THE INFLATION-INDEXED BOND PUZZLE

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Abstract

This paper presents new insights into the dynamics and determinants of arbitrage mispricing in and across seven of the world's largest and most liquid financial markets. Specifically, this paper analyzes mispricing between nominal and inflation-linked bonds (ILB mispricing) in the G7 government bond markets, and extends the slow moving capital explanation of the persistence of arbitrage mispricing in financial markets. Nominal bonds are "richer" than cash-flow matched inflation-linked bonds on average. The mispricing is stunning in magnitude: aggregate mispricing is in excess of $22 billion on average during the period from July 2004 to September 2011. In the aftermath of the 2008 financial crisis, it peaks at $101 billion which represents more than eight percent of the total size of the G7 inflation-linked bond markets. Furthermore, the index-linked–nominal bond trade generates positively-skewed risk-adjusted excess returns across all countries. The key new insight for the slow-moving capital theory is that capital available to specific types of arbitrageurs is significantly related to the inflation-linked–nominal bond mispricing. Specifically, returns of hedge funds following fixed income strategies strongly predict subsequent changes in ILB mispricing, whereas other hedge fund categories lack statistically significant forecasting power. This paper also presents new insights into the effects of monetary policy on arbitrage mispricing. Specifically, during the 2008 financial crisis, central banks around the world may have exacerbated ILB mispricing through large-scale asset purchase programs.

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1 INTRODUCTION

The government bond markets in the United States, the United Kingdom, Japan, Canada, France, Italy, and Germany are among the largest and most actively traded fixed-income markets in the world. Despite this, there are persistent violations of the law of one price within these markets. The inflation-linked bond (ILB) arbitrage strategy is executed by converting the index-linked cash flows from an inflation-indexed bond issue into fixed cash flows using inflation swaps such that the resulting cash flows match exactly the cash flows from a nominal bond with the same maturity date as the index-linked bond issue. Price differences between the inflation-swapped index-linked bond and the actual nominal bond represent violations of the law of one price which will be referred to as ILB mispricing.

Arbitrage mispricing presents a major challenge to classical asset pricing theory. Still, several such puzzles have been documented in the literature.[1] However, ILB arbitrage mispricing in the G7 government bond markets is unique in that it represents one of the largest examples of arbitrage ever documented. In all countries, prices of nominal bonds almost always exceed those of inflation-linked bonds (ILB). The magnitudes are stunning: aggregate mispricing between nominal and inflation-linked bonds (ILB mispricing) in the G7 government bond markets is in excess of $22 billion on average during the period from July 2004 to September 2011. In the aftermath of the 2008 financial crisis, it peaks at $101 billion which represents more than eight percent of the total size of the G7 inflation-linked bond markets. In the United Kingdom, the price of a nominal gilt and an inflation-swapped index-linked gilt issue exactly replicating the cash flows of the nominal gilt can differ by more than $20 per $100 notional.[2]

This paper presents new insights into the properties, dynamics and determinants of arbitrage mispricing in and across seven of the world's largest and most liquid financial markets. Specifically, ILB no-arbitrage violations are positively correlated across markets contemporaneously and in the time series. Furthermore, VAR results reveal that an increase in the mispricing in the United States, for instance, is associated with subsequent increases in ILB mispricing in the other G7 countries, but with a lag of about one to two months. After about twelve months the increase due to the initial shock disappears across all countries. ILB mispricing in any of the G7 countries is strongly forecastable from lagged mispricings in the other countries. Therefore, this paper presents direct evidence that that there is a channel through which arbitrage mispricing propagates across global financial markets. Although these pricing violations occur in very different markets, there is strong commonality between them which is consistent with the existence of a common factor driving these arbitrages. Furthermore, ILB arbitrage produces positively-skewed risk-adjusted excess returns across all countries ranging from 0.51 percent per month in France to 0.69 percent per month in the United States, contrary to the notion that ILB arbitrage is merely a strategy that earns small positive returns most of the time, but occasionally experiences dramatic losses, similar to "picking up nickels in front of a steamroller"[3] or writing deep out-of-the-money puts.

Recent theoretical work has put forward potential explanations for the existence of persistent mispricing in financial markets. In particular, Mitchell, Pedersen, and Pulvino (2007) and Duffie (2010) discuss the role that slow-moving capital may play in allowing arbitrage opportunities to exist for extended periods of time. The slow moving capital hypothesis attributes the persistence of arbitrage to various market frictions. It captures the notion that capital constraints, liquidity problems and other frictions limit the speed at which investors can take advantage of mispricings in the market.

This paper not only analyzes ILB mispricing in the context of the slow-moving capital theory, but its findings broaden our understanding of the nature of slow moving capital and the dynamics of arbitrage

[1] For examples of significant mispricing in financial markets, see Dammon, Dunn, and Spatt (1993), and Lamont and Thaler (2003), Duffie (2010), Krishnamurthy (2002)), and Longstaff (2004).

[2] For simplicity, all bond prices and dollar mispricing values will be expressed in terms of dollars per $100 notional or par amount throughout the paper.

[3] Duarte, Longstaff, and Yu (2007).

mispricing. Specifically, changes in the supply of capital available to specific types of arbitrageurs is inextricably linked to subsequent changes in mispricing in specific markets. This captures the notion that not all arbitrageurs are equally able to exploit arbitrage opportunities due to idiosyncratic constraints which may include special knowledge and abilities required in implementing such strategies, available funds, and the ability to take on leverage.[4] The key contribution is that capital available to specific types of arbitrageurs is significantly related to ILB mispricing across all G7 government bond markets. Returns of hedge funds following fixed-income strategies strongly predict subsequent changes in ILB mispricing, whereas returns of hedge funds following non fixed-income related investment styles lack statistically significant forecasting power. Furthermore, ex-ante measures of changes in aggregate investor wealth such as stock, bond, and hedge fund returns predict subsequent changes in ILB mispricing in all countries.

This paper also presents new insights into the effects of monetary policy on arbitrage mispricing. In the aftermath of the 2008 financial crisis, central banks implemented large scale asset purchase programs to stabilize financial markets. Coincidentally, ILB mispricing spikes in the G7 countries during the same time period. This paper provides evidence that central bank liquidity programs may have exacerbated ILB mispricing. In the United States, the announcement effect of monetary policy measures is associated with an increase in the mispricing by 94.7 cents per $100 notional, which is consistent with the notion that large scale asset purchases by the major central banks during and in the aftermath of the financial crisis have affected market prices of the government bonds involved in ILB arbitrage, allowing mispricing to persist, and even to increase.

The remainder of this paper is organized as follows. Section 2 reviews the extant literature. The ILB arbitrage strategy is described in Section 3. Section 4 examines the size of the mispricing between cash-flow matched inflation-linked and nominal bonds for all G7 fixed-income markets and in aggregate. Section 5 analyzes ILB mispricing in the context of the slow-moving capital theory. Section 6 analyzes the impact of monetary policy interventions on the mispricing. The risk-and-return characteristics of ILB arbitrage are analyzed in Section 7. Section 8 discusses whether there are other factors that could account for the mispricing. Section 9 summarizes the results and presents concluding remarks. Appendix A provides introductions to the inflation-linked bond markets in the United States, the United Kingdom, Japan, Canada, France, Italy, and Germany, and describes the dataset for each country. Appendix B discusses the inflation swaps markets in these countries. Details on the implementation of the ILB aribtrage strategy are described in Appendix C.

2 LITERATURE REVIEW

This paper contributes to the literature on the pricing of inflation-linked bonds and limits to arbitrage. Other important papers on real bonds include Roll (1996, 2004), Barr and Campbell (1997), Evans (2003), Seppälä (2004), Bardong and Lehnert (2004), Buraschi and Jiltsov (2005), Ang, Bekaert, and Wei (2007, 2008), Campbell, Shiller, and Viceira (2009), Dudley, Roush, and Steinberg Ezer (2009), Fleming and Krishnan (2009), Adrian and Wu (2009), Barnes, Bodie, Triest, and Wang (2009), Gürkaynak, Sack, and Wright (2010), Christensen, Lopez, and Rudebusch (2010a, 2010b), Andonov, Bardong, and Lehnert (2010), Pflueger and Viceira (2011a, 2011b), and many others. Fleckenstein, Longstaff and Lustig (2012) were the first to formally study the no-arbitrage relation between TIPS and Treasury bonds and to explore determinants of the mispricing. Their key findings have also been confirmed in subsequent studies, for example, in Haubrich, Pennacchi, and Ritchken (2011).

Examples of fixed-income arbitrage mispricing reported in the literature include Cornell and Shapiro (1990), Amihud and Mendelson (1991), Boudoukh and Whitelaw (1991), Daves and Ehrhard (1993), Kamara (1994), Longstaff (1992, 2004), Grinblatt and Longstaff (2000), Longstaff, Santa Clara, and

[4]See, for example, Longstaff, Duarte, and Yu (2007).

Schwartz (2001), Yu (2006), Duarte, Longstaff, and Yu (2007), Jordan, Jorgensen, and Kuipers (2000) and many others.

The strand of literature on limits to arbitrage is large. Shleifer and Vishny (1997), Gromb and Vayanos (2002), Liu and Longstaff (2005), Fostel and Geanakoplos (2008), Gorton and Metrick (2009), and Ashcraft, Gârleanu, and Pederson (2010) argue that margins, haircuts, and other collateral-related frictions may permit arbitrage or deviations from the law of one price to occur. Brunnermeier and Pedersen (2009) emphasize the role that the availability of funding may play in allowing liquidity effects on security prices. Mitchell, Pedersen, and Pulvino (2007) and Duffie (2010) discuss the role that slow-moving capital may play in allowing arbitrage opportunities to exist for extended periods of time. Specifically, Shleifer and Vishny (1997), Liu and Longstaff (2005), and others show that an arbitrageur subject to margin constraints could suffer mark-to-market losses and be forced to liquidate a position in a textbook arbitrage at a loss prior to the date of convergence

The risk-and-return characteristics of arbitrage strategies has received significant attention by academics and practitioners alike. Closest to section 7 are the important studies of fixed income arbitrage returns by Duarte, Longstaff, and Yu (2007) and on equity arbitrage strategies by Mitchell and Pulvino (2001) and Mitchell, Pulvino, and Stafford (2002). Duarte, Longstaff, and Yu (2007) study returns on fixed income arbitrage strategies. Important work on equity arbitrage strategies include Mitchell and Pulvino (2001) and Mitchell, Pulvino, and Stafford (2002). There is a large literature focusing on the actual returns reported by hedge funds. These papers include Fung and Hsieh (1997, 2001, 2002), Ackermann, McEnally, and Ravenscraft (1999), Brown, Goetzmann, and Ibbotson (1999), Brown, Goetzmann, and Park (2000), Dor and Jagannathan (2002), Brown and Goetzmann (2003), Getmansky, Lo, and Makarov (2004), Agarwal and Naik (2004), Malkiel and Saha (2004), Chan, Getmansky, Haas, and Lo (2007) and Chan, et al. (2005). There is strand of literature that investigates the profitability of breakeven inflation (BEI) trades in the U.S. market. Bardong and Lehnert (2004a, 2004b, and 2008) study breakeven trades and find that investors were able to earn positive average excess returns over the 1997–2003 period. Breakeven trades are based on differences between the BEI and inflation forecasts. For instance, if the estimated future inflation rate is higher than BEI, it can be interpreted as a signal of future increases in the BEI, which would lead to an increased demand for TIPS. The trading strategy would then go long in a TIPS position. These results are not unique to the U.S., as Bardong and Lehnert (2004b) find similar results for breakeven trades in French OATi bonds. Andonov, Bardong and Lehnert (2010) find that the break-even strategy is consistently profitable across different forecasting horizons and over three, six and twelve month holding periods even after accounting for trading costs.

This paper also contributes to the literature on the effects of monetary policy actions in the aftermath of the financial crisis. Examples include Baba and Packer (2009), Bauer and Rudebusch (2011), Christensen and Rudebusch (2012), Christensen, Lopez and Rudebusch (2009), D'Amico and King (2011), Gagnon et al. (2011), Goldberg, Kennedy and Miu (2010), McAndrews (2009), McAndrews, Sarkar and Wang (2008), Sarkar and Shrader (2010), Taylor and Williams (2009), Wu (2008), and many others.

A number of important recent papers have studied the impact of liquidity programs that were implemented by the Federal Reserve and other central banks. Taylor and Williams (2009) find that the actual lending from the Federal Reserve's Term Auction Facility (TAF) had no significant impact on easing credit markets. McAndrews, Sarkar and Wang (2008), on the other hand, present evidence that announcements about the TAF did significantly lower credit spreads.

The strand of literature focusing on inflation expectations and breakeven rates includes Sack and Elsasser (2004), Gürkaynak, Sack, and Wright (2008), Christensen, Lopez and Rudebusch (2010), Gürkaynak, Sack and Wright (2010), Hördahl and Tristani (2007), Hördahl and Tristani (2010).

3 THE ILB ARBITRAGE STRATEGY

The arbitrage strategy is executed in the same way for all seven countries in this study. Without loss of generality, it is described for the U.S. TIPS market. The exact algorithm is described in the Appendix.

An investor buys a TIPS issue at par which has a coupon rate of s per semiannual period. Due to the inflation adjustment, the coupon paid at time t will be sI_t. Concurrently, the investor executes a zero-coupon inflation swap with a maturity date and notional amount matching that of the coupon payment for the TIPS issue. At date t, the inflation swap pays a cash flow of $s(1+f)^t - sI_t$, where f is the fixed inflation swap rate. The sum of the two cash flows is $sI_t + s(1+f)^t - sI_t = s(1+f)^t$ which is constant. Similarly, by executing zero-coupon inflation swaps with maturities and notional amounts matching the indexed cash flows from the TIPS issue, the investor converts all indexed cash flows into fixed cash flows.

Table 1 shows the various components of the strategy and their associated cash flows. The first part of the table shows the cash flows associated with a Treasury bond purchased at price P and with a coupon rate of c. The Treasury bond pays a semiannual coupon of c per period with a principal payment of 100 at maturity date T.

The second part of the table shows how the cash flows from the Treasury bond are replicated exactly from a TIPS position. First, the arbitrageur purchases a TIPS issue with a coupon rate of s and the same maturity date as the Treasury bond for a price of V. The TIPS bond pays coupons of sI_t each period, and then makes a principal payment of $100I_T$ at maturity. The arbitrageur then enters into an inflation swap for each coupon payment date with a notional amount of s (or $s + 100$ for the final principal payment date). This converts all indexed cash flows from the TIPS into fixed cash flows. To match exactly the cash flows from the Treasury bond, the arbitrageur also goes long or short a small amount of Treasury STRIPS for each coupon payment date. As shown at the bottom of the second part of the table, the net result is a portfolio that exactly replicates the cash flows from the Treasury bond in the first part of the table.

Inflation-indexed bonds and nominal bonds are matched based on their respective maturities. The number of days between the maturity of an inflation-indexed bond issue and that of a nominal bond with the closest maturity to that of the index-linked issue is defined as maturity mismatch. To adjust for differences in maturity, the yield to maturity on the synthetic fixed rate bond formed from the inflation-linked bond issue and the inflation swaps is applied to obtain the price of a synthetic nominal bond that would exactly match the maturity of the Treasury bond in the pair. It is important to note that for any maturity mismatch, the cash flows of the synthetic nominal bond always exactly match those of the underlying nominal bond by construction.

Dollar mispricing is defined as the price difference per \$100 notional between the nominal bond and the synthetic nominal bond formed from the inflation-linked bond and the inflation swaps. Similarly, basis-point mispricing is defined as the difference in yields to maturity between the nominal bond and the synthetic nominal bond formed from the inflation-linked bond and the inflation swaps.

In most of the study, ILB mispricing is aggregated at the country level. Country-specific details are available in an online appendix.[5] The ILB dollar mispricing index for each country is constructed for each day during the sample period as the linker–notional-weighted average mispricing per \$100 notional for all individual nominal–inflation-linked pairs in that country on that day. Similarly, the ILB basis-point mispricing index for each country is constructed for each day during the sample period as the linker–notional-weighted average basis-point mispricing per \$100 notional for all individual nominal–inflation-linked pairs in that country on that day. The G7 dollar mispricing index is constructed by taking the notional-weighted average of the individual country's index-linked–nominal bond mispricing,

[5] `http://www.mfleckenstein.com`

expressed in units of dollars per $100 notional, across the pairs included in the sample for that country. The G7 basis-point mispricing index is constructed by taking the notional-weighted average of the individual country's basis-point mispricing expressed in basis points across the pairs included in the sample for that country.

4 MAGNITUDE OF ILB MISPRICING

This section describes the magnitude of ILB mispricing in the United Kingdom, Japan, Canada, France, Germany, Italy, and the United States. Table 3 reports summary statistics for the indexed-bond-nominal bond mispricing for all G7 countries separately, and in aggregate. The left panel shows summary statistics for the mispricing measured in dollars per $100 notional, and the right panel for the mispricing measured in basis points. The mispricing in each country is the weighted-average index-linked-nominal bond mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked bond issue. The basis-point mispricing for each country is the weighted-average index-linked-nominal bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked bond issue. The middle panel in Table 3 shows summary statistics for the period from June 14, 2007 to September 20, 2011 in which all countries are included. The bottom panel in Table 3 shows summary statistics for the period from May 22, 2006 to September 20, 2011 which excludes Canada and Japan, since both countries enter the sample period at later dates. Results for the individual bonds in each country are available in the online appendix.

Table 3 shows that in all countries, prices of nominal bonds always exceed those of their inflation-linked counterparts on average. In the aftermath of the financial crisis of 2008, ILB mispricing peaks at $101 billion which represents more than eight percent of the total size of the inflation-linked bond markets in the study. On average, aggregate G7 ILB mispricing is $22.09 billion which represents 1.40% of the total G7 Index-Linked notional amount outstanding. Over the sample period from July 2004 until September 2012, nominal bonds are always relatively more expensive than their cashflow-matched inflation-linked counterparts: aggregate G7 mispricing is always in excess of $1.8 billion. The right panels in the fourth row of Figures 1 and 2 plot the time-series of the G7 dollar and basis-point mispricing indices, respectively. In aggregate, the average G7 mispricing is $1.93 for the dollar and 33.54 basis points for the basis-point mispricing, respectively. In early 2009, the mispricing peaked at $9.46, or 226.87 basis points which amounts to $101 billion dollars in terms of the total notional amount of G7 Index-Linked debt outstanding. These findings are significant since the G7 government bond markets are among the largest and most-liquid financial markets in the world.

