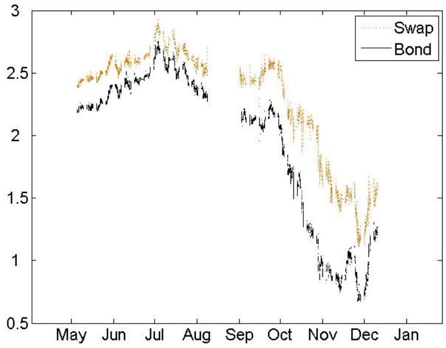
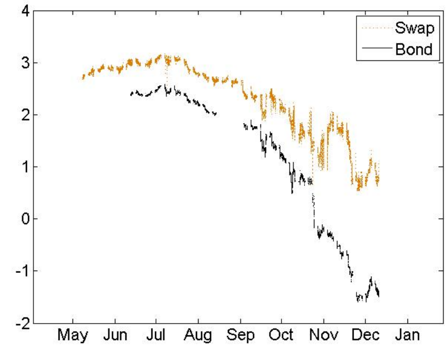
Appendix



(a) Euro area



(b) US

Figure A-1: Break-even inflation rate from bonds and swaps for tenor 7 years.

Table A-1: List of euro area bonds

Tenor	ISIN	Coupon	Type	First Issue	Maturity
2 years	FR0108664055	1.25	real	20 Apr 2006	25 Jul 2010
	FR0107674006	2.50	nominal	16 Jun 2005	12 Jul 2010
4 years	FR0000188013	3.00	real	25 Jul 2001	25 Jul 2012
	FR0000188328	5.00	nominal	25 Apr 2001	25 Apr 2012
5 years	DE0001030518	2.25	real	24 Oct 2007	15 Apr 2013
	DE0001135234	3.75	nominal	04 Jul 2003	04 Jul 2013
7 years	FR0010135525	1.60	real	25 Jul 2004	25 Jul 2015
	FR0010163543	3.50	nominal	25 Apr 2004	25 Apr 2015
8 years	DE0001030500	1.50	real	08 Mar 2006	15 Apr 2016
	DE0001135291	3.50	nominal	23 Nov 2005	04 Jan 2016
12 years	FR0010050559	2.25	real	25 Jul 2003	25 Jul 2020
	FR0010192997	3.75	nominal	04 May 2005	25 Apr 2021

Notes: Real bonds indexed to the harmonized euro area HICP ex tobacco. Indexation month for French paper is April, for German January.

Table A-2: List of US nominal bonds

Tenor	ISIN	Coupon	First Issue	Maturity
2 years	US912828CX62	3.375	10/15/2004	10/15/2009
3 years	US912828FD71	4.875	5/1/2006	4/30/2011
4 years	US912828GQ75	4.5	4/30/2007	4/30/2012
5 years	US912828HY90	3.125	4/30/2008	4/30/2013
6 years	US912828CT50	4.25	8/16/2004	8/15/2014
7 years	US912828EE63	4.25	8/15/2005	8/15/2015
8 years	US912828FQ84	4.875	8/15/2006	8/15/2016
9 years	US912828HA15	4.75	8/15/2007	8/15/2017
10 years	US912828HR40	3.5	2/15/2008	2/15/2018

Notes: US bonds pay interest biannually.

Table A-3: List of US inflation-indexed bonds (TIPS)

Tenor	ISIN	Coupon	First Issue	Maturity
2 years	US912828CZ11	0.875	10/29/2004	4/15/2010
3 years	US912828FB16	2.375	4/28/2006	4/15/2011
4 years	US912828GN45	2.0	4/30/2007	4/15/2012
5 years	US912828HW35	0.625	4/30/2008	4/15/2013
6 years	US912828CP39	2.0	7/15/2004	7/15/2014
7 years	US912828EA42	1.875	7/15/2005	7/15/2015
8 years	US912828FL97	2.5	7/17/2006	7/15/2016
9 years	US912828GX27	2.625	7/16/2007	7/15/2017
10 years	US912828HN36	1.625	1/15/2008	1/15/2018

Notes: TIPS are indexed to the CPI-U and pay interest biannually.

Table A-4: Number of observations by instrument: Euro area

tenor	nominal bond	real bond	inflation swap
2 years	32,655	27,488	72,002
4 years	49,024	45,241	73,410
5 years	57,452	18,733	73,312
7 years	56,934	42,337	73,850
8 years	63,017	12,617	73,942
12 years	55,782	38,973	72,213
total	314,864	185,389	438,729

Notes: Number of bid-ask pairs. 5 May to 8 December 2008.