In the United States, the overall average sizes of the dollar and basis-point mispricing are $2.23 and 39.81 basis points, respectively. The amount of mispricing peaked at $11.77 or 292.72 basis points around the time of the Lehman bankruptcy in the Fall of 2008, but there were clearly earlier periods when the average mispricing was in excess of $3 or 60 basis points. The top left panel in Figure 1 plots the weighted-average dollar mispricing for the TIPS-Treasury pairs. There is significant time series variation in TIPS-Treasury mispricing throughout the sample period. ILB mispricing for individual TIPS–Treasury pairs reaches values in excess of $10 for many of the TIPS-Treasury pairs with maturities exceeding 2015. In fact, the mispricing for the TIPSTreasury pair maturing in 2025 reaches a level in excess of $23. In almost every case, the value of the Treasury bond is larger than its synthetic equivalent constructed from the matching TIPS issue and the inflation swap.

In the United Kingdom, ILB mispricing is most significant during the crisis period of 2008–2009. In particular, the amount of mispricing peaked at $14.07 or 203.66 basis points around the time of the Lehman bankruptcy in the fall of 2008. Figures 1 and 2 show significant time series variation in index-linked–nominal gilt mispricing throughout the sample period. These results do not depend on whether the index-linked bond has an eight-month indexation or a three-month lag. The average basis-point size of the mispricing is fairly uniform across all maturities and lags of the individual pairs. During the period leading up to the financial crisis, the mispricing in the U.K. is only about half that observed in the United States. The overall average size of the mispricing is \$1.14 compared to \$2.23 in the United States. Similarly, the overall average basis-point size of the mispricing is 16.36 basis points in the U.K. versus 39.81 basis points in the United States. Hence, the mispricing is about twice as large in the United States compared to the United Kingdom. In the aftermath of the financial crisis, there are times when the mispricing switches sign. This never occurs in the United States during the whole sample period. Similar observations hold for the basis-point mispricing. However, the magnitudes of these sign reversals are small, and compared to the mispricing observed during the financial crisis, hardly different from zero. Specifically, the overall average size of the negative mispricing is only -0.49 basis points and the maximum in absolute terms is -2.17 basis points. The standard deviation is 0.3877 basis points. A simple test of means applied to the sample period excluding the financial crisis, defined as the time span from September 1, 2008 until January 1, 2010, does not reject the null hypothesis at the five percent significance level that the mean of the basis-point mispricing is zero during that period.

The government bond market in Japan exhibits mispricing throughout the entire sample period, not just during the crisis period of 2008-2009. In particular, while the amount of mispricing peaked at \$9.63 or 139.64 basis points around the time of the Lehman bankruptcy in the Fall of 2008, there were clearly earlier periods when the average mispricing was in excess of \$2 or about 40 basis points. In addition, figures 1 and 2 show particularly strong time series variation in JGB-JGBi mispricing throughout the sample period. The large decline during the financial crisis stands out. The overall average sizes of the dollar and basis-point mispricing are \$2.16 and 31.46 basis points, respectively. While the mispricing in the U.S. is uniformly positive, ILB mispricing in Japan reverses sign when the Japan Ministry of Finance introduced index-linked bonds and in the aftermath of the financial crisis. The dollar and basis-point mispricing reached levels of $-\$3.24$ and -44.33 basis points around December 2008, respectively. When this period is excluded from the sample, the mispricing is almost always positive. A few sign reversals occur during the first half of 2007, but a simple test of the mean cannot reject that the mispricing is zero during that period at the five percent significance level. The stark decline in the dollar and basis-point mispricing around December 2008 is a result of policy intervention by the Ministry of Finance, when it started to aggressively buy back Japanese inflation-indexed bonds. However, figures 1 and 2 show that the mispricing quickly changes sign again after the policy intervention in the first half of 2010 which suggests that the buy-back programs only provided temporary relief.

The middle right panels of figures 1 and 2 show ILB mispricing in Canada. In contrast to the other G7 countries, ILB mispricing in the Canadian government bond market exhibits strong time variation with frequent sign reversals. The mispricing is most evident during the crisis period of 2008-2009 where the amount of mispricing peaked at \$9.60 or 67.99 basis points around the time of the Lehman bankruptcy in the fall of 2008. However, ILB mispricing reaches levels in excess of \$5 (35 basis points) even before the financial crisis. Furthermore, the mispricing switches sign during the first half of 2008 before rising dramatically at the onset of the financial crisis. Towards the end of 2009 the mispricing switches sign again, but reverses to a level of around \$2 around July 2011. A simple test of means applied to the sample period excluding the financial crisis, defined as the time span from September 1, 2008 until January 1, 2010, does not reject the null hypothesis at the five percent significance level that the mean of the basis-point mispricing is zero during that period. Therefore, while there is overwhelming evidence of ILB mispricing in Canada during the financial crisis, there is no statistically significant evidence of arbitrage mispricing apart from this period.

Figures 1 and 2 show that ILB mispricing in France is significantly smaller in magnitude than in the United States, the United Kingdom, and Japan. ILB mispricing is most significant during the 2008–2009 crisis where the amount of mispricing peaked at \$4.01 or 3.91 basis points around the time of the Lehman bankruptcy in the fall of 2008. These results do not depend on whether the index-linked bond has the French CPI or the Europen HICPX as reference index. The average basis-point size of the mispricing is fairly uniform across all maturities and the two reference indices. In contrast to the United States and Japan, there is significantly less time series variation in ILB mispricing before and after the financial crisis. In the period leading up to the financial crisis, the average mispricing in France is only about 18 percent of the U.S. mispricing. The overall average sizes of the dollar and basis-point mispricing are only \$0.40 and 6.87 basis points, respectively, compared to \$2.23 and 39.81 basis points in the United States. The online appendix shows that the individual pairs reflect these observations as well. In the United States, the average size of the mispricing between the TIPS and Treasury bonds maturing in January 2027 and February 2027, respectively, is \$4.49. In the French government bond market, by contrast, the average mispricing never exceeds \$1.80 for any pairs. While the mispricing in the U.S. is uniformly positive, the dollar and basis-point mispricing in the French market switch sign several times during the sample period. Even before the financial crisis, there are periods where the basis-point mispricing becomes negative, and in the aftermath of the financial crisis, the mispricing is negative for prolonged periods. Interestingly, the mispricing surges again around June 2011 at the onset of the European debt crisis. The overall mean of the negative ILB mispricing is -3.91 basis points and the standard deviation is 6.30 basis points. The French inflation-linked bonds have a par floor. Section 8.5 discusses in detail that the negative mispricing is overestimated in absolute terms due to this feature. Specifically, if the deflation floor is taken into account, a simple back-of-the envelope calculation using the estimates in Heider, Li, and Verma (2012) for the value of the par floor (mean estimate of 3.22 basis points with the maximum estimated at 5.5 basis points) shows that the average ILB mispricing is $-3.91 + 3.22 = -0.69$ basis points during the periods when ILB mispricing is negative. A simple test of means cannot reject the null hypothesis that the mean of the basis-point mispricing is zero before and after the financial crisis at the five percent significance level. Therefore, there is overwhelming evidence of ILB mispricing in France during the financial crisis and at the onset of the European debt crisis. However, there is no statistically significant evidence of arbitrage mispricing apart from this period when the value of the deflation floor is accounted for.

ILB mispricing in the Italian government bond market is most significant during the crisis period of 2008–2009, and at the onset of the European debt crisis in Summer 2011 where it surges even higher, peaking at \$6.43 (114.24 basis points). The bottom left panels in figures 1 and 2 show that there is significant time series variation in index-linked–nominal BTP mispricing throughout the sample period. In the Italian government bond market, the average sizes of the mispricing across all BTP pairs are significantly smaller than in the U.S. government bond market. First, during the financial crisis the mispricing in the United States peaks at \$11.77 or 292.72 basis points around the time of the Lehman bankruptcy in the fall of 2008. The maximal dollar and basis points mispricing for the index-linked–nominal BTP pairs never exceed \$4 or and 70 basis points during that period. Second, in the period leading up to the financial crisis, the average mispricing in Italy is only about one quarter that observed in the United States. The overall average size of the mispricing is only \$0.56 compared to \$2.23 in the United States. The overall average basis-point size of the mispricing is 8.77 basis points in Italy and 39.81 basis points in the U.S. While the mispricing in the U.S. is uniformly positive, the dollar and basis-point mispricing in the Italian government bond market switch sign several times during the sample period. Even before the financial crisis, there are periods where the basis-point mispricing becomes negative. and in the aftermath of the financial crisis, the mispricing is negative for prolonged periods. The overall mean of the negative ILB mispricing is -3.55 basis points and the standard deviation is 8.74 basis points. Inflation-linked BTP have a par floor. Section 8.5 discusses that the negative mispricing is overestimated in absolute terms as a result of this feature. If the deflation floor is taken into account, a simple calculation using the estimates in Heider, Li, and Verma (2012) for the value of the par floor (mean estimate of 2 basis points with the maximum estimated at 3 basis points) shows that the average ILB mispricing is $-3.55 + 2 = -1.55$ basis points during the periods when ILB mispricing is negative. A simple test of means cannot reject the null hypothesis that the mean of the basis-point mispricing is zero before and after the financial crisis at the five percent significance level. Therefore, there is overwhelming evidence of ILB mispricing in Italy during the financial crisis and at the onset of the European debt crisis. However, there is no statistically significant evidence of arbitrage mispricing apart from this period.

In Germany, ILB mispricing is highest during the crisis period of 2008–2009 where it peaks at \$5.41 and 99.80 basis points. Furthermore, at the onset of the European debt crisis in 2011, the mispricing surges again reaching values in excess of \$3 (70 basis points). The average sizes of the mispricings across all Bund pairs are significantly smaller than in the United States. The average mispricing never exceeds \$6.06 for any pair, and the overall average basis-point size of the mispricing is 28.13 basis points in Germany compared to 39.81 basis points in the United States. Furthermore, there is little variation in the average dollar mispricing across all maturities which never exceeds \$2. The dollar and the basis-point mispricing in the German government bond market switch sign several times during the sample. Even before the financial crisis, there are periods where the basis-point mispricing becomes negative, and in the aftermath of the financial crisis, the mispricing is negative for prolonged periods. The overall mean of the negative ILB mispricing is -3.01 basis points and the standard deviation is 2.20 basis points. Inflation-linked Bunds feature a par floor. A simple back-of-the envelope calculation using the estimates in Heider, Li, and Verma (2012) for the value of the par floor (mean estimate of 2.80 basis points with the maximum estimated at 3.80 basis points) shows that the average ILB mispricing is $-3.01 + 2.80 = -1.55$ basis points during the periods when ILB mispricing is negative. A simple test of means cannot reject the null hypothesis that that the mean of the basis-point mispricing is zero before and after the financial crisis at the five percent significance level. Therefore, there is overwhelming evidence of ILB mispricing in Germany during the financial crisis and at the onset of the European debt crisis. However, there is no statistically significant evidence of arbitrage mispricing apart from this period. This stands in stark contrast to the observations in the United States where there is clear evidence of mispricing even before and after the financial crisis.

5 TESTS OF THE SLOW–MOVING CAPITAL THEORY

This section analyzes ILB mispricing in the context of the implications from the slow moving capital literature. At the core of the theory is the notion that arbitrage opportunities may persist because capital constraints, liquidity problems, and other frictions limit the speed at which investors can take advantage of mispricings in the market.

The key finding is that capital available to specific types of arbitrageurs is significantly related to ILB mispricing across all G7 government bond markets. Returns of hedge funds following fixed-income strategies strongly predict subsequent changes in ILB mispricing, whereas returns of hedge funds following non fixed-income related investment styles lack statistically significant forecasting power. This broadens our understanding of the nature of slow moving capital and the dynamics of arbitrage mispricing. Specifically, changes in the supply of capital available to specific types of arbitrageurs is inextricably linked to subsequent changes in mispricing in specific markets. This is consistent with the notion that not all arbitrageurs are equally able to exploit arbitrage opportunities due to idiosyncratic constraints which may include special knowledge and abilities required in implementing such strategies, available funds, and the ability to take on leverage.[6]

The slow-moving capital theory predicts that in response to a downward shock in the aggregate amount of capital available to arbitrageurs, the amount of mispricing between securities is expected to widen in multiple markets simultaneously, even if the violations of the law of one price occur in vastly different markets. Therefore, the slow moving capital literature predicts that different types of arbitrages may be correlated. All correlations between the dollar and basis-point mispricings for all G7 countries during the period from June 14, 2007 to September 20, 2011 using daily data are positive and large

[6]See, for example, Longstaff, Duarte, and Yu (2007).

in magnitude. Canada, France, Germany, and the U.K. all have correlation coefficients in excess of 0.7 to the United States during the period June 14, 2007 to September 20, 2011. Similar results hold for the subperiods May 22, 2006 to September 20, 2011 which excludes Canada and Japan, and the period July 23, 2004 to September 20, 2011, which excludes Germany, Canada and Japan. Furthermore, ILB mispricings in all other countries are strongly positively correlated with correlation coefficients in excess of 0.30. These observations are consistent with the notion that violations of the law of one price are correlated, even across global financial markets. Table 4 reports summary statistics for the regression of monthly changes in average basis-point ILB mispricing in each country on changes in average basis-point mispricing in the previous month in the other G7 countries. All regression coefficients are positive and the R^2 test statistics are all in excess of 0.5, with exception of the United States where the R^2 is 0.48. Furthermore, there is evidence of regional clustering. Within the European Union, for example, each country's mispricing is statistically significantly related to the other member countries' ILB mispricings.

The question naturally arises whether there is a channel through which mispricing propagates across global financial markets. Specifically, following a sudden increase in ILB mispricing in the United States, will there be a subsequent spike in ILB mispricing in the other G7 countries? Furthermore, how long does it take for ILB mispricing to manifest itself in the other countries? To investigate these questions, I estimated a vector auto regression on the dollar and basis point mispricing indices for the United States, Europe, the United Kingdom, and Japan using four lags on monthly data. The number of autoregressive lags is determined based on the Akaike information criterion. The top and bottom panels in figure 4 show the impulse response of the dollar and basis-point mispricing to a one standard-deviation shock to the mispricing in the United States. The horizontal axis denotes the number of months after the shock and the vertical axis shows the relative change in the mispricing in the United States, Europe, Japan, and the United Kingdom to the case when there is no shock in the United States. In response to a shock in the United States, the mispricing increases in all other G7 countries, and peaks approximately after two months. In Europe, the basis point mispricing is about five percent larger two months after the initial shock compared to when the United States experiences no shock. The other G7 countries exhibit similar dynamics. At the twelve month mark, the impact of the initial shock to the mispricing in the U.S. has almost died out. In summary, there is strong evidence that the occurrence of ILB arbitrage is strongly linked across markets. ILB arbitrage mispricings are positively correlated, and there is a channel through which arbitrage mispricing is transmitted across markets. Although ILB arbitrages occur in very different markets, there is strong commonality among them which suggests that these types of arbitrages are driven by a common factor.

The slow-moving capital theory implies that changes in the supply of capital to arbitrageurs may have forecasting power for subsequent changes in ILB mispricing. Specifically, if capital flows slowly to global arbitrageurs after a negative shock to aggregate arbitrage capital, then a sudden increase in capital will tend to reduce mispricing, but only with a lag as arbitrage capital is being deployed. To empirically test this prediction, Table 5 presents results from the regression of monthly changes in average basis-point ILB mispricing of each country on lagged stock, bond, and volatility index returns. The equity index for each country is the MSCI Index for that specific country in the previous month. The bond index is the Bloomberg EFFA government bond index for that country with maturity exceeding two years in the previous month. Hedge Fund denotes the return on Bloomberg BAIF Government and Corporate Bonds Hedge Fund Index in that specific country in the previous month. All member funds for each of the seven country indices are incorporated in that specific country. The JP Morgan G7 Volatility Index is a measure of market distress and captures the notion that arbitrageurs may be more constrained in times of financial turbulence. I regress changes in the average basis point mispricing for each country on one month lagged returns on the three indices. Although not shown, similar results hold for the dollar mispricing. Table 5 shows summary statistics of the regression results. In the United States, the U.S. basis point mispricing narrows by 2.33 basis points when the MSCI index returns one percent in the previous month, and in France the basis point mispricing widens by 1.89 basis points when the one month prior G7 volatility index increased by one percent. The regression coefficients in all countries are consistent with the notion that when capital flows slowly to arbitrageurs, then an increase in capital today will tend to reduce mispricing in the markets with a lag.

The ILB arbitrage could essentially be riskless from the perspective of a relatively unconstrained arbitrageur, such as a sovereign wealth fund, yet risky from the perspective of a highly leveraged and constrained hedge fund. Therefore, it is natural to expect that changes in the supply of capital available to specific types of arbitrageurs should be inextricably linked to subsequent changes in ILB mispricing in specific markets. Specifically, changes in the supply of capital to fixed-income arbitrageurs should forecast subsequent changes in fixed-income mispricing. This captures the notion that not all arbitrageurs are equally able to exploit arbitrage opportunities due to idiosyncratic constraints which may include special knowledge and abilities required in implementing such strategies, available funds, and the ability to take on leverage.[7] To empirically test this predication, I regress monthly changes in the average basis-point mispricing on one-month lagged monthly returns on the HFRX Hedge Fund indices. These hedge fund indices are classified by investment style.[8] The HFRX Macro Strategy Index consists of strategies in which the investment process is predicated on movements in underlying macroeconomic variables and the impact these have on equity, fixed income, currency and commodity markets. Funds in the Equity Hedge category maintain positions both long and short in primarily equity and equity derivative securities. The HFRX Event Driven Strategy Index consists of funds that maintain positions in companies currently or prospectively involved in corporate transactions of a wide variety including but not limited to mergers, restructurings, financial distress, tender offers, shareholder buybacks, debt exchanges, security issuance or other capital structure adjustments. The HFRX Relative Value index consists of funds that maintain positions in which the investment thesis is predicated on realization of a valuation discrepancy in the relationship between multiple securities ranging across equity, fixed income, derivatives or other security types. Intuition suggests that relative value funds would be more likely to engage in ILB arbitrage. Table 6 presents summary statistics of the regression results. For each country in the study, the relative value funds significantly predict changes in ILB mispricing at the five percent level. Consistent with theory, all regression coefficient are negative. The Equity Hedge and Event Driven indices are not statistically predictors of changes in ILB mispricing. These results confirm the notion, that a negative wealth shock at time $t-1$ will constrain specific arbitrageurs and mispricing widens. Conversely, after a positive shock to the the wealth of specific types of arbitrageurs capital may be more abundant to that specific type and mispricing decreases as these arbitrageurs align market prices. More succinctly, it is capital available to specific types of arbitrageurs that matters for the ILB mispricing, not just arbitrage capital in general.

The HFRX Relative Value index is subdivided into the style categories Convertible Arbitrage, Volatility Strategies, Multi-Strategy, Corporate Fixed Income, Asset Backed Securities, Sovereign Fixed Income, Real Estate, Fixed Income Alternative Yield, and Energy. Of particular interest are the Sovereign Fixed Income and Convertible Arbitrage subcategories. Convertible Arbitrage includes strategies in which the investment thesis is predicated on realization of a spread between related fixed income instruments. Fixed Income Sovereign strategies are predicated on the realization of a spread between related instruments in which one or multiple components of the spread is a sovereign fixed income instrument. Strategies employ an investment process designed to isolate attractive opportunities between a variety of fixed income instruments, typically realizing an attractive spread between multiple sovereign bonds or between a corporate and risk free government bond. Funds in these two subcategories present likely candidates that would engage in ILB arbitrage. To assess this predication empirically, I regress monthly changes in the average basis-point mispricing on one-month lagged monthly returns on these subcategory indices. Table 7 presents summary statistics of the regression results. The sovereign and covertible substrategy indices are statistically significant predicators for ILB mispricing at the five percent. The regression coefficients are negative which is consistent with the notion, that a negative wealth shock at time $t-1$ will constrain arbitrageurs in these two subcategories and mispricing widens

[7] See, for example, Duarte, Longstaff, and Yu (2007)

[8] For detailed description of these style categories see `http://www.hedgefundresearch.com/index.php?fuse=indices-str\#2889`.

for specific arbitrages that these types engage in. Conversely, after a positive shock to the the wealth of specific types of arbitrageurs, capital becomes more abundant to that specific type and mispricing decreases as these arbitrageurs are then able to align market prices. Almost none of the other subcategories have statistically significant explanatory power for ILB mispricing. These results provide additional evidence, that it is capital available to specific types of arbitrageurs that matters for the specific types of arbitrages, such as the ILB mispricing.

Instead of using hedge fund returns, an alternative proxy for the wealth of different types of arbitrageurs is capital invested in specific types of hedge funds. To explore this, I regress monthly changes in ILB Mispricing on one-month lagged percentage changes in total Hedge Fund assets for the HFRX reference hedge fund indices. Table 8 presents summary statistics of the regression results for the basis-point and dollar ILB mispricing. The results confirm that the relative value funds category is a statistically significant predicator for ILB mispricing at the five percent level. In the United States, for example, a decline of total assets of relative value hedge funds by one percent is associated with an increase in ILB mispricing by $1.08, or 21.26 basis points. In summary, this section provides strong empirical evidence for the slow moving capital theory of arbitrage mispricing in global markets. As specific types of arbitrageurs become wealth constrained, the mispricing widens. It is capital available to these specific types of arbitrageurs that is crucial for explaining arbitrage mispricing, not just arbitrage capital in general.

6 EFFECTS OF MONETARY POLICY ON ILB MISPRICING

In August 2007, the world was hit by what Alan Greenspan, former Chairman of the Fed, described in Congressional testimony as a “once-in-a-century credit tsunami”. The tsunami from the 2007–2009 financial crisis, not only flattened economic activity, producing the most severe world-wide economic contraction since the Great Depression, but it also seemed to sweep away confidence in the ability of central bankers to successfully manage the economy. Therefore, monetary policy played a key role in restoring confidence in the world’s capital markets.

During and in the aftermath of the financial crisis of 2008, policymakers took a number of extraordinary steps to improve the functioning of financial markets and to stimulate the economy which resulted in huge expansions of their balance sheets. With interest rates already at the zero bound, the Federal Reserve and other central banks initiated large scale asset purchases to provide support to strained capital markets. The U.S. Fed, in particular, started an unprecedented expansion of its balance sheet by purchasing large amounts of Treasury debt and federal agency securities of medium and long maturities. The Federal Reserve’s purchases of large quantities of government backed securities in the secondary market, conventionally known as the Large Scale Asset Purchase –or “LSAP”– programs were among the most important measures, in terms of both scale and prominence. The LSAPs included debt obligations of the government-sponsored housing agencies, mortgage-backed securities (MBS) issued by those agencies, and coupon securities issued by the U.S. Treasury, and they collectively amounted to $1.7 trillion over a period of about 15 months–the single largest government intervention in financial-market history. The Bank of England also purchased longer-term debt securities during the financial crisis. On March 5 2009, the Bank of England announced plans to purchase £75 billion in assets, mainly gilts with residual maturities between five and twentyfive years. The program was extended multiple times: to £125 billion in May 2009, to £175 in August 2009, and to £200 in Noveber 2009. In February 2010, the BOE stated that it would make additional purchases if necessary. The Bank of England’s gilt purchases, at 14 percent of U.K. GDP, were similar in scale to the Federal Reserve’s LSAPs which amounted to 12 percent of U.S. GDP. Asset purchases by the Bank of Canada were $75b in 2008. In Japan, purchases by the Bank of Japan were not large as a share of GDP and they were skewed toward bonds with short residual maturities. McCauley and Ueda (2009) show that the BOJ purchases were mainly seasoned JGBs with short residual maturities; the average maturity of the BOJ's holdings of JGBs fell from more than five years to less than four years. However, as discussed further below, the Bank of Japan retired a significant amount of inflation-linked debt during the financial crisis. The ECB used outright bond purchases less frequently as a monetary policy tool to regulate the money supply. Instead, the ECB relied on refinancing facilities, in which, instead of purchasing bonds, the ECB uses bonds as collateral in repo transactions and collateralized loans. However, with the onset of the European sovereign-debt crisis, direct bond purchases became more frequent, primarily for Spanish and Italian government debt. In May 2009, the European Central Bank (ECB) announced plans to purchase €60 billion of covered bonds, and in May 2010, the ECB announced plans to purchase sovereign bonds of its member countries in order to improve market depth and liquidity.

There was particular cause for skepticism regarding the program to purchase Treasury securities. The market for U.S. government debt is among the largest and most liquid in the world, and it was not obvious that even such a sizeable intervention-the $300 billion purchased by the Fed constituted about eight percent of the market at the time-would have significant effects, given the array of other securities that serve as potential substitutes for Treasuries. Given the unprecedented size and nature of these programs and the speed with which they were proposed and implemented, policymakers could have had, at best, only a very rough ex ante sense of their potential impact. The minutes of the December 2008 Federal Open Market Committee meeting summarized the prospects thus: "The available evidence indicated that [LSAP] purchases would reduce yields on those instruments, and lower yields on those securities would tend to reduce borrowing costs for a range of private borrowers, although participants were uncertain as to the likely size of such effects." In the second part of 2010 the Fed implemented a second round of monetary stimulus (LSAP 2) by both reinvesting principal payments from its securities holdings and carrying out new purchases in longer-term Treasury securities in order to jump-start the sluggish economic recovery and to avoid undershooting the inflation target. The objective of the Fed's large-scale asset purchases (LSAPs) was to reduce long-term yields in order to ease financial markets and spur economic growth. Several studies provide evidence that the LSAP program was effective in lowering interest rates below levels that otherwise would have prevailed in the market.

Coincidentally, ILB mispricing spikes consistently across all countries during the same time period which raises the question whether central banks have affected mispricing in the markets through active monetary policy. This Financial Times blog post from April 4, 2012 by Sam Jones (Jones(2012)) provides anecdotal evidence in support of this notion:[9]

> Wide pricing anomalies in European bond markets caused by the ECB's longer-term refinancing operations have led to bumper profits for a small group of arbitrage hedge funds in recent months. "It's a good environment for them to generate alpha [a measure of hedge fund managers skill-based returns] because of the actions of central banks," said Ermanno Dal Pont, head of Barclays' European capital solutions business, which deals with hedge funds.
>
> Italian bond markets, for example, exhibited unprecedented price discrepancies between different classes of bond issued by the government as a result of the ECB's LTRO liquidity injection. In January, investors dumped inflation-protected Italian bonds, fearful that they would automatically drop out of key European bond indices if the country's credit rating was downgraded, while at the same time Italian banks snapped up regular Italian bonds with LTRO cash. Hedge funds bought the cheap inflation-protected bonds, wrote swaps to offset inflation and then shorted expensive regular Italian bonds, thereby completely hedging out credit risk and inflation and locking in the supply and demand-driven difference between the two bonds. The spread between them was more than 200 basis points, according to Bob Treue, the founder of Barnegat, a US-based fixed income arbitrage hedge fund that has made 18 per cent on its investments so far this year.

There is a growing literature on the impact of monetary policy on financial markets, in particular

[9]See `http://www.ft.com/intl/cms/s/0/cb74d63a-7e75-11e1-b009-00144feab49a.html#axzz24lB77mEm`

in the aftermath of the 2008 financial crisis. Gagnon et al. (2011) examine changes in the ten-year Treasury yield and Treasury yield term premium. They document that after eight key LSAP announcements the ten-year yield fell by a total of 91 basis points, while their measure of the ten-year term premium fell by 71 basis points. The authors argue that the Fed's asset purchases primarily lowered long-term rates through a portfolio balance channel that reduced term premia. Furthermore, they examine the effects of similar asset purchase programs in Japan and the United Kingdom and find effects that are generally consistent with those found in the United States. Krishnamurthy and Vissing-Jorgensen (2011) evaluate the effect of the Federal Reserve's purchase of long-term Treasuries and other long-term bonds (QE1 in 2008-2009, and QE2 in 2010-2011) on interest rates using an event-study methodology. Treasuries-only purchases in QE2 had a significantly larger effect on Treasuries and Agency Securities relative to corporate bonds and mortgage-backed securities, with yields on the latter falling primarily through the market's anticipation of lower future federal funds rates. Rosa (2011a and 2011b) examine the effects of decisions and statements by the FOMC on the level and volatility of U.S. stock and volatility indices, and the U.S. dollar exchange rates using an intraday event-study analysis. Rosa (2012) examines the impact of large-scale asset purchases (LSAP) on U.S. nominal and inflation-indexed bonds, stocks, and U.S. dollar spot exchange rates, and finds that LSAP announcements had economically large and highly significant effects on the prices of these assets. Particularly, these asset pricing effects are similar to an unanticipated cut in the fed funds target rate. Furthermore, the response of U.K. asset prices the Bank of England's gilt purchases is quantitatively similar to the reaction of U.S. asset prices to the Fed's asset purchases. Kuttner (2001) estimates the impact of monetary policy actions on Treasury bill, note, and bond yields, and finds that there is only a small effect of anticipated target rate changes on interest rates. However, there is a large and significant effect from unanticipated changes. Beechey and Wright (2009) study the response of nominal and index-linked bond yields to macroeconomic and monetary news announcements. They document an increase in yields in response to stronger-than-expected data and a decrease on the weaker-than-expected data. Bernanke and Kuttner (2005) analyze the impact of changes in monetary policy on equity prices, and document that, on average, a hypothetical unanticipated 25-basis-point cut in the Federal funds rate target is associated with about a 1 percent increase in broad stock indexes. Andersen, Bollerslev, Diebold and Vega (2003) and Faust, Rogers, Wang and Wright (2007) examine the intraday response of the U.S. spot exchange rate to real-time U.S. monetary and macroeconomic news. Christensen and Rudebusch (2012) analyze the declines in government bond yields that followed the announcements of plans by the Federal Reserve and the Bank of England to buy longer-term government debt by decomposing these declines into changes in expectations about future monetary policy and changes in term premia. Joyce et al. (2011) investigate the impact of the Bank of England's quantitative easing policy on U.K. asset prices and find that asset purchases by the central bank have depressed medium to longterm government bond yields by about 100 basis points.

This section is different from prior studies on quantitative easing programs in that it studies the effects of monetary policy announcements on arbitrage mispricing. These announcements represent the initiation of government bond purchase programs and liquidity facilities, changes in interest rates, and other quantitative easing measures. In the United States, these events dates include QE1 and QE2 announcements on November 25, 2008, December 1, 2008, December 16, 2008, January 28, 2009, March 18, 2009, August 8, 2010, and September 21, 2010. The reason for studying announcement effects it that with forward-looking financial markets, a policy of asset purchases, for instance, is expected to impact asset prices not at the time that the purchases are actually made, but rather at the time that investors learn that they will take place. Large Scale Asset Purchases (LSAPs) are announced ahead of time, in the statements that follow FOMC meetings. These statements are in turn anticipated to some extent by investors, whose expectations have been guided by speeches and other comments by FOMC members. Furthermore, whereas the federal funds futures market gives a fairly clear measure of investors' real-time expectations for changes in the target federal funds rate, there is no such measure for other policy measures such as the expectations of the size of LSAPs. FOMC statements and days with other announcements can change investors' views about the likely extent of monetary policy actions and about the underlying state of the economy. The methodology in this paper is similar to the event-study in Krishnamurthy and Vissing-Jorgensen (2011). To analyze the impact of monetary policy on arbitrage mispricing in the markets, I regress changes in the ILB mispricing on indicator variables representing monetary policy announcements by the central banks of Canada, Europe, Japan, the United Kingdom, and the United States. Periods of financial turmoil, such as the period from Fall of 2008 to Spring 2009, make inference from an event-study more difficult. To the extent that inflation-linked bonds are less liquid than their nominal counterparts, the prices of the less liquid assets may react slowly in response to an announcement. I address this issue by using both one and two day changes (from the day prior to the day after the announcement) in arbitrage mispricing and find that the results are qualitatively similar in both cases. Therefore, Table 9 presents regression results for one-day changes only. A second issue is the identification of monetary policy announcements as causative events for changes in ILB mispricing. Arrival of other economic news around announcement dates could potentially create measurement errors. Krishnamurthy and Vissing-Jorgensen (2011) address this issue by presenting intraday movements in Treasury yields and trading volume for each of the QE event dates in the United States. They show that the events identify significant movements in Treasury yields and Treasury trading volume and that the announcements do appear to be the main piece of news released on the event days.

Table 9 reports summary statistics from the regression of changes in the ILB mispricing on indicator variables representing monetary policy announcements by central banks using daily data. Monetary policy announcements increased ILB mispricing in Canada, France, Germany, Italy, the United Kingdom, and the United States. In the United States, the announcement effect of monetary policy measures is associated with an increase in the dollar mispricing by 94.7 cents per $100 notional, and a 21.061 basis points increase in the basis-point mispricing. These results are significant at the five percent level. Although not reported, this represents an increase the mispricing on average by $38 million. These results are consistent with Wright (2011) who finds evidence of a rotation in breakeven rates from Treasury Inflation Protected Securities (TIPS), with short-term breakevens rising and long-term forward breakevens falling. If the policy announcement dates were predictable, this would represent a significant wealth transfer to arbitrageurs. As for the United States, one may be sceptical of these results because the Federal Reserve's asset purchase programs included Treasury Bonds as well as TIPS–neither the Bank of England nor the ECB have included inflation-linked bonds in their purchase programs. The System Open Market Account (SOMA) managed by the Federal Reserve Bank of New York shows an increase in TIPS holdings from $44.5 billion on August 26, 2008 to $65.9 billion on August 24, 2011. Holdings in Treasury bonds and notes increased from $676 billion to $ 1.554 trillion over the same period. However, the share of TIPS in the SOMA decreased since QE1 from 3.01% on August 26, 2009, to 2.02% on August 25, 2010. By contrast, the share of U.S. Treasury Notes and Bonds has increased from 45.70% on August 26, 2009 to 58.86% on August 24, 2011. FLL (2012) provide clear evidence that the supply or liquidity of both TIPS and Treasuries is directly linked to the size of the arbitrage. The Federal Reserve's Asset Purchase programs decreased the total supply of both TIPS and Treasuries in the market and shifted the relative supply of both securities. Therefore, the increase in ILB mispricing in response to the Federal Reserve's LSAPs provides further support for the notion that the size of the arbitrage is expected to widen as supply or liquidity of both TIPS and Treasuries is reduced. Furthermore, Krishnamurthy and Vissing-Jorgensen (2011) show that decreases in TIPS yields is partially offset by changes in inflation swap rates, and the direction is consistent with an increase in ILB mispricing.

In contrast to the other G7 countries, monetary policy in Japan is associated with a decrease in ILB mispricing. In January 2007, the Ministry of Finance declared inflation-indexed bonds eligible for their buyback operations. In each of five buyback operations the Ministry of Finance retired about ¥45 billion of outstanding linkers until April 2008. In the wake of the financial crisis, prices of inflation-linked bonds declined significantly (in March 2008 the on-the-run 10 year JGBi breakeven rate approached -2 basis points) which lead to increased buybacks by the Ministry of Finance. During the 2008 financial crisis the liquidity of the 10-year inflation indexed bonds dropped precipitously. As breakeven rates continued to decline during the peak of the financial crisis, reaching a low of -323 basis points in mid-December 2008, the Ministry of Finance stepped up their buyback operations and cancelled two linker auctions scheduled for October 2008 and February 2009. From October 2008, average monthly inflation-linked bond buybacks were in the order of ¥215 billion. Over 39 linker buyback operations took place between 2007 and 2009, bringing the total amount retired from the secondary inflation-indexed market to about ¥3.74 trillion. This represents nearly 40% of the total linker issuance and the secondary market declined in size from around $87 billion at the end of 2008 to around $61 billion at the end of 2009. After additional linker buybacks the size of the secondary inflation-linked bond market was around $32 billion at the end of 2010. However, breakeven rates at the long-end of the maturity curve, recovered to near -50 basis points by the end of 2009, and liquidity improved significantly as well with bid/ ask spreads in the 10-year maturities narrowing by over 50%.

Measures of inflation expectations are important for conducting monetary policy and for assessing its credibility. In particular, the differential between yields on nominal Treasury securities and on TIPS of comparable maturities, often called the breakeven inflation (BEI) rate, has often been used in policy circles and the financial press as a proxy for the market's inflation expectations (see, for example, D'Amico, Kim and Wei (2010)). However, using breakeven inflation rates as measures of inflation expectations can be problematic as many researchers have pointed out. Most studies base their criticism on the notion that the yield differential between nominal and index-linked bonds reflects, besides expected inflation, other components such as risk and liquidity premia. Among them are, for example, Christensen and Gillan (2011c), Höerdahl (2008), Grishchenko and Huang (2008), Carlstrom and Fuerst (2004), Trehan (2010), and Shen (2006, 1998). It is also important to acknowledge that practitioners have long recognized that breakeven inflation spreads appear mispriced relative to inflation swaps. These discussions, however, have generally attributed the discrepancy to some form of risk premium. The findings in this paper imply that this explanation can be ruled out since the ILB mispricing is a violation of the law of one price and, therefore, cannot be reconciled with an equilibrium model of risk premia. This section sheds new light on this issue by relating ILB mispricing and breakeven inflation rates. To the extent that breakeven rates are correlated with the ILB mispricing, the common market practice of using breakeven rates to gauge the market's inflation expectations is flawed and provides a noisy measure of inflation expectations at best. Specifically, the implied measure is biased downwards and, moreover, the bias worsens in times of increased volatility in financial markets.