Table A-5: Number of observations by instrument: US

tenor	nominal bond	real bond	inflation swap
2 years	26,798	17,831	95,349
3 years	46,858	25,651	94,599
4 years	55,833	29,308	95,463
5 years	58,825	37,561	91,589
6 years	64,525	36,599	98,166
7 years	62,793	35,823	94,420
8 years	66,964	43,040	98,673
9 years	69,090	47,661	90,027
10 years	68,935	51,196	99,973
total	520,621	324,670	858,259

Notes: Number of bid-ask pairs. 12 June to 9 December 2008.

Table A-6: Descriptive statistics of break-even inflation rates in the euro area

	Pre-crisis/ Summer 08			*Crisis/ Autumn 08*		
	Mean	*Std.dev.*	*Kurtosis*	*Mean*	*Std.dev.*	*Kurtosis*
2 year bond BEIR	2.35	0.24	2.54	0.91	0.90	1.40
4 year bond BEIR	2,34	0.17	2.58	1.17	0.75	1.36
5 year bond BEIR	2.25	0.16	2.53	1.11	0.71	1.31
7 year bond BEIR	2.36	0.13	2.34	1.41	0.53	1.38
8 year bond BEIR	2.34	0.12	2.58	1.43	0.53	1.41
12 year bond BEIR	2.39	0.11	2.41	1.70	0.40	1.67
2 year swap BEIR	2.73	0.23	2.56	1.36	0.82	1.43
4 year swap BEIR	2.65	0.16	2.69	1.67	0.67	1.52
5 year swap BEIR	2.62	0.14	2.61	1.79	0.59	1.55
7 year swap BEIR	2.59	0.11	2.67	1.98	0.45	1.60
8 year swap BEIR	2.58	0.10	2.61	2.05	0.39	1.62
12 year swap BEIR	2.59	0.09	2.06	2.24	0.28	1.85

Table A-7: Descriptive statistics of break-even inflation rates in the US

	Pre-crisis/ Summer 08			*Crisis/ Autumn 08*		
	Mean	*Std.dev.*	*Kurtosis*	*Mean*	*Std.dev.*	*Kurtosis*
2 year bond BEIR	3.07	0.26	1.74	-1.75	2.77	1.51
3 year bond BEIR	2.87	0.20	1.68	-1.22	2.11	1.48
4 year bond BEIR	2.75	0.20	1.68	-0.26	1.46	1.48
5 year bond BEIR	2.67	0.19	1.76	0.49	0.95	1.51
6 year bond BEIR	2.33	0.17	1.98	-0.05	1,23	1.56
7 year bond BEIR	2.30	0.15	2.56	0.26	1.08	1.60
8 year bond BEIR	2.40	0.14	2.55	0.62	0.97	1.66
9 year bond BEIR	2.43	0.11	2.54	0.90	0.75	1.80
10 year bond BEIR	2.47	0.12	3.00	1.01	0.60	1.97
2 year swap BEIR	3.04	0.33	1.96	-0.49	1.64	1.58
3 year swap BEIR	3.03	0.30	1.90	0.25	1.27	1.64
4 year swap BEIR	3.00	0.26	1.88	0.89	0.90	1.92
5 year swap BEIR	3.00	0.22	1.96	1.26	0.77	2.34
6 year swap BEIR	2.98	0.20	2.02	1.41	0.66	2.06
7 year swap BEIR	2.96	0.17	2.07	1.56	0.58	2.03
8 year swap BEIR	2.93	0.14	2.22	1.67	0.53	2.15
9 year swap BEIR	2.92	0.12	2.44	1.82	0.46	2.29
10 year swap BEIR	2.93	0.10	2.36	1.96	0.38	2.38

Table A-8: Long-run relation between swap BEIR and bond BEIR in the euro area

	Pre-crisis/ Summer 08		
	# coint. vectors (cv)		*Restriction on cv*
	None	*At most 1*	*(1,-1,c)*
2 year swap-bond BEIR	66.91***	2.59	1.18
4 year swap-bond BEIR	111.07***	3.05	2.85*
5 year swap-bond BEIR	97.61***	2.66	22.43***
7 year swap-bond BEIR	166.85***	3.41	67.49***
8 year swap-bond BEIR	187.65***	3.31	66.10***
12 year swap-bond BEIR	61.64***	5.23	16.65***
	Crisis/ Autumn 08		
	# coint. vectors (cv)		*Restriction on cv*
	None	*At most 1*	*(1,-1,c)*
2 year swap-bond BEIR	151.93***	2.93	60.71***
4 year swap-bond BEIR	44.94***	3.09	11.39***
5 year swap-bond BEIR	23.88***	3.47	7.46***
7 year swap-bond BEIR	23.27***	2.97	5.19**
8 year swap-bond BEIR	35.19***	3.36	19.33***
12 year swap-bond BEIR	46.67***	3.13	30.17***

Rejections of the null at the 10%, 5%, or 1% level is indicated by a superscript *,**, or *** respectively.