Sack and Elsasser (2004) report that the spread between ten-year yields on nominal securities and TIPS was, on average, about 50 basis points below the long-run inflation expectations reported in the Survey of Professional Forecasters which implies that the breakeven inflation rate has been 50 basis points below the expected long-term rate of inflation. Gürkaynak, Sack, and Wright (2008) provide evidence that breakeven inflation rates are not a pure measure of inflation expectations due to the presence of inflation risk premium and liquidity premium components. Christensen, Lopez and Rudebusch (2010) decompose breakeven rates into inflation expectation and inflation risk premia using an affine arbitrage-free term structure model and propose to adjust breakeven inflation rates by subtracting inflation risk premia from the breakeven rates. Gürkaynak, Sack and Wright (2010) also argue that breakeven-inflation rates do not solely reflect inflation expectations and provide evidence that the interpretation of breakeven rates as expected inflation is complicated by inflation risk premia and the differential liquidity premia between TIPS and nominal securities. Hördahl and Tristani (2007) decompose breakeven inflation rates in the U.S. using a macrofinance model with monthly data on nominal and real yields, inflation, and the output gap. Their results suggest that fluctuations in breakeven rates have mostly reflected variations in the inflation risk premium, while long-term inflation expectations have remained anchored from 1999 to 2007. Hördahl and Tristani (2010) extend their prior work and estimate inflation risk premia in the United States and the Euro area.

The correlations between the basis-point mispricing for each country and the ten-year breakeven rates at daily frequency are -0.93, -0.28, -0.65, -0.51, -0.85, -0.67, and -0.87 for Canada, France, Germany, Italy, Japan, the United Kingdom, and the United States, respectively. All p-Values are zero. For all countries in the sample, the basis point mispricing is significantly negatively correlated with the ten-year breakeven rate. Since changes in breakeven rates are negatively correlated with arbitrage mispricing, the findings in Wright (2011) and Krishnamurthy and Vissing-Jorgensen (2011) are also cosistent with an increase in the mispricing in response to monetary policy actions. To further analyze the question of whether breakeven rates are appropriate proxies for inflation expectations, I regress the time-series of ten-year breakeven inflation rates on the ILB mispricing for all G7 countries. Table 10 shows the regression results. All regression coefficients are negative in sign, and all adjusted R-Squared test statistics are larger than 0.70. In the United States, the adjusted R-Square test statistic is 0.8506 and in the United Kingdom it is 0.7650. This suggests ILB mispricing accounts for a large fraction of the variation in breakeven inflation rates. ILB mispricing does not reflect inflation expectations by construction. Therefore, using breakeven inflation rates as market expectations of inflation to guide monetary policy is flawed. In summary, this section provides evidence that monetary policy interventions by central banks, in particular the large scale asset purchase programs that were implemented in the aftermath of the financial crisis, may have exacerbated the mispricing. Furthermore, this section adds to the literature that criticizes the market practice of using breakeven inflation rates as a proxy for inflation expectations by relating the variation in breakeven inflation rates to variation in ILB mispricing. The results provide additional evidence that breakeven are a noisy measure of inflation expectations at best and hence that using breakeven inflation rates as gauge of the market's inflation expectations is flawed.

7 RISK AND RETURN CHARACTERISTICS OF ILB MISPRICING

Even an arbitrage in the text-book sense can generate mark-to-market losses that might force an arbitrageur facing constraints to unwind a position at a loss prior to convergence.[10] An arbitrage could essentially be riskless from the perspective of a relatively unconstrained arbitrageur such as a sovereign wealth fund, yet risky from the perspective of a highly leveraged and constrained hedge fund. This raises the question, whether ILB arbitrage is truly riskfree or whether it is risky leveraged strategy that could result in losses for an arbitrageur trying to take advantage of the mispricing between nominal and index-linked bonds. Several hedge funds and institutional asset managers have in fact implemented trading strategies that exploit the divergence between the prices of nominal bonds, inflation-indexed bonds, and inflation swaps in the United States and Europe. To quote from a recent Financial Times blog by Sam Jones (Jones (2012)):

> Hedge Funds bought the cheap inflation-protected bonds, wrote swaps to offset inflation and then shorted expensive regular Italian bonds, thereby completely hedging out credit risk and inflation and locking in the supply and demand-driven difference between the two bonds. The spread between them was more than 200 basis points, according to Bob Treue, the founder of Barnegat, a US-based fixed income arbitrage hedge fund that has made 18 per cent on its investments so far this year.

Furthermore, as reported by in Financial Times blogs by Kaminska (2010) and Jones and Kaminska (2010) about Barnegat Fund Management:

> But as Barnegat explains: "We will buy the TIPS, short the nominal bond, and lock in the inflation rate with the inflation swap. The result is that the net initial payment is zero, but until 2014 this trade yields up to 2.5 percent per year of the notional."

[10] See, for example, Liu and Longstaff (2005).

> For a small group of savvy traders the pricing discrepancies at their widest led to one of the most successful hedge fund trades in recent memory. One of the biggest beneficiaries was the low-profile New Jersey-based $450 million Barnegat fund founded in 1999. Barnegat acquired TIPS bonds shortly after the collapse of Lehman Brothers and then shorted-bet on a fall in rates-regular Treasury bonds of an equivalent maturity. As the pricing discrepancy narrowed, the fund realised huge gains. The fund returned 132.6 percent to investors in 2009.

Furthermore, there has been a recent increase in market interest in nominal–inflation-linked bond trading strategies, which are often referred to as breakeven inflation trades. In late 2011, both ProShares Advisors and State Street announced plans to offer ETFs based on long-short positions in TIPS and Treasuries. Nonetheless, there is empirical evidence suggesting that ILB arbitrage strategy may expose constrained arbitrageurs to substantial risks. Such constraints include costs and funding risks of financing securities positions in the repo markets, as well as the regulatory, mark-to-market, and capital costs of keeping security positions on the balance sheet. In the context of breakeven trades one example may be Morgan Stanley. From a June 29, 2011 Bloomberg article[11]:

> The banks interest-rates trading group lost at least tens of millions of dollars on the trade, which the firm has been unwinding ... Traders at the bank bet that inflation expectations for the next five years would rise in Treasury markets ... Such wagers on so-called breakeven rates involve paired purchases and short sales of Treasuries and Treasury Inflation Protected Securities, or TIPS, in both maturities.

In light of this anecdotal evidence, this section specifically analyzes the risk and return characteristics of the ILB trade. It is of particular interest, whether ILB arbitrage earns small positive returns most of the time, but occasionally experiences dramatic losses and whether the strategy earns positive excess returns, or "alpha", on a risk-adjusted basis.

For each day of the sample period when the mispricing is positive, the ILB arbitrage trade is initiated by going long the synthetic nominal bond and shorting the actual bond. After a one-month holding period, the trade is unwound. This is to reflect that a hedge fund actually implementing the trade may not be able to hold the position until convergence. Monthly returns are calculated for each index-linked–nominal bond pair and then notional-weighted to construct the return index for each country.

Summary statistics of daily ILB arbitrage returns for all G7 countries are reported in Table 11. The average monthly excess returns from the individual countries are all statistically significant and range from about 0.43 to 0.56%. Furthermore, the ILB arbitrage trade generates positively-skewed excess returns on average. Thus, despite producing large negative returns from time to time, the ILB arbitrage strategy generates even larger offsetting positive returns.

To analyze the extent to which these positive excess returns represent compensation for bearing market risk, I regress excess returns on the ILB arbitrage strategy on the Fama-French factors. The analysis does not include controls for credit risk because subsection 8.3 shows evidence that ILB mispricing is not significantly related to systemic credit risk. Table 12 presents the regression results for all G7 countries, and by region for Europe, Japan, and North America. For all regions, the market risk factor is statistically significant at the five percent level and the sign of the regression coefficient is negative. The fact that the ILB trade exhibits equity market risk may seem counterintuitive given that it is a pure fixed-income strategy. Previous research by Campbell (1987), Fama and French (1993), Campbell and Taksler (2002), and others, however, documents that there are common factors driving returns in both bond and stock markets. Duarte, Longstaff, and Yu (2007) also show that the fixed income arbitrage strategies in their study exhibit high equity market risk. The negative loading on the market risk factor in the United States is consistent with Roll (2004) who finds finds that TIPS were negatively correlated with equities during the 1997–2004 period. The factor loadings on SMB,

[11]See `http://www.bloomberg.com/news/2011-06-29/morgan-stanley-said-to-suffer-trading-loss-after-wager-on-u-s-inflation.html`.

HML, and WML are not statistically significant. The regression intercept is positive and statistically significant at the the five percent level in all regions, except in Canada. There is clear evidence that after risk adjusting for equity market factors, the ILB arbitrage strategy produces significant “alpha” in all countries ranging from 0.51 percent per month in France to 0.69 percent per month in the United States. Although not shown, the results qualitatively still hold if a conservative estimate of transactions costs is applied.

Duarte, Longstaff, and Yu (2007) document that arbitrage strategies requiring “more intellectual” capital to implement show significant positive alpha. The results in this section are consistent with this notion. Furthermore, the fact that a number of these factors share sensitivity to financial market “event risk” argues that the positive alpha are not merely compensation for bearing the risk of an as-yet-unrealized “peso” event. Furthermore, these results are consistent with the slow moving capital theory according to which arbitrage opportunities are expected to arise in multiple markets at the same time. In summary, the ILB arbitrage strategies generate significant risk-adjusted excess returns. The returns are positively skewed, contrary to the notion that arbitrage strategies generate small positive returns most of the time, but experience infrequent heavy losses as a result of bearing risk of a “peso” event.

8 IS ILB MISPRICING DRIVEN BY OTHER FACTORS?

The following subsections address whether ILB mispricing is a violation of the law of one price or whether there are other factors that may drive a wedge between the prices of nominal and inflation-indexed government bonds. Subsection 8.1 discusses transaction costs. Subsection 8.2 analyzes the potential impact of mispricing in the inflation swaps market. Subsection 8.3 studies whether market-wide liquidity and liquidity differences between nominal and inflation-indexed bonds can account for ILB mispricing. Subsection 8.4 discusses differences in taxation between nominal and index-linked bonds. Finally, subsection 8.5 discusses the effects of the embedded deflation floor in many index-linked government bonds on ILB mispricing. This section presents clear evidence that neither a single one of these factors nor all factors in ensemble are able to account for ILB mispricing in the magnitude observed in the G7 financial markets.

8.1 Transaction Costs

The question naturally arises whether the ILB arbitrage strategy would be profitable after accounting for transaction costs. Fleckenstein, Longstaff and Lustig (2012) provide an analysis for the U.S. market. A conservative estimate in the United States for two-year, five-year, and ten-year horizons are 20.2, 29.5, 46.3 cents per $100 notional amount, respectively. These transaction costs are clearly orders of magnitude smaller than the arbitrage. Subsection 8.3 shows that market liquidity in the other G7 markets is not significantly different compared to the United States. Even if transaction costs were twice or three times as large as in the U.S. market, they cannot begin to account for mispricing of the magnitude observed in the G7 countries.

8.2 Mispricing of Inflation Swaps

As described in section 3, the relative prices of inflation-linked bonds, nominal bonds, and inflation swaps are tied together by no-arbitrage restrictions. Section 4 shows that this restriction is frequently violated in all G7 government bond markets. The arbitrage strategy consists of three legs, however, and mispricing in any one of these three could cause ILB arbitrage to occur. Since inflation swaps are relatively recent financial innovations, it is natural to explore whether potential mispricing of inflation swaps may be the underlying explanation for the ILB arbitrage results.

In the United States, beginning with the first TIPS auction in 1997, market participants began making markets in inflation swaps as a way of hedging inflation risk. As the TIPS market has grown, the inflation swaps market has become liquid and actively traded.[12] Inflation swaps have also become widely used among institutional investment managers because of their high correlation with realized CPI.[13] The notional size of the inflation swap market is estimated by Pond and Mirani (2011) to be on the order of hundreds of billions.

In the United Kingdom, there is about £100 billion of inflation swaps outstanding, according to estimates from the Royal Bank of Scotland. As in the U.S. market, inflation swaps have also become popular among institutional investment managers and are widely used by U.K. pension funds and insurance companies to hedge inflation-linked liabilities because. Inflation swaps pay out according to the retail price index, which is the standard measure of inflation in the U.K. for pension schemes.

In Japan, inflation swaps are among the most frequently traded inflation derivatives as well. Inflation swaps are linked to the same reference index as the JGBis and feature the same three-month indexation lag with interpolation to the tenth of the month. Liquidity in the zero-coupon inflation swaps market was initially tilted towards the six to ten year maturities, but trading in the shorter and longer maturities has significantly picked up since 2006. Bid/Ask spreads are of the same order of magnitude as those of index-linked Japanese government bonds. At the short end of the maturity spectrum, all tenors including the one year inflation swaps are traded, and at the long end, both the fifteen and twenty year maturities are traded, whereas trading activity for the thirty-year inflation swaps has been limited. However, the maturity range of the JGBi in this study is such that only the actively traded inflation swaps are needed to implement the arbitrage strategy. Therefore, limited trading activity in the 30-year maturity swaps cannot have any impact on the mispricing results in Japan.

In France, French CPIx inflation swaps first began trading in 1998 even before the first OATi was issued. Euro HICP inflation swaps started trading with the introduction of the Euro currency in 1999. Anecdotal reports by market practitioners indicate that liquidity in both the French CPIx and the Euro HICPx inflation swaps markets is comparable to that of their inflation-linked bonds counterparts. Zero-coupon inflation swaps referenced to the Euro HICPx are among the most common inflation derivatives. The contracts have a lag of three months, meaning that the base inflation index for the swap is the value of the HICPx three months before settlement. As swaps on the next base month also start to trade towards to end of the month, there is a discontinuity in the quoted rates at the time of the roll from one month to the next which reflects typical monthly seasonality in the CPI index. The most commonly-traded maturities are the five year and ten year swaps, but the maturity range above two years is traded frequently out to the thirty year maturity contracts. As Italy and Greece started issuing long-dated fifty year bonds linked to Euro HICPx in 2007, inflation swaps with the same maturities started to trade. The depth and liquidity in that maturity range is limited. However, since these longer maturities are not needed to implement the arbitrage strategy for the inflation-linked bonds in the sample, the results cannot be due to stale prices and limited trading activity in inflation swaps. In 2005, monthly volumes were around €5 billion, up from €500 million in mid-2002. By 2007 monthly broker volumes were around €15 billion.

To strengthen the argument against mispricing in the inflation swap market even further, one may ask what the inflation swap rates would have to be in order to make the mispricing disappear. One way to explore this is to solve for the size of the parallel shift in the inflation swap curve that would be required to eliminate the mispricing. This analysis is carried for the United Kingdom and the United States. Although not presented here, similar results apply for all other countries in this study.

[12]See Kerkhoff (2005).

[13]As one example, inflation swaps are a key element of J.P. Morgan's Columbus Fixed Income Inflation Managed Bond Strategy.

The results argue strongly against the mispricing being due entirely to inflation swap mispricing. In particular, inflation swap rates which are already viewed by many market participants as anomalously low would actually need to be significantly lower to explain ILB mispricing. The top panel of Figure 5 plots the term structure of U.K. RPI inflation swap rates that would be needed to reconcile the March 17, 2009 mispricing with magnitude of $19.45 between the 4.25 percent gilt with maturity date December 27, 2027 and the 1.25 percent index–linked gilt issue with the same maturity. The market would need to be anticipating significant deflation for sixteen years to reconcile the mispricing. The bottom panel of Figure 5 plots the term structure of inflation swap prices that would be needed to reconcile the December 30, 2008 mispricing between the 7.625 percent Treasury bond with maturity date February 15, 2025 and the 2.375 percent TIPS issue with the same maturity. Similarly to the case of the United Kingfom, the U.S. market would need to be anticipating significant deflation for ten years to reconcile TIPS–Treasury mispricing. Furthermore, the maximum inflation swap rate over the entire horizon of the strategy would only be 0.28 percent. It is very implausible that ILB mispricing could be explained by mispricing in inflation swaps of this magnitude and in this direction. Furthermore, in the case of the U.S., inflation swap rates would need to be 51.5 basis points lower on average to explain TIPS-Treasury mispricing between July 23, 2004 and November 19, 2009. This is roughly ten times as large as the bid-ask spread for inflation swaps. Furthermore, 51.5 basis points represents an average error of more than 21 percent of the average level of the five-year inflation swap during the sample period. Inflation swap pricing errors of this magnitude seem very implausible.

Fleckenstein, Longstaff and Lustig (2012) applied the same arbitrage strategy to matching corporate fixed-rate and inflation-linked bonds with the same set of inflation swap prices. The mispricing between corporate fixed-rate and inflation-linked debt is much smaller than the contemporaneous TIPSTreasury mispricing. Furthermore, there is very little correlation between the corporate and TIPSTreasury mispricing series. In fact, the correlation between the two time series is negative in sign. There is little or no evidence of systematic mispricing between corporate fixed-rate and inflation-linked debt, so that the notion that mispricing in the U.S. inflation swap market is the source of the TIPS mispricing can be ruled out. In this study, a similar comparison is not feasible because only a few countries have developed corporate index-linked debt markets. In conclusion, there is strong evidence suggesting that there is a liquid market for zero-coupon inflation swaps in all G7 countries. While it cannot be ruled out that inflation swaps may be occasionally mispriced, it is highly unlikely that mispricing in the inflation swaps markets is large enough to account for ILB mispricing: whatever mispricing there may be in the inflation swaps market is too small to explain the magnitude of ILB arbitrage mispricing documented in Section 4.

8.3 Illiquidity

The notion that liquidity patterns can have significant effects on the valuation of securities is well established in the literature. For example, see Boudoukh and Whitelaw (1993), Vayanos and Vila (1999), Acharya and Pedersen (2005), Amihud, Mendelson, and Pedersen (2005), Huang and Wang (2008), Brunnermeier and Pedersen (2009), Longstaff (2009), Huang and Wang (2010), and many others.

To study the effects of changes in liquidity on ILB mispricing, five variables proxy for liquidity conditions in the market. The first is the swap spread which is the difference between the current ten-year interest rate swap yield and the yield of the current reference ten-year bond future. The second is the swap rate which represents the current ten-year interest rate swap rate for a period ending at the maturity of the bond underlying the next-expiring ten-year bond future. The third is an index of implied volatilities on index options (VIX in the United States). The fourth is the price of a swaption on a one-year straddle on ten-year interest rate swaps with the strike price reset to the current at-the-money swap rate at the beginning of every roll period. The fifth is the current five-year CDX index by Markit. The choice of these liquidty proxies is motivated by the Citigroup CLX index which uses the same set of variables to construct the CLX liquidity index. Table 13 presents summary statistics of the regression results. Across all liquidity variables, a worsening of market liquidity as measured by the liquidity proxy variable is associated with an increase in ILB mispricing. The swap rate and the swaption variables are statistically significant at the ten percent level across all regions, and the volatility index is significant at the five percent level across all regions. These results provide strong evidence, that market-wide liquidity conditions have significant effects on ILB mispricing. The swap spread and the CDX index of CDS spreads are not significantly related to the mispricing. For the United States, these results are consistent with those first reported in Fleckenstein, Longstaff, and Lustig (2012). The latter variables, however, are also measures of credit risk.[14] Thus, to the extent that the swap spread and CDX index of CDS spreads capture credit risk, the ILB mispricing is not significantly related to systemic credit risk.

Another possible difference between nominal bonds and their index-linked counterparts could be in their trading costs. However, all seven countries in this study have liquid bond markets and the costs of trading nominal bonds and inflation-linked bonds are both small. Indexed-linked bonds in Japan were restricted to specific investors and therefore may have been illiquid. However, the restrictive requirements on the investor clientele were significantly relaxed by the time Japanese inflation-linked bonds enter the study. For the U.S. market, Fleckenstein, Longstaff and Lustig (2012) provide evidence that on average, a large financial institution would typically face a bid-ask spread for Treasury bonds on the order of a quarter of a basis point in yield. In terms of price, this would translate into a two or three cent bid-ask spread for a ten-year Treasury note. The same financial institution would generally face a bid-ask spread for a TIPS issue of about one basis point in yield during much of the study period. Bid-ask spreads for TIPS, however, roughly doubled with the onset of the financial crisis in 2008 and 2009 and are now about two basis points in yield. This would translate into roughly a 15 cent bid-ask spread for a 10-year TIPS issue. The bid-ask spreads for Treasury STRIPS would be on the same order of magnitude as that of TIPS. Finally, the bid-ask spread on inflation swaps is on the order of five basis points. Taken together, these values imply that TIPS-Treasury mispricing greater than about eight basis points cannot be explained in terms of transaction costs; the transaction costs are very small relative to the typical size of the pricing differences between Treasury bonds and TIPS. Qualitative similar results hold true for the United Kingdom and the Euro-Zone countries. Fleckenstein, Longstaff and Lustig (2012) also address the issue of index-linked bond illiquidity in the U.S. market. As one measure of the relative liquidity of TIPS and Treasury bonds, the average trading volume of the two types of securities by primary dealers was examined. This information is tabulated and reported online by the Federal Reserve Bank of New York. Focusing on 2009, the total average daily trading volume in Treasury bonds with maturities of three years or more by primary dealers was about $207 billion. In contrast, the same measure for TIPS bonds was roughly $5 billion. TIPS bonds, however, represent less than ten percent of the total amount of Treasury debt held by the public. Thus, while TIPS may not be as intensively traded as Treasury bonds, these results suggest that the average daily trading volume for TIPS is still very substantial. Furthermore, Treasury bond and TIPS traders confirmed this assessment of the relative liquidity of the two markets. In particular, anecdotal reports by TIPS traders confirm that TIPS were liquid and that trades could be executed rapidly. The European and UK markets are very similar in terms of liquidity to the U.S. markets and it is safe to conclude that transaction costs and illiquidity cannot explain the magnitude of the mispricing between index-linked and nominal bonds observed in these developed bond markets.

8.4 Differences in Taxation

In the United States, the Federal and State income taxation of Treasury bonds is identical to that of TIPS in all but one small aspect. Specifically, since the notional amount of TIPS accretes over time with realized inflation, taxable investors must treat this "phantom income" as if it were interest income

[14]For a discussion of U.S. sovereign CDS, see Ang and Longstaff (2011).

for Federal tax purposes. In contrast, taxable investors holding Treasury bonds only include coupons as interest income (abstracting from original issue discount (OID) and premium amortization issues). Interest income from both Treasury bonds and TIPS (including any accreted notional amounts) is exempt from State income taxation. A large portion of outstanding TIPS issues are held either directly or indirectly by tax-sheltered entities such as pension plans and retirement funds. Thus, the phantom income provision is irrelevant for many of these investors. This view is consistent with a survey by the Bond Market Association in which 79 percent of respondents indicated that the current tax status of TIPS is not a deterrent to buying TIPS, some indicating that this was because of the tax-free status of their funds.[15] Finally, it is important to observe that if the taxation of phantom income were to affect the valuation of TIPS, it should do so uniformly across all issues since the accretion rate is the same for all TIPS. Furthermore, the effects should also be present in the pricing of Treasury STRIPS since they are also subject to the phantom income provisions. In actuality, however, studies of the pricing of Treasury STRIPS have not found evidence of phantom income related tax effects.[16]

In the United Kingdom, inflation-linked gilts are granted a more favorable tax treatment compared to their nominal counterparts because the inflation accumulated between tax year-ends is tax-exempt. Investors are only taxed on the real return, not on inflation compensation. In effect, it is as if the inflation increase in the principal is not taxable. The U.K. pension and insurance sectors are key investors in and holders of index-linked Gilts. In 2003 insurance companies and pension funds held over 90% of all outstanding index-linked debt, but their share has decreased significantly since then. However, according to the NAPF, pension fund allocations to inflation linked gilts increased to 12.3%, from 7.9% per cent in 2010 (NAPF Annual Survey (2010)). U.K. pension funds hold more than £100 billion of U.K. Gilts which represents around 11% of total issuance.[17] In contrast to the government bond market, the inflation uplift for corporate inflation linked bonds is taxed. Consequently, similar to the United States, most index-linked debt is held by pension funds or within the pension business lines of life assurance companies, which are tax-exempt. Tax differences between nominal and index-linked gilts are irrelevant for many of these investors. Therefore, the tax treatment of index-linked bonds cannot drive a wedge between the market prices of index-linked and nominal gilts.

In Japan, prior to 2006, the principal portion of inflation-indexed bonds was classified as a derivative security by the Accounting Standards Board of Japan (ASBJ), since investors may be repaid less than par at maturity in case of persistent deflation. This implied that mark-to-market gains and losses had to be recognized on the income statement instead of on the balance sheet, as is the case for most nominal bonds. Therefore, inflation-indexed bonds were less attractive to domestic investors compared to nominal bonds. In 2006, however, the accounting classification was changed so that mark-to-market gains and losses did not have to be recognized on the income statement. Furthermore, since October 2008, holdings of off-the-run inflation indexed bonds could be recorded at theoretical value rather than at market value on the balance sheet. The coupon payments on index-linked bonds are subject to income tax. As is the case in the United States, the inflation-uplift in the principal is treated as an interest payment and is taxed as such. However, pension funds and life insurance companies are not major holders of indexed bonds in Japan. There are at least two explanations. First, Japan has not experienced inflationary pressures in the past decade. Second, Japan's public pension is based on a pay-as-you-go system, so that hedging demand from public pension funds is small. Importantly, however, more than 50% of index-linked bonds are held by foreign investors such as life insurance, pension funds and hedge funds according to the Ministry of Finance. For these investors interest and the gains or losses on principal would be exempt from withholding taxes. Therefore, it is highly unlikely that differences in taxation is causing ILB mispricing in Japan.

The tax treatment for Canadian Real Return Bonds is comparable to that of U.S. TIPS in that the

[15] See http://archives1.sifma.org/research/tipssurvey.pdf.

[16] For example, see Grinblatt and Longstaff (2000) and Jordan, Jorgensen, and Kuipers (2000).

[17] See http://www.ons.gov.uk/ons/rel/fi/investment-by-insurance-companies--pension-funds-and-trusts/mq5/quarter-4--2010.pdf.

full nominal interest payments, including the inflation uplift, are taxable. For any given tax year, bondholders must declare as income the amount by which the compensation for inflation on the principal has increased, even though this accrual is not paid out until the bond matures. Capital gains are not taxed until realized. For non-residents, the Canadian Treasury is not ordinarily required to withhold tax from interest or principal paid on RRBs.[18] As in the United States, a large portion of outstanding Real Return Bond issues are held either directly or indirectly by tax-sheltered entities such as pension plans and retirement funds. The phantom income provision is irrelevant for most of this investor class. Therefore, the tax treatment of index-linked bonds is highly unlikely to be the source of ILB mispricing in Canada.

In the Euro Zone, the tax treatment of inflation-indexed OATs, Bunds, and BTPs is similar to that of these countries' respective nominal bonds. The annual uplifted coupons and any capital gains realized at redemption or when the bond is sold are taxed. Taxation rules slightly differ between institutional and retail investors in that institutional investors pay tax on capital gains before redemption or sale. The investor class is similar to that in the United States, the United Kingdom and Canada. Therefore, tax differences between nominal bonds and index-linked bonds are unlikely to be able to account for ILB mispricing in Europe.

In conclusion, while it cannot be completely ruled out that tax differences may have a slight effect on the relative prices of nominal and index-linked bonds, it is highly unlikely that tax differences can account for ILB mispricing of the magnitude documented in Section 4.

8.5 Deflation Floor

The implementation of the arbitrage strategy abstracts from the fact that many inflation-indexed bonds in the study, such as TIPS bonds in the U.S., feature an embedded deflation floor. As discussed earlier, the principal amount of a TIPS issue is protected against deflation since the principal amount received by a TIPS holder at maturity cannot be less than par. Thus, there is an embedded option or deflation floor incorporated into the TIPS issues. Because of this, the value of a TIPS issue may be somewhat higher than it would be if there was no protection against deflation. The analysis in the previous sections abstracts from the value of the deflation option. It is clear, however, that prices of inflation-linked bonds were adjusted by subtracting out the value of the deflation option, then the estimated ILB mispricing would be potentially much larger than reported. Thus, the deflation floor goes in the wrong direction to explain inflation-indexed/nominal mispricing when the indexed bonds feature a deflation floor. Furthermore, the countries in the sample, except Japan, have not experienced prolonged periods of deflation. Therefore, abstracting from the par floor is a non-issue for the robustness of the quantitative results in this paper. Even for Japan, any impact would be negligible since it enters the sample period in 2007 when deflationary pressures were not a concern.

The results in section 4 showed that there are times when the mispricing in the European countries switches sign. Inflation-linked bonds in France, Germany, and Italy feature a par floor, similar to TIPS in the United States. Clearly, in the case of negative mispricing, the fact that the analysis abstracts from the embedded inflation floor, works in the other direction. If the results were adjusted by the value of the deflation floor, the negative mispricing would be smaller in absolute terms, or, "less negative".

To provide a back-of-the-envelope calculation for the impact of the inflation floor on the ILB mispricing in the United States, I collected data on inflation options on the U.S. CPI from the Bloomberg terminal. These are zero-coupon floors whose payoff is tied to the realized inflation rate. The market for these securities developed first in the Euro area and the U.K., but has expanded in the U.S. during the last few years. A zero-coupon inflation floor is a contract entered into at time t. The seller of the floor

[18] See `http://www.fin.gc.ca/invest/taxtreat-eng.asp.`

is contractually obligated to pay a fraction $max\left((1+k)^n - (1+\pi(n))^n\right)$ of the contract's notional amount as a single payment in n years from the inception of the contract, where $\pi(n)$ denotes the average annual CPI inflation rate from t to $t+n$, and k denotes the strike of the floor. Without loss of generality, the notional amount is normalized to $100, so that it matches the face value of the underlying index-linked bond. In exchange, the buyer makes an up-front payment of $P_t(k,n)$. If realized inflation is less then k at maturity of the contract, then the option expires out-of-the money. A zero-coupon inflation cap is identical, except that the payoff is $max\left((1+\pi(n))^n - (1+k)^n\right)$. The dataset consists of daily quotes on zero-coupon inflation floors at strike prices of 0 percent. The sample period is from October 5, 2009 until September 23, 2011. Since the average notional-weighted maturity of the TIPS bonds was 8.951 years during that period, the analysis use zero-coupon inflation floors with a matching ten year maturity. During the period from October 5, 2009 until September 23, 2011 the average price of a zero-strike inflation floor was 8.55 basis points per annum. Therefore, the ILB mispricing could have potentially been around nine basis points higher during that period. This rough estimate illustrates that the deflation floor goes in the wrong direction to explain inflation-indexed–nominal bond mispricing. To provide a back-of-the-envelope calculation for the impact of the inflation floor on the ILB mispricing in the Euro Zone, I collected data on inflation options on the Euro HICPX from the Bloomberg terminal. These are zero-coupon floors whose payoff is tied to the realized inflation rate as measure by the Euro HICPX. The sample period is from October 5, 2009 until September 23, 2011. Since the average notional-weighted maturity of the Euro-Zone bonds was 8.561 years during that period, the analysis uses zero-coupon inflation floors with a closely matching ten year maturity. During the period from October 5, 2009 until September 23, 2011 the average price of a zero-strike inflation floor was 6.26 basis points per annum. Therefore, the ILB mispricing could have potentially been around six basis points higher during periods of positive mispricing. These back-of-the envelope calculations are consistent with results reported in Heider, Li, and Verma (2012) who estimate the value of the embedded deflation floor for the U.S., France, Germany, and Italy. Their reported maximum values of the par floor during the sample period are 7, 5.5, 3, and 3.8 basis points for the United States, France, Italy, and Germany, respectively.

8.6 Asset Swaps

Inflation asset swaps are widely used by inflation dealers to reduce balance sheets costs. Inflation dealers are typically short inflation because they sell structured inflation products, such as inflation swaps, to their customers. In order to hedge against the short exposure, dealers buy inflation-linked bonds which need to be recorded on their balance sheets. By selling asset swaps, inflation dealers get the inflation-linked bonds off their balance sheets while still keeping the exposure to the inflation-linked payments. Several variations of inflation asset swaps exist. In the simplest form, the par inflation asset swap, the asset swap buyer receives an inflation-linked bond from the asset swap seller. The buyer then enters into a series of inflation swaps to pay the asset swap seller inflation linked coupons equal to that of the inflation linked bond. In return, the asset swap seller pays floating rate payments of Libor plus (or minus) an agreed fixed spread, referred to as the asset swap spread. At maturity, there is an exchange of principal, the seller receiving the inflation uplifted notional and asset swap buyer receiving par. In this structure, counterparty credit risk plays a role. The notional on all the floating payments remains the same because the asset swap seller receives the inflation-accreted notional and pays par. However, the swap seller is exposed to counterparty credit risk because the inflation-uplifted redemption can be substantially higher than par. For example, with an annual inflation rate of two percent, the notional accretion over thirty years equals 81.1 percent. By contrast, Fleckenstein, Longstaff, and Lustig (2012) argue that it is unlikely that counterparty credit risk has much of an effect on the pricing of inflation swaps. Pflueger and Viceira (2011b) suggest that ILB arbitrage is related to the relative cost of financing a TIPS position versus a Treasury Bond position. They measure these costs as the asset swap spread differential between inflation-linked and nominal bond asset swap spreads. The asset swap spread rose sharply during the financial crisis, reaching 130 basis point in

December 2008. ILB basis-point mispricing peaks at 175 basis points around the time of the Lehman bankruptcy in the Fall of 2008 in the United States. First, one potential pitfall in comparing the ILB arbitrage trade against the asset swap trade is that the asset swap trade reflects counterparty risk, whereas counterparty risk has a negligible effect on the ILB arbitrage trade (FLL (2012)). Second, TIPS asset swaps are also driven by inflation swap demand. Furthermore, there were clearly earlier periods when the average mispricing was in excess of 60 basis points, whereas the asset swap spread varies within a relatively narrow range of 21 to 41 basis points from January 2004 through December 2006. It is even more critical to point out that the asset swap argument applies to levered investors. A non-levered investor who perceives TIPS to be undervalued relative to Treasury Bonds can enter a net zero portfolio, which is long one dollar of TIPS and short one dollar of nominal Treasuries. The levered investor would enter one TIPS asset-swap and go short one nominal Treasury asset swap. Even if levered investors could not take advantage of ILB mispricing in the U.S. market, it still remains a puzzle as to why unlevered investors would not engage in the TIPS-Treasury arbitrage trade and align prices. While it cannot be ruled out that the relative financing costs of a TIPS position compared to a position in Treasury bonds may have played a role for ILB mispricing during the financial crisis, it is highly unlikely that financing costs could explain arbitrage mispricing in the magnitude observed in the United States during and in the aftermath of the financial crisis.

9 CONCLUSION

The government bond markets in the United States, the United Kingdom, Japan, Canada, France, Italy, and Germany are among the largest and most actively traded fixed-income markets in the world. Despite this, there are persistent violations of the law of one price within these markets. In all countries, prices of nominal bonds exceed those of their inflation-linked counterparts. In the United Kingdom, the price of a nominal gilt and an inflation-swapped index-linked gilt issue exactly replicating the cash flows of the nominal gilt can differ by more than $20 per $100 notional. In the aftermath of the 2008 financial crisis, ILB mispricing peaks at $101 billion which represents more than eight percent of the aggregate size of the inflation-linked bond markets in the study. On average, aggregate G7 ILB mispricing is in excess of $22 billion.

This paper is the first to document mispricing between nominal and inflation-linked bonds and to analyze the properties and dynamics of arbitrage mispricing in and across seven of the largest fixed-income markets. Although these arbitrages occur in different global markets, ILB mispricing is significantly correlated contemporaneously and in the time series. Furthermore, ILB mispricing in the G7 countries is forecastable based on lagged ILB mispricing in the other countries. There is evidence that many hedge funds have indeed profited from the ILB trade. This paper shows that the ILB arbitrage strategy consistently earns positively-skewed excess returns in all G7 countries, and therefore it is not merely similar to "picking up nickels in front of a steam-roller," or writing deep out-of-the money puts.

This paper provides key new insights into the role slow-moving capital plays for the persistence and the dynamics of arbitrage mispricing. Specifically, it presents evidence consistent with the notion capital that available to specific types of arbitrageurs is significantly related to the mispricing: returns of hedge funds following fixed-income strategies strongly predict subsequent changes in ILB mispricing, whereas returns of other types of hedge funds lack statistically significant forecasting power.

In the aftermath of the financial crisis, central banks around the world have taken measures to stabilize financial markets. This paper also presents new insights into the effects of monetary policy on arbitrage mispricing. Specifically, during the 2008 financial crisis, central banks around the world may have exacerbated ILB mispricing through large-scale asset purchase programs.

APPENDIX

A THE G7 INFLATION–LINKED BOND MARKETS

This section provides an overview of the inflation-linked and nominal bond markets in the United States, the United Kingdom, Japan, Canada, France, Italy, and Germany, and describes the dataset for each country. For expositional convenience, all nominal debt obligations of any country will be referred to as bonds and inflation-indexed debt will be referred to as inflation-index bonds (IIB), inflation-linked bonds (ILB), or linkers. Table 2 gives an overview of the key features of the G7 inflation-linked government bond markets.

A.1 The United States

Treasury Inflation-Protected Securities (TIPS) are direct obligations of the U.S. Treasury and are similar in most respects to Treasury bonds. The key difference is that the principal amount of a TIPS issue is adjusted over time to reflect changes in the price level as measured by the non-seasonally adjusted consumer price index (CPI). Since the fixed coupon rate for the TIPS issue is applied to its principal amount, the actual semiannual coupon received varies over time as the principal amount changes in response to the realized inflation or deflation rate. Similarly, the final principal amount paid to the bondholder equals the maximum of the original principal amount or the inflation-adjusted principal amount. Thus, TIPS investors' principal is protected against deflation (although the same is not the case for coupon payments). Practitioners refer to this feature as the "par floor".