Table A-9: Long-run relation between swap BEIR and bond BEIR in the US

	Pre-crisis/ Summer 08		
	# coint. vectors (cv)		*Restriction on cv*
	None	*At most 1*	*(1,-1,c)*
2 year swap-bond BEIR	34.23***	0.73	1.98
3 year swap-bond BEIR	87.77***	0.96	16.53***
4 year swap-bond BEIR	90.90***	0.75	29.07***
5 year swap-bond BEIR	122.79***	0.94	26.83***
6 year swap-bond BEIR	179.55***	1.07	71.53***
7 year swap-bond BEIR	139.04***	1.61	44.11***
8 year swap-bond BEIR	122.31***	2.15	0.04
9 year swap-bond BEIR	128.65***	1.56	0.48
10 year swap-bond BEIR	145.78***	2.10	19.13***
	Crisis/ Autumn 08		
	# coint. vectors (cv)		*Restriction on cv*
	None	*At most 1*	*(1,-1,c)*
2 year swap-bond BEIR	119.73***	12.05***	
3 year swap-bond BEIR	181.45***	31.88***	
4 year swap-bond BEIR	54.65***	9.21**	
5 year swap-bond BEIR	25.30***	7.34	4.40**
6 year swap-bond BEIR	52.28***	10.76**	
7 year swap-bond BEIR	61.18***	6.94	44.68***
8 year swap-bond BEIR	56.14***	7.71	40.39***
9 year swap-bond BEIR	41.20***	7.28	22.89***
10 year swap-bond BEIR	41.89***	2.70	24.92***

Rejections of the null at the 10%, 5%, or 1% level is indicated by a superscript *,**, or *** respectively.

Table A-10: Bounds on Hasbrouck information shares in the euro area

	Summer		*Autumn*	
	Lower	*Upper*	*Lower*	*Upper*
2 year swap BEIR	0.44	0.47	0.08	0.11
2 year bond BEIR	0.53	0.56	0.89	0.92
4 year swap BEIR	0.42	0.47	0.03	0.07
4 year bond BEIR	0.54	0.58	0.93	0.97
5 year swap BEIR	0.41	0.46	0.04	0.08
5 year bond BEIR	0.54	0.59	0.92	0.96
7 year swap BEIR	0.27	0.32	0.03	0.06
7 year bond BEIR	0.68	0.73	0.93	0.97
8 year swap BEIR	0.08	0.10	0.03	0.06
8 year bond BEIR	0.90	0.92	0.94	0.98
12 year swap BEIR	0.29	0.30	0.01	0.03
12 year bond BEIR	0.63	0.70	0.97	0.99

Note: Where appropriate according to the results in Table A-8 the restriction of an unity vector is imposed.

Table A-11: Bounds on Hasbrouck information shares in the US

	Summer		*Autumn*	
	Lower	*Upper*	*Lower*	*Upper*
2 year swap BEIR	0.27	0.27		
2 year bond BEIR	0.73	0.73		
3 year swap BEIR	0.44	0.47	0.08	0.11
3 year bond BEIR	0.11	0.12		
4 year swap BEIR	0.88	0.89		
4 year bond BEIR	0.13	0.13		
5 year swap BEIR	0.86	0.87	0.03	0.04
5 year bond BEIR	0.10	0.11	0.96	0.97
6 year swap BEIR	0.18	0.19		
6 year bond BEIR	0.81	0.82		
7 year swap BEIR	0.09	0.09	0.02	0.02
7 year bond BEIR	0.91	0.91	0.98	0.98
8 year swap BEIR	0.04	0.04	0.00	0.00
8 year bond BEIR	0.96	0.96	1.00	1.00
9 year swap BEIR	0.04	0.04	0.01	0.02
9 year bond BEIR	0.96	0.96	0.98	0.99
10 year swap BEIR	0.04	0.04	0.00	0.01
10 year bond BEIR	0.96	0.96	1.00	0.99

Note: Where appropriate according to the results in Table A-9 the restriction of an unity vector is imposed.