The principal amount of a TIPS issue is adjusted daily based on the Consumer Price Index for All Urban Consumers, known as CPI-U. Let I_t denote the inflation adjustment for a TIPS issue as of date t. The inflation adjustment is computed as the ratio of the reference CPI at the valuation date t divided by the reference CPI at the issuance date which is normalized to be time zero. The reference CPI for a particular date during a month is linearly interpolated from the CPI reference index for the beginning of that month and the CPI reference index for the beginning of the subsequent month. The CPI reference index for the first day of any calendar month is the CPI-U index for the third preceding calendar month. Thus, the reference CPI for April 1 would be the CPI-U index for the month of January, which is reported by the Bureau of Labor Statistics during February. Details on how TIPS are adjusted for inflation are described on the U.S. Treasury's website[19].

The Treasury first began auctioning TIPS in January 1997. As of the end of the sample period, 40 separate TIPS issues have been auctioned. Currently, the Treasury issues 5-year, 10-year, and 30-year TIPS on a regular cycle. The increase in the frequency of TIPS auctions has made the inflation–linked market more dense thus improving continuous market making.

Since inception of the program, large structural changes have affected the cash market for inflation protection. At the beginning of the sample period in July 2004, the notional amount of TIPS outstanding was $222.61 billion, representing 5.8 percent of total marketable debt. Towards the end of the sample period in September 2011, the total notional outstanding was at $681 billion, representing a 7.3 percent share of total marketable U.S. government debt. Since 2006, the outstanding amount of TIPS have almost doubled, from $393 billion to $782.0 billion in July 2012. With total marketable debt at $10607.35, TIPS represented a share of 7.4 percent in July 2012. In 2002, by contrast, TIPS made up only 4.5 percent of total marketable U.S. debt. In terms of issuance, TIPS made up 3.4% of total bond issuance at year end 2010, up from 3% at the end of 2009. Furthermore, the maturity spectrum has widened significantly, particularly through the re-introduction of 30-year TIPS since 2010. With

[19] See `http://www.treasurydirect.gov/instit/statreg/auctreg/auctreg/gsr31cfr356.pdf`

the 2040, 2041, and 2042 TIPS issues, the 30-year sector represents 7.7 percent of the overall TIPS market.

Monthly turnover in TIPS has also increased significantly since inception of the program in 1997. In January 2000, monthly turnover was at $25 billion. Since then, monthly turnover has increased tenfold to $250 billion on January 2012. During the financial crisis, monthly turnover decreased significantly. In January 2008, it was at $225 billion. During the crisis, monthly turnover dipped below $125 billion.

Even with the explosive growth in the U.S. inflation-linked bond market, TIPS only represent around 7.5 percent of total marketable U.S. debt which compares to 23.3 percent for the United Kingdom, 13 percent for France, and 7.9 percent for Italy. Germany falls behind the United States, with index-linked debt only making up around 5 percent of total marketable debt.

The investor base in TIPS is tilted towards domestic investors. Investment fund accounted for 30.2% of TIPS sold at auction, but only 11.5% of notes and bonds. Foreign investors accounted for 8.2% of TIPS sold at auction but 21.1% of nominal notes and bonds. However, recent auction results show signs that the investor clientele in TIPS is broadening with foreign investors becoming more involved. Still, the mutual fund industry still dominates the U.S. TIPS inflation market. The total amount held by these institutions in 2012 was around $150 billion, almost 20% of the total notional of TIPS outstanding. Strikingly, this is not the case in Europe where the mutual funds industry only holds around €3.5 billion which is less than one percent of the total notional outstanding.

The data for the United States consist of daily closing prices for U.S. Treasury bonds, TIPS, STRIPS, and inflation swaps for the period from July 23, 2004 to September 20, 2011. All data are obtained from the Bloomberg system. The TIPS and Treasury pairs in the dataset have maturities ranging from 2007 to 2041. Daily closing prices for TIPS and Treasury bonds are adjusted for accrued interest following standard market conventions.

For the analysis, TIPS and Treasury bonds are matched based on their respective maturities. Maturity mismatch is defined as the number of days between the maturity of a TIPS issue and that of a Treasury bond with the closest maturity to that of the TIPS issue. Only pairs of TIPS and Treasury bonds with a maturity mismatch of less than or equal to 31 days are included in the sample. This leads to a total of 36 TIPS-Treasury bond pairs. Specifically, the Treasury issued 41 TIPS bonds prior to the end of the sample period. One of these issues had matured by the beginning of the sample period. Four issues had maturity mismatches in excess of 31 days. In particular, there are 13 exact matches, 12 mismatches of 15/16 days, and 11 mismatches of 31 days. The 31-day mismatches occur only for maturities of February 2015 or later. Thus, these mismatches represent a very small percentage mismatch in the maturities of the TIPS and Treasury bonds.

A.2 The United Kingdom

In the United Kingdom, inflation-linked bonds have been in existence since 1981. The first index-linked gilt, the 2% September 1996, was auctioned in a single price auction by the U.K. Treasury on 27 March 1981, for £1 billion. In September 1998, a specialist index-linked market maker list was introduced and in November 1998, the issuance method was changed to a uniform price auction. The U.K. DMO's stated rationale for index-linked gilt issuance was to reinforce the U.K. Government's anti-inflationary credibility, to reduce debt servicing costs by offering a lower real return in exchange for inflation protection, to increase the DMO's flexibility to borrow even in times of high inflation, and to provide flexibility to the pension industry. At the end of 2010, the size of the inflation linked bond market was $420 billion, up from $320 billion in 2009. Total marketable debt outstanding at the end of 2010 was $1.9 trillion with linkers representing 22%, up from 21.5% in 2009, but down from 24% at the end of 2008. Inflation-linked bonds represented 23% of the gilt market at the end of 2010. Gross inflation-linked bonds issuance was $53 million in 2010 which made up 8.92% of gross total marketable debt issuance of $592 million, and 20% of total gilt issuance of $259 million. In uplifted nominal terms, the index-linked gilt market was at £284 billion in August 2012, and accounted for 23% of the total gilt market. The three-month lag U.K. gilts accounted for 64% of the DMO's index-linked gilt portfolio as of August 2012. As in the United States, the index-linked gilt market has seen significant growth. Between 2006 and 2012, the total notional amount of index-linked gilts outstanding has tripled from £108.7 to £282 billion. The number of index-linked Gilt-edged market makers also more than doubled from 9 in 1999–2000 to 21 in 2011–2012.

In the United Kingdom, inflation-linked bonds reference the U.K. Retail Price Index (RPI). Transportation (14.1%), food, beverages and tobacco (25.8%), and housing (23.6%) represent close to two thirds of the index. The RPI is constructed with arithmetic rather than geometric aggregation which results in an upward bias compared to a geometric aggregation because it uses the average of relative prices rather than a ratio of averages. Since 2003, the RPI is no longer used as the inflation measure targeted by monetary policy. The inflation target is measured against the U.K. CPI which is a harmonized index of consumer prices constructed similarly to the Eurostat's HICP index. Despite this, however, the U.K. real bond market remains linked to the RPI because most inflation-linked liabilities reference the RPI. The majority of pension fund liabilities, for example, accrue on a limited price indexation basis to the RPI.[20] Around 74% of pension indexation is explicitly linked to the RPI, and only about 3% is linked to a different index.

Prior to September 2005, all issued index-linked gilts were using an eight-month indexation lag with no interpolation. Initially, the justification for an eight-month lag was to allow two months for the compilation and publication of the RPI and a further six months to ensure that the nominal size of the next coupon payment is known at the start of each coupon period in order to compute accrued interest. However, to conform to other major inflation-linked bond markets, index-linked gilts issued from September 2005 onwards employ the three-month indexation lag structure first used in the Canadian real return bond market. In fact, in September 2005 the U.K. DMO issued the world's first 50-year sovereign index-linked bond which also was the first index-linked gilt to use a three-month indexation lag. In uplifted nominal terms, the three-month lag design accounted for 53% of the index-linked gilt market at the end of March 2011. The breakeven-point was reached in July 2010. U.K. inflation-linked gilts have no deflation floor and hence can be redeemed below par if the RPI falls over the lifetime of the bond. The eight-month lag linkers also have no deflation floor, but they have accreted a considerable amount of inflation since issuance. With the introduction of the three-month lag design, index-linked gilts also trade on a real clean price basis as in the U.S. market.

In contrast to the 3-month lagged gilts which trade in real space with a real price and with settlement amounts uplifted to account for the inflation accreted over the life of the bond, the linkers using an eight month lag trade in clean price cash terms, with the traded price rising and falling to reflect inflation that has occurred. In a positive inflation environment, the clean price of the old-style linker increases over time with inflation. Consequently, linkers first issued in the 1980s trade at prices above £200. Since the price of an eight-month linker already incorporates accrued inflation, no index ratio is used to determine the settlement price.

Monthly turnover in index-linked gilts has also increased significantly since inception of the program in 1981. In April 2008, monthly turnover was at £6 billion. Since then, monthly turnover has almost tripled to £18 billion in August 2011. In August 2012, monthly turnover was around £14 billion, up from recent low of just above £8 billion in February 2012.

The U.K. pension and insurance sectors are key investors in and holders of index-linked gilts.[21] In 2003 insurance companies and pension funds held over 90% of all outstanding index-linked debt, but their

[20]This means that the liabilities increase each year by the rate of RPI inflation capped at a certain level, e.g. 5% with an implicit floor of 0%.

[21]See `http://www.ons.gov.uk/ons/rel/fi/investment-by-insurance-companies--pension-funds-and-trusts/mq5/quarter-4--2010.pdf`

share decreased significantly since then.[22] However, according to the NAPF, pension fund allocations to inflation linked gilts increased to 12.3%, from 7.9% in 2010. U.K. pension funds hold more than £100 million of U.K. gilts which represents around 11% of total issuance.

The data for the United Kingdom consist of daily closing prices for U.K. gilts, index-linked gilts, U.K. STRIPS, and inflation swaps for the period from July 23, 2004 to September 20, 2011. All data are obtained from the Bloomberg system. The gilt and inflation-linked gilt pairs in the dataset have maturities ranging from October 2004 to November 2055. Daily closing prices for gilts and inflation-indexed gilts are adjusted for accrued interest following standard market conventions. Note that accrued interest is calculated differently for three-month and the eight-month lag gilts.[23]

For the analysis, inflation-linked gilts and nominal gilts are matched based on their respective maturities. The maturity mismatch is defined as the number of days between the maturity of an inflation-linked gilt issue and that of a nominal gilt with the closest maturity to that of the real gilt. For the U.K., only pairs of gilts and inflation-linked gilts with maturity mismatch less than or equal to 55 days are included in the sample. This leads to a total of nine nominal gilt–real gilt bond pairs, five of which have an eight-month indexation lag, and four with a three-month indexation lag. Throughout most of the sample, there are four bonds with an eight-month indexation lag and three bonds with a three-month indexation lag.

A.3 Japan

Japan issued the first 10-year maturity index-linked bonds (JGBi) in March 2004 in an amount of ¥100 billion. Initially, the issue traded at a 15 basis points breakeven rate while year-on-year inflation was negative. Despite prolonged periods of deflation in Japan, inflation-linked bonds did not have a deflation floor. However, the Ministry of Finance is taking a deflation floor for future issues into consideration. By the end of 2008, there were a total of 16 bonds outstanding with a total capitalization of close to ¥10 trillion ($90 billion).

Net issuance increased from around $18 billion in 2005 to around $26 billion in 2007. The total amount outstanding peaked at $87 billion in 2008. At that time the inflation-linked bond market represented around 1.62% of total marketable debt and around 3.5% of total long-term bonds outstanding. Inflation-linked bonds represented about 3% of total bond issuance in 2007 and made up around 1.37% of total bonds outstanding at the end of 2008.

Japan JGBi pay semiannual coupons and reference the Japan nationwide CPI index ex-fresh food (Japan Core CPI). The indexation lag is three months and the indexation style follows the Canadian model with linear interpolation to the tenth of the month. The reference index for inflation-linked Japanese government bonds and inflation swaps is the Japan non-seasonally adjusted consumer price index excluding perishable food items. The CPI is calculated using the Laspeyres method which is based on year-on-year changes in prices of goods and services with respect to the base year 2005. The base year fixes the weights of goods and services included in the index. The Laspeyres method is biased upwards as time passes from the base year. Due to fixed weightings, goods that increase in price are weighted more heavily than goods which decline in price. Japan JGBi do not feature a deflation floor and are not strippable. Similar to U.S. TIPS, Japan inflation-indexed bonds are quoted in real price terms (without inflation adjustment). Identical settlement and day-count conventions as for nominal bonds (3 day settlement, actual/365 day-count) apply to the linker market. The Ministry of Finance typically scheduled auctions on a bimonthly basis using a Dutch style auction process identical to that of nominal bonds (since 2007 re-openings were held as price-competitive auctions).

[22] See `http://research.dwp.gov.uk/asd/asd5/WP102.pdf`

[23] See `http://www.dmo.gov.uk/documentview.aspx?docname=/giltsmarket/formulae/igcalc.pdf\&page=Formulae/Calc`

Initially, the investor base of inflation-indexed bonds was restricted to financial institutions and foreign governments: non-financial corporations, foreign investors, and individuals were not eligible to hold inflation-linked debt. Since 2005, foreign juridical persons including foreign governments, foreign local governments, foreign central banks, international organizations and foreign government agencies are eligible for proprietorship except when subject to taxation on interest from Japanese Government Bonds (JGBs).[24]

In January 2007, the Ministry of Finance declared inflation-indexed bonds eligible for their buyback operations. In each of five buyback operations the Ministry of Finance retired about ¥45 billion of outstanding linkers until April 2008. In the wake of the financial crisis, prices of inflation-linked bonds declined significantly (in March 2008, the on-the-run 10 year JGBi breakeven rate approached -2 basis points) which lead to increased buybacks by the Ministry of Finance. During the 2008 financial crisis the liquidity of the 10-year inflation indexed bonds dropped precipitously. As breakeven rates continued to decline during the peak of the financial crisis, reaching a low of -323 basis points in mid-December 2008, the Ministry of Finance stepped up their buyback operations and cancelled two linker auctions scheduled for October 2008 and February 2009. From October 2008, average monthly inflation-linked bond buybacks were on the order of ¥215 billion. Over 39 linker buyback operations took place between 2007 and 2009, bringing the total amount retired from the secondary inflation-indexed market to about ¥3.74 trillion. This represents nearly 40% of the total linker issuance and the secondary market declined in size from around $87 billion at the end of 2008 to around $61 billion at the end of 2009. After additional linker buybacks, the size of the secondary inflation-linked bond market was around $32 billion at the end of 2010. However, breakeven rates at the long-end of the maturity curve, recovered to near -50 basis points by the end of 2009, and liquidity improved significantly as well with bid/ ask spreads in the 10-year maturities narrowing by over 50%.

Nonetheless, the liquidity in the secondary inflation-linked bond market did not recover to pre-crisis levels with bid-ask spreads occasionally widening to levels seen during the financial crisis. In response to market conditions, new issuances of 10-year inflation-indexed bonds were suspended after August 2008. The planned issuance of ¥0.3 trillion in ten-year inflation-linked bonds in 2010 was put on hold in light of market conditions and in 2011 their issuance was dismissed again as opinions calling for suspension of issuance remain in the majority at the Meeting of JGB Market Special Participants.[25]

The Bank of Japan targets the Japanese core CPI, along with the corporate goods price index (CGPI), in conducting monetary policy. Prior to 2011, however, the Bank of Japan did not narrowly define long-run price stability based on the core CPI describing medium- to long-term price stability as an "approximate range [of the year-on-year increase in the CPI] between zero and two percent".[26] However, in their 2011 annual review, the Bank of Japan revised their stance on monetary policy and set a goal of one percent for year-on-year increases in the consumer price index.[27]

The data for Japan consist of sixteen maturity-matched inflation-linked–nominal Japanese government bonds, JGB STRIPS and inflation swaps. All data are obtained from the Bloomberg system. Daily closing prices for JGBs and JGBis are adjusted for accrued interest following standard market conventions. Inflation-linked JGBi and JGB are matched based on their respective maturities. Maturity mismatch is defined as the number of days between the maturity of an inflation-linked bond and that of the nominal bond closest in maturity to the indexed bond. In contrast to other countries, the maturity mismatch for all sixteen pairs is ten days. The maturity range for the sixteen pairs is from March 2014 until June 2018, reflecting the fact the Japan Ministry of Finance has only been issuing ten-year maturity bonds to date. The sample period is from March 7, 2007 until September 20, 2011.

[24]See `http://www.mof.go.jp/english/jgbs/publication/debt\_management\_report/2010/index.htm`
[25]See Ministry of Finance Japan, 2011 Annual Debt Management Report, p. 12
[26]See `http://www.boj.or.jp/en/announcements/release\_2006/data/mpo0603a1.pdf`
[27]See `http://www.boj.or.jp/en/announcements/release\_2012/k120214b.pdf`

A.4 Canada

In December 1991, the Government of Canada began issuing inflation-indexed debt securities called Real Return Bonds(RRB), and as of September 2011, there are six issues outstanding. Issuance has been concentrated in the thirty year maturity. With an adjusted principal amount outstanding of $30.4 billion as of December 2010, RRBs made up 5.3% of total marketable Canadian government debt, 8.25% of Canadian government bonds, and 21.11% of long-term bonds with maturities exceeding 20 years. The notional amount outstanding, as of March, 31, 2011, is Can$30.8 billion in real terms and Can$37.7 billion in inflation adjusted terms. The initial real return bond issue, the 4.25% 2021, was a 30-year maturity and as of September 2011 is the shortest RRB bond on maturity spectrum. The Treasury issues new bonds at four-year intervals; the 4.25% 2026 being issued in 1995, the 4% 2031 in 1999, the 3.0% 2036 in 2003, the 2.0% 2041 in 2007, and the 1.5% 2044 in 2010. Hence, each new issue extends the initial maturity by one year. In 2011, RRBs made up 5.33% of total marketable debt issuance and 21.72% of all long-term bonds issuance by the Canadian government.

Canadian RRBs are indexed against the non-seasonally adjusted all-items consumer price index. The index constituents represent goods and services from transportation, clothing, housing, food and recreation, and are weighted according to consumer spending patterns. The fixed basket price index is an arithmetic average of price relatives for all index commodities contained in the basket.

The Bank of Canada currently operates under a quarterly funding schedule with one 30-year RRB auction every three months. RRBs tend to trade at general collateral levels in the repo market.[28]

The indexation methodology for Canada real return bonds is referred to as the "Canadian Model". At the time, the established indexation methodology was the U.K. model with an eight month lag. The Canadian indexation process uses a more contemporaneous measure of inflation by shortening the indexation lag to three months. The innovation in the indexation structure was the use of an index ratio to inflate principal and coupon payments for a given settlement date. With few exceptions, this methodology has been followed by all subsequent major issuers, including the U.K., which has been issuing all inflation-linked gilts with a three-month lag since 2005.

The index ratio for a given settlement date is defined to be the ratio of the reference CPI at that date divided by reference CPI at issue date of the bond. A reference CPI value is calculated for every day based upon the CPI values for three months and two months prior to the month containing the settlement date. The reference CPI for the first day of any calendar month is defined to be the published CPI index level for the month three months prior. The reference CPI for any other date is calculated by linear interpolation. Coupons accrue on an actual/actual basis and are paid semiannually. Canadian RRBs do not have a par floor on the inflation adjusted principal.

The data for Canada consist of daily closing prices Canadian nominal bonds, real-return bonds, STRIPS, and inflation swaps. Daily closing prices for real-return and nominal bonds are adjusted for accrued interest following standard market conventions. The real return bonds are the 4.25% December 2021 and the 4.25% December 2026 real return bonds. The corresponding matches are the 9.75% June 2021 and the 8% June 2027 nominal bonds. The maturity mismatches are 183 and 182 days, respectively. The 4% December 2031 bond is excluded because the mismatch is 548 days. The 3% December 2036, the 2 December 2041, and the 1.5% December 2044 real returns bonds are excluded due to lack of a good nominal bond match. The sample period is from June 14, 2007 until September 20, 2011. Real Return Bond data prior to June 14, 2007 is not included because inflation swap data is not available in the Bloomberg system.

[28]See http://www.bankofcanada.ca/stats/cars/f/bd_auction_schedule.html

A.5 France

The Agence France Tresor (AFT) issued the first index-linked government bond, the 3% OATi 2009, in September 1998. The issue was linked to the French CPI index excluding tobacco (CPIx) using the Canadian model. As with TIPS, the AFT decided to include a deflation floor which guarantees that the redemption payment on the linker bonds would not be less than the original par value in case of persistent deflation over the lifetime of the bond. The same protection, however, does not apply to the coupon payments. The inaugural issue was brought to market through a syndication process led by Banque Nationale de Paris, Barclays Capital and Société Générale. With the introduction of the Euro, the OATi 2009 was re-denominated in January 1999, as were all fixed-rate French government bonds, thus creating the first Euro denominated inflation-indexed bond issue. In the second half of 1999, the AFT issued a second inflation-indexed bond, the OATi 3.4% July 2029, again linked to the French CPI index excluding tobacco. With the creation of the monetary union, there was demand for securities indexed to the European inflation index (Euro HICPx). In October 2001, the AFT issue €6.5 billion of the OAT €i 3% July 2012, linked to the HICPx. The indexation methodology was identical to that of the OATi securities using a three-month lag, a deflation floor and annual coupons.

The Euro HICPx is a weighted average of harmonized price indices of the individual Euro area countries with weights determined according to each country's share of consumption expenditure within the Euro area as measured by the household final monetary consumption expenditure. By construction, country weights change over time and also when new countries enter the European Monetary Union. The HICP is published by Eurostat on a non-seasonally adjusted basis. The European Central Banks (ECB) main reference for monetary policy, however, is the headline all-items HICP Index, referred to as the Monetary Union Index of Consumer Prices (MUICP). By mandate, the ECB has to maintain price stability defined as a level of MUICP inflation close to but below two percent.

With the successful launch of the first Euro HICP linker bond, the AFT started issuing new indexed bonds each year, while auctioning existing issues nearly every month. The OAT€i July 2032 was syndicated in 2002 and the OATi July 2013 was the first issue to be launched via auction in 2003. In 2004, the OAT€i 2020 was brought to market via syndication, but the OATi11, OAT€i15, OATi16, and the OATi17 were launched via auction in the second half of 2004 and 2005, respectively. In April 2006, the first BTAN linked to Euro HICPx, the BTAN€i10, was auctioned off. The OAT€i40 and the OATi23 were again brought to market via syndication in the first half of 2007 and the first half of 2008, respectively. In January 2010, the OATi19 was issued via auction.

Issuance of inflation-indexed bonds has continuously increased since inception of the program. Prior to 2009, the AFT's issuance schedule allocated a minimum of ten percent of total bond issuance each year to indexed bonds. In 2004 and 2005, a total of €24 billion, and €17 billion, respectively, were issued which represented 14% of gross bond supply in 2005. In 2006 and 2007, the amounts were €18 billion and €17 billion, respectively. After issuance of €15 billion in 2008, the amount dropped to €12 billion in 2009 as demand for indexed bonds fell in the aftermath of the financial crisis. Despite the decrease, the AFT tapped specific issues that were in demand. In 2010, the AFT was scheduled to issue about 10% of total bond issuance in index-linked bonds. As in the United States, the index-linked French bond market has seen significant growth. Between 2006 and 2012, the total notional amount of index-linked bonds outstanding doubled from €93 to €177 billion. As a share of total long-term debt, index-linked bonds stand at around 22%, compared to around 9 percent in Italy, 13 percent in Germany, and 5 percent in the United Kingdom. French inflation-linked OAT outstanding represent around 8–10 percent of the Euro HICPX market.

The data for France consist of twelve maturity-matched French inflation-linked–nominal OAT Bonds, STRIPS and Euro HICPx inflation swaps. All data is obtained from the Bloomberg terminal. Daily closing prices for OATi (OAT€i) and OAT bonds are adjusted for accrued interest following standard market conventions. The maturity mismatches of the twelve pairs is either 91 or 92 days. There are a total of seven bonds linked to the French CPI ex-tobacco (FRCPXTOB) and five bonds linked to the

European HICPX index. The sample period is from July 23, 2004 until September 20, 2011. During most of the sample, there are fourteen inflation-linked OATs in the database. However, only the twelve pairs are included because the maturity mismatches for the 1.85% July 2007 and the 1.8% 2040 OATis are 456 and 274 days, respectively.

A.6 Italy

Italy issued its first five-year inflation-linked BTP (Buono del Tesoro Poliennale) (BTPi) in the second half of 2003 via syndication with an initial size of €7 billion. A re-opening in October of that year brought the amount outstanding to over €10 billion. The indexation methodology of the BTPi 1.65% Sep 2008 was analogous to that of French Euro OATi bonds except that coupon payments were on a semi-annual basis like the corresponding nominal BTPs. The Italy Ministry of Economy and Finance next issued a ten-year maturity inflation-linked bond, the BTPi 2.15% September 2014. The initial size was €5 billion, but the notional size increased to €14.5 billion through multiple re-openings. The BTPi 2.35% 2035 was auctioned in the second half of 2004 with and initial size of €4 billion. The second five year issue, the BTPi10 was launched in January 2005. Towards the end of the first half of 2006, the ten-year BTPi 2.1% September 2017 was brought to market for €4 billion via syndication. The first index-linked bond to be auctioned was the BTPi 2012 during the first half of 2007. Later that year, however, the first fifteen-year index-linked bond the BTPi 2023 was brought to market via syndication. Lastly, two long-dated euro HICPx linkers maturing in September 2057 and September 2062 were issued. The ten-year BTPi 2019 was syndicated in May 2009 and in the second half of 2009 the BTPi 2041 was brought to market.

The total amount of inflation-linked BTP outstanding at the end of 2010 was on the order of $138 billion, down from $147 billion in 2009. In 2009 and 2010, inflation-indexed debt represented around 7% and 6.8% of Italy's total marketable debt outstanding, respectively. In 2010, gross issuance of inflation-linked BTPs made up around 3% of total gross debt issuance. Inflation-linked BTPs represented 14.53% of total long-term bonds outstanding at the end of 2010, down from 15.76% at the end of 2009. In 2010, issuance of indexed bonds represented 16.93% of total long-term bond issuance, down from a peak of 30% in 2007. As a result of the Buono del Tesoro Poliennale's commitment to the inflation-linked market, Italy became the country with the largest notional amount linked to the Euro HICPx in 2005. However, as market conditions deteriorated during the financial crisis, the BTP starkly reduced its inflation-linked issuance from the third quarter of 2008 and in 2009.

The data for Italy consist of nine maturity-matched inflation-linked–nominal BTP Bonds, STRIPS, and Euro HICPx inflation swaps. Daily closing prices for BTP and BTPi bonds are adjusted for accrued interest following standard market conventions. The maturity mismatches of the nine pairs ranges from 0 days for the 1.65% September 2008 BTPi to 47 days for the 0.95% September 2010, the 2.6% September 2023, and the 3.1% September 2026 BTP. All inflation-linked bonds are indexed to the European HICPX index. The sample period is from July 23, 2004 until September 20, 2011. During most of the sample, there are eleven inflation-linked BTPs in the database. However, only the nine pairs are included because the maturity mismatches for the 2.15% July 2014 and the 2.35% 2035 BTPis are 139 and 410 days, respectively.

A.7 Germany

The Deutsche Finanzagentur (DFA) issued the first inflation-index bond in March 2006. Since then, all G7 countries have been issuers of inflation-indexed securities. The DFA brought the ten-year Bund€i 1.5% April 2016 to market via syndication with an initial size of €5.5 billion. It was re-opened in September 2006 for €3.5 billion. The inaugural issue was priced against the January 2016 nominal Bund bond. The second German inflation-indexed bond, the OBL€i 2.25% April 2013, was issued in October 2007 for €4 billion and the third German linker was launched in June 2009. During the aftermath of the 2008 financial crisis, fears of deflation were widespread and breakeven rates fell precipitously. However, the DFA did not suspend inflation linked issuance and the Bund€i 2020 was the first Euro linker launched after the crisis. The DFA announced in 2010 to issue €3–4 billion in inflation-linked bonds quarterly.

At inception of the program in 2006, inflation-linked issuance represented 3.86% of total marketable debt issuance and 15.76% of total long-term bonds issuance. At the end of 2010, indexed Bunds represented 3.52% of Germany's total marketable debt and around 6% of total long-term bonds outstanding. The face amount outstanding of inflation-linked Bunds has been increasing steadily since March of 2006. At the end of 2010, the total amount of indexed-debt outstanding was on the order of $50 billion, up from $39 billion at the end of 2009.

The data for Germany consist of four maturity-matched inflation-linked–nominal bonds, STRIPS, and Euro HICPx inflation swaps. The maturity mismatches of the four pairs range from 80 days for the 2.25% April 2013 and 1.5% April 2016 index-linked bonds to 101 and 102 days for the 0.75% April 2018, and the 1.75% April 2020 index-linked bonds. All inflation-linked bonds reference the European HICPX index. The sample period is from May 22, 2006 until September 20, 2011.

B THE G7 INFLATION SWAP MARKETS

This section provides a brief introduction to the mechanics of inflation swaps and gives details on the country-specific indexation mechanisms. In particular, differences between the indexation mechanism in the inflation swap markets and that in index-linked bond markets are addressed.

An inflation swap contract is executed between two counterparties at time zero and has only one cash flow which occurs at the maturity date of the swap and involves the exchange of a notional adjusted for inflation that has accrued over a specified time period against the notional capitalized with a fixed rate. The fixed rate, agreed at inception, reflects expected future inflation over the lifetime of the contract and is quoted as an annualized rate. The payoff on the inflation leg varies solely based on the final value of the reference inflation index at maturity of the swap. The cash flow on the fixed leg is predetermined by the quoted swap rate.[29]

The mechanics of inflation swaps are identical across the different markets. Hence, consider without loss of generality the United States. To describe the payoff structure of an inflation swap, imagine that at time zero, the five-year zero-coupon inflation swap rate is 200 basis points. As is standard with swaps, there are no cash flows at time zero when the swap is executed. At the maturity date of the swap in five years, the counterparties to the inflation swap exchange a cash flow of $(1 + .0200)^5 - I_t$, where I_t is again the inflation adjustment factor. Thus, if the realized inflation rate was 1.50 percent per year over the five year horizon of the swap, $I_t = 1.015^5 = 1.077284$. In this case, the net cash flow from the swap would be $(1 + .0200)^5 - 1.077284 = \$0.026797$ per dollar notional of the swap. The timing and index lag construction of the index I_t used in an inflation swap are chosen to match precisely the definitions applied to TIPS issues.

Inflation swaps are quoted in terms of the constant rate on the contract's fixed leg. The traded maturities are 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20, 25, and 30 years for all countries in this study. Longer swap maturities are not included in this study since trading activity at the maturities exceeding 30 years is limited. In order to implement the arbitrage strategy described in the next section, swap rates for intermediate maturities are needed. These are obtained by cubic spline interpolation. For maturities that include fractional years (e.g. 2.3 years), seasonal patterns in inflation must be taken into account. To do this, first seasonal weightings for the CPI-U for each month of the year are estimated

[29]For more details see Kerkhof (2005), Jarrow and Yildirim (2003) and Hinnerich (2008), and Pond and Mirani (2011).

by regressing the CPI-U index values for each country for the period January 1980 to August 2011 on monthly indicator variables. The estimated seasonal weights are normalized to ensure than there is no seasonal effect for full-year swaps and then used to adjust the interpolated inflation swap curve. The algorithm is exactly the same for all countries in the sample. The details about the algorithm used to compute the seasonally-adjusted inflation swap curves are provided in the Appendix.

Analogous to inflation-linked bonds, the reference index on the inflation swap is subject to a lag. However, the lagging mechanism may differ from that used in the bond market. For standard U.S. CPI, FRCPIx (French CPI ex-tobacco), Canadian CACPI swaps, the inflation index reference value is determined on the same three-month lag and interpolated principle as in their corresponding bond markets. For standard U.K. RPI and Euro HICPx swaps, the lagging mechanisms are notably different from the corresponding inflation linked bond markets: the reference index for the inflation swaps are not interpolated, with a two-month lag in the U.K. and three months for Euro HICPx swaps. Consequently, a Euro HICPx swap traded on any given day of a particular month is indexed to the same starting reference value published three months prior.

These differences must be taken into account when the interpolated inflation swap curve is used to match coupon payments on indexed bonds. For any given maturity date, Euro-Zone inflation swaps reference the HICPx value three months prior to that date. The corresponding reference index value for Euro-Zone inflation-indexed bonds is interpolated between the HICPx index values two and three months prior to that date. Hence, the inflation swap rate corresponding to a coupon payment at any date is obtained by applying exactly the same interpolation mechanism as for index-linked bonds to the inflation swap rates associated with the time of the coupon payment and the inflation swap rate for one month prior to that date. In the United Kingdom, there is an additional six month lag between the inflation swap and the eight-month index-linked gilts. Hence, the swap rate associated with a coupon payment at any date is the inflation swap rate six months prior to the coupon payment date. For index-linked gilts using the Canadian model there is an additional one month lag to the inflation swap. Hence, the swap rate associated with a coupon payment at any date is the inflation swap rate one month prior to that date. The interpolation is applied in exactly the same way as for European HICPx swaps.

C Measuring TIPSTreasury Mispricing

This section describes how the size of the ILB mispricing is computed. The algorithm is exactly the same for all countries in the sample. The adjustments to the inflation swap rates to account for differences in the indexation mechanism between inflation swaps and inflation-linked bonds are as discussed in section 3.1.

Without loss of generality, consider the United States. In addition to the pricing data for TIPS, Treasury bonds, and STRIPS issues, I also download daily closing prices of inflation swaps with maturities of 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 12, 15, 20, 25 and 30 years for the period from July 23, 2004 to November 19, 2009 from the Bloomberg terminal. Inflation swaps are identified on the Bloomberg system by the ticker USSWITn, where n denotes the maturity of the swap. For a few of these swaps, inflation swap data are missing for several days. In these cases, I replace missing data points by the last available observation.

To implement the arbitrage strategy, the notional amount of each inflation swap is set to match the corresponding semiannual coupon payment (before inflation adjustment) on the TIPS issue which is designated s. At date t, the inflation swap pays a cash flow of $s\left(1+f_t\right)^t - sI_t$, where I_t is the indexed leg and f_t is the fixed inflation swap rate for maturity t.

Implementing the arbitrage strategy requires interpolating the quoted inflation swap rates for all maturities ranging from 0 to 30 years. Furthermore, seasonal patterns in inflation must be taken into account for swap maturities that include fractional years (e.g. 2.3 years). To interpolate the inflation swap rate curve, I first fit a standard cubic spline through the quoted maturities using a grid size of one month. Let the interpolated swap rates be denoted by $f_{i,j},\ i = 1, 2, \ldots, 30,\ j = 1, 2, \ldots, 12$, where the first index refers to the year and the second to the month.

I then estimate seasonal components in inflation from the monthly non-season-ally adjusted U.S. CPI index (CPI-U NSA) series between January 1980 and October 2009 by estimating an OLS regression of monthly log changes in the CPI index on month dummies. More specifically,

$$\Delta CPI_t \equiv \log\left(\frac{CPI_t}{CPI_{t-1}}\right) = \sum_{i=1}^{12} \beta_i\ d_i\ +\ \varepsilon_i, \tag{A1}$$

where t is measured in months. The month dummies d_i, $i = 1, 2, \ldots, 12$ are defined as

$$d_i = \begin{cases} 1, & \text{for month } i, \\ 0, & \text{otherwise.} \end{cases} \tag{A2}$$

and d_1 =January, d_2 =February, ... , d_{12} =December. I obtain an estimate of the seasonal effect in month i by subtracting the average of the coefficients $\bar{\beta} = \frac{1}{12}\sum \hat{\beta}_i$ from the estimated coefficients $\hat{\beta}_i,\ i = 1, 2, \ldots, 12$. Let this estimate be denoted by $\hat{b}_i = \hat{\beta}_i - \bar{\beta},\ i = 1, 2, \ldots, 12$.

Next, I construct monthly forward rates $H_{i,j},\ i = 1, 2, \ldots, 30,\ j = 1, 2, \ldots, 12$ from the interpolated swap rates $f_{i,j}$. Then, I normalize the seasonal factors $\hat{b}_i$ so that their product is unity. Let the normalized monthly adjustment factors be denoted by $\hat{m}_i,\ i = 1, 2, \ldots, 12$, where $\prod_{i=1}^{12} \hat{m}_i = 1$. I then multiply the forward rates $H_{i,j}$ by the corresponding adjustment factor $\hat{m}_j,\ j = 1, 2, \ldots, 12$ to obtain seasonally adjusted forward rates $\tilde{H}_{i,j},\ i = 1, 2, \ldots, 30,\ j = 1, 2, \ldots, 12$. By construction, there will be no seasonal effects for full-year swaps. In the last step, I obtain the seasonally adjusted inflation swap curve by converting the forward rates $\tilde{H}_{i,j}$ into inflation swap rates $\tilde{f}_{i,j},\ i = 1, 2, \ldots, 30,\ j = 1, 2, \ldots, 12$. I do not interpolate or adjust maturities smaller than one year, but use the one-year swap rate instead, because the interpolated rates are sensitive to short-term inflation assumptions in that case. I set $\tilde{f}_{0j} = f_1,\ j = 1, 2, \ldots, 12$.

With the inflation swap curve, I implement the TIPS–Treasury arbitrage strategy and compute the size of the mispricing in the following way. First, I take a position in a TIPS issue with a semi-annual coupon rate of s and maturity T for a price of V. Each period, the TIPS issue pays coupons of sI_t and makes a principal payment of $100I_T$ at maturity.

Next, I enter into an inflation swap for each coupon payment date $t = 1, 2, \ldots, T$ with notional amount of s for $t < T$ and $s + 100$ for the final principal payment at time T. Let f_t denote the fixed rate on the inflation swap for date $t = 1, 2, \ldots, T$ obtained from the interpolated inflation swap curve. At each coupon payment date t, the inflation swap pays a cash flow of $s\,(1 + f_t)^t - sI_t$ and $(s + 100)\,(1 + f_T)^T - (s + 100)\,I_T$ at maturity T. The sum of the cash flows at date t from the TIPS issue and the inflation swap is constant, since $sI_t + s\,(1 + f_t)^t - sI_t = s\,(1 + f_t)^t$. Similarly, at maturity $(s + 100)\,I_T + (s + 100)\,(1 + f_T)^T - (s + 100)\,I_T = (s + 100)\,(1 + f_T)^T$. This converts all of the indexed cash flows from the TIPS bond into fixed cash flows.

Let P and c denote the price and the semiannual coupon payment for the Treasury bond, respectively. To match the cash flows c from the Treasury bond exactly, the replicating portfolio must include a small long or short position in Treasury STRIPS for each coupon payment date t and the maturity date T, such that $s\,(1 + f_t)^t + x_t = c$ and $(s + 100)\,(1 + f_T)^T + x_T = c + 100$, where x_t denotes the notional amount of STRIPS for date $t = 1, 2, \ldots, T$. This step converts the indexed bond into a synthetic security with fixed cash flows that exactly replicate the magnitude of the cash flows from the

Treasury bond. Given the fixed cash flows and the value of the replicating portfolio, I then calculate the yield to maturity for the replicating portfolio.

In the last step, I use the yield to maturity for the replicating portfolio to determine the price of a synthetic Treasury bond with the same maturity, coupon rate, and cash flows as the matched Treasury bond. The difference between the prices of the synthetic Treasury bond and the matched Treasury bond represents the TIPS–Treasury mispricing.

The procedure is analogous for all countries in the sample.

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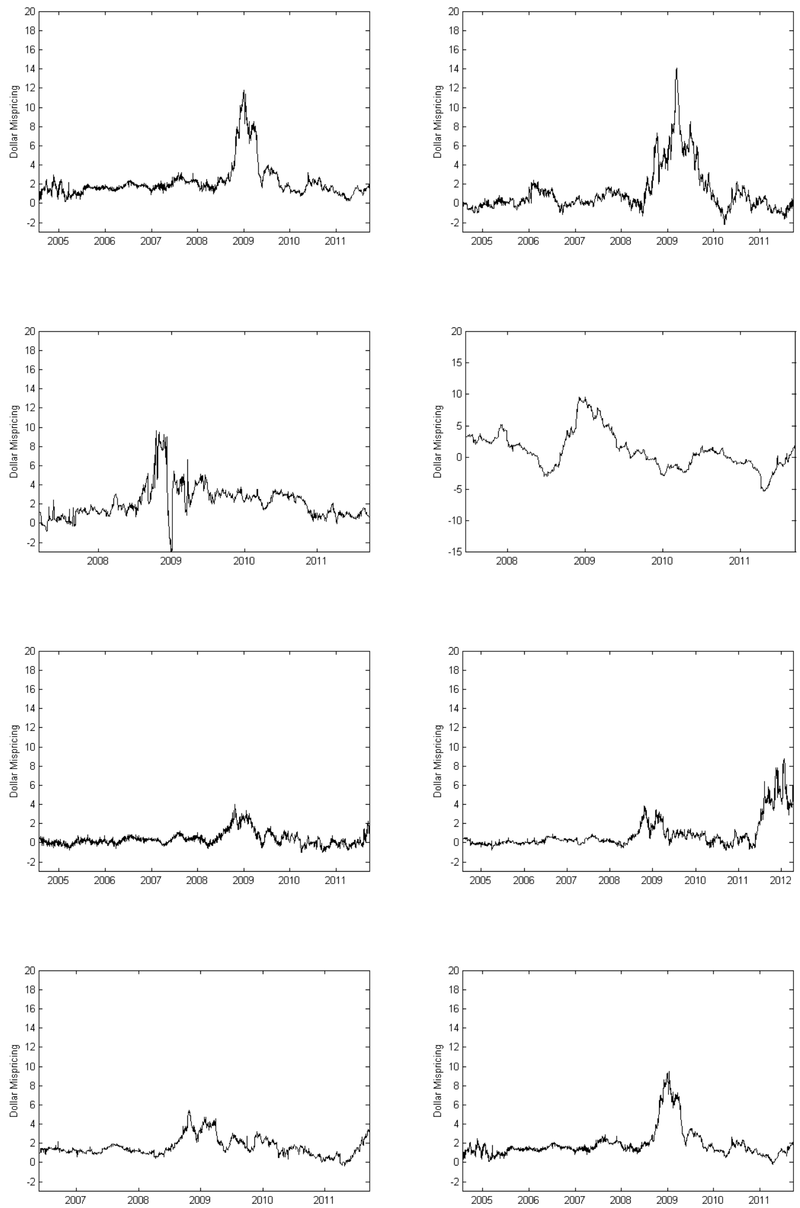


Figure 1 – ILB Mispricing. This figure plots the time series of the weighted-average nominal–index-linked bond mispricing for all countries in the study, as well as the aggregate ILB mispricing in the G7 countries. From the top-left to the bottom-right: United States, United Kingdom, Japan, Canada, France, Italy, Germany, Aggregate G7. ILB mispricing is expressed in units of dollars per $100 notional, across the pairs included in the sample, where the average is weighted by the notional amount of the index-linked issue.

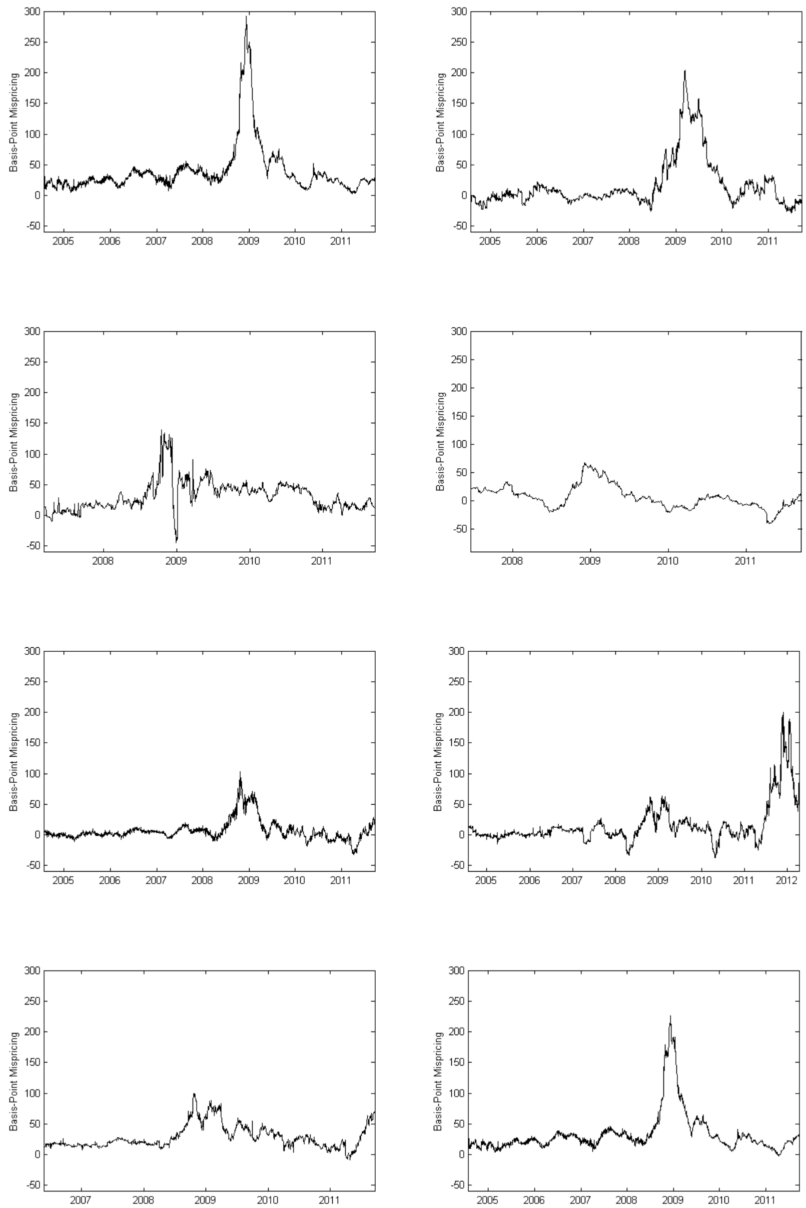


Figure 2 – ILB Basis-Point Mispricing. This figure plots the time series of the weighted-average nominal–index-linked bond mispricing for all countries in the study, as well as the aggregate ILB mispricing in the G7 countries. From the top-left to the bottom-right: United States, United Kingdom, Japan, Canada, France, Italy, Germany, Aggregate G7. ILB mispricing is expressed in basis points, across the pairs included in the sample, where the average is weighted by the notional amount of the index-linked issue.

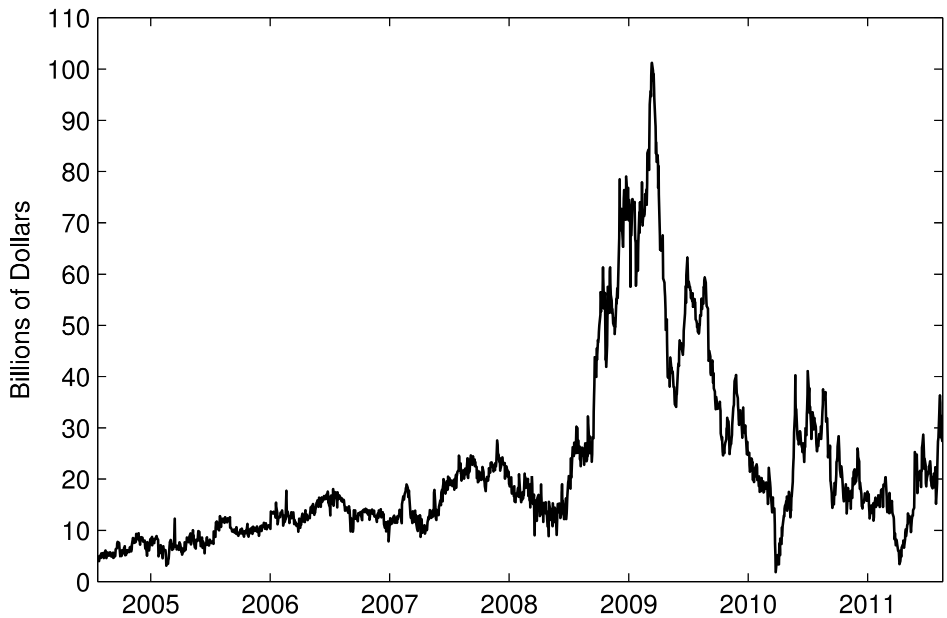


Figure 3 – Aggregate G7 ILB Mispricing. This figure plots the time series of the aggregate nominal–index-linked bond mispricing in all G7 countries, measured in billions of dollars.

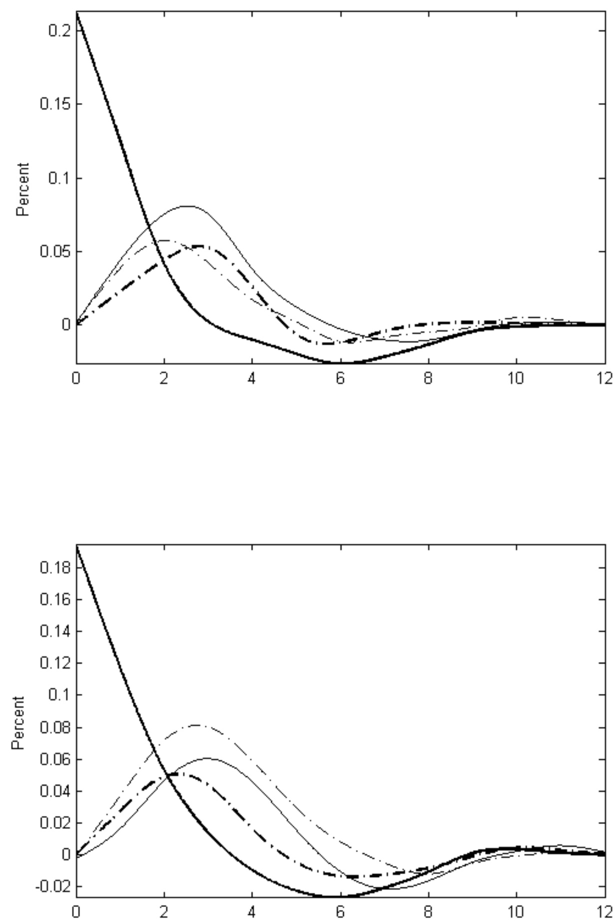
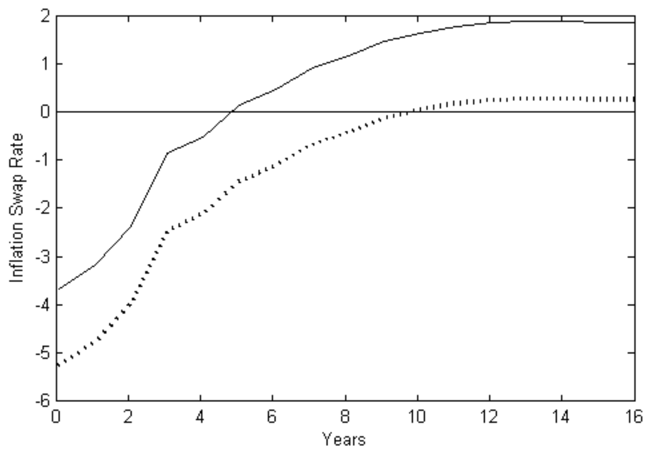


Figure 4 – Impulse Response of Nominal–Index-Linked Bond Mispricing. This figure plots the impulse response of the average nominal–index-linked bond mispricing in United States, Europe, Japan, and the United Kingdom to a one standard deviation shock to the mispricing in the United States, expressed as percent change to the base case when no shock occurs. The solid thick line represents the United States, the thick dashed line Europe, the solid thin line represents the United Kingdom, and the thin dashed line represents Japan. The top panel shows the dollar and the bottom panel the basis point mispricing.



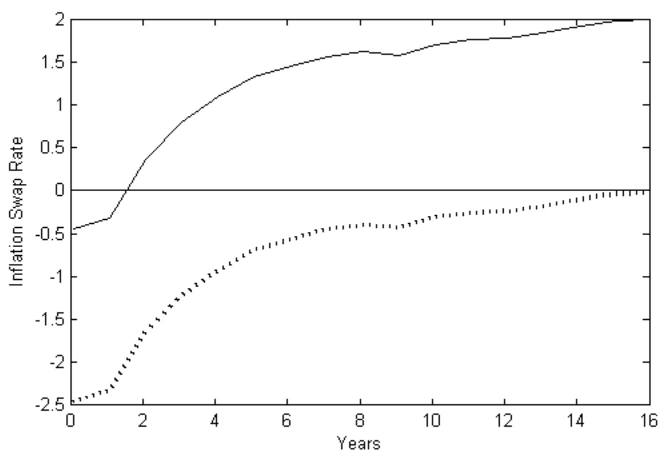


Figure 5 – **Implied Inflation Swap Curve that Reconciles ILB Mispricing.** The figure on the top panel plots the actual U.K. RPI inflation swap curve for March 17, 2009 (solid curve) and the implied inflation swap curve (dotted curve) for the same date that would reconcile the pricing of the U.K. gilt with maturity date December 27, 2027 and the corresponding index–linked gilt issue. The figure on the bottom panel plots the actual U.S. CPI inflation swap curve for December 30, 2008 (solid curve) and the implied inflation swap curve (dotted curve) for the same date that would reconcile the pricing of the Treasury bond with maturity date February 15, 2025 and the corresponding TIPS issue.

Table 1 – **Cash Flows from the Treasury Bond and the Synthetic Treasury Bond Replicating Strategy.** This table shows the cash flow generated each period from the indicated positions. P denotes the price of the Treasury bond with coupon c, V denotes the price of the TIPS bond with the same maturity date as the Treasury bond and a coupon rate of s, and $D(t)$ denotes the price of a Treasury STRIP with a maturity of t. F_t denotes the fixed payment on a zero-coupon inflation swap of maturity t (calculated as $(1+f)^t$, where f is the corresponding inflation swap rate). The inflation index I_t denotes the ratio of the CPI-U index at time t divided by the CPI-U index at time zero.

Strategy	0	1	2	3	...	T
Buy Treasury	$-P$	c	c	c	...	$c+100$
Buy TIPS	$-V$	sI_1	sI_2	sI_3	...	$(s+100)I_T$
Inflation Swap$_1$	0	$s(F_1-I_1)$	0	0	...	0
Inflation Swap$_2$	0	0	$s(F_2-I_2)$	0	...	0
Inflation Swap$_3$	0	0	0	$s(F_3-I_3)$	...	0
⋮	⋮	⋮	⋮	⋮		⋮
Inflation Swap$_T$	0	0	0	0	...	$(s+100)(F_T-I_T)$
STRIPS$_1$	$(c-sF_1)D(1)$	$c-sF_1$	0	0	...	0
STRIPS$_2$	$(c-sF_2)D(2)$	0	$c-sF_2$	0	...	0
STRIPS$_3$	$(c-sF_3)D(3)$	0	0	$c-sF_3$	...	0
⋮	⋮	⋮	⋮	⋮		⋮
STRIPS$_T$	$(c+100)D(T)-$ $(s+100)F_TD(T)$	0	0	0	...	$(c+100)-$ $(s+100)F_T$
Total Cash Flow	$\sum_{i=1}^{T}(c-sF_i)D(i)+$ $100(1-F_T)D(T)-V$	c	c	c	...	$c+100$

Table 2 – **G7 Inflation-Indexed Bond Markets.** This table presents an overview of the inflation–linked bond markets in the G7 countries: Canada (CAN), France (FRA), Germany (GER), Italy (ITA), Japan (JPN), the United Kingdom (GBR), and the United States (USA). "Prc.Tot.Mrkt.Debt" denotes the ratio of ILB notional outstanding to total marketable debt for each country. All data is as of the September 2011.

	USA	GBR	FRA	GER	ITA	CAN	JPN
Inception	Jan 97	Mar 81	Sep 98	Mar 06	Sep 03	Dec 91	Mar 04
Index	CPI-U NSA	UK RPI	EUR HICPX	EUR HICPX	EUR HICPX	CPI NSA	JPN CPI
No. Bonds Outstanding	28	16	10	3	7	5	16
Notional Outstanding	$563.235b	$341.074b	$218.692b	$43.239b	$131.650	$43.474b	$69.012
Prc.Tot.Mrkt.Debt	7.3%	22.3%	22%	3.52%	6.8%	5.3%	1.62%
Indexation Lag (months)	2–3	8 or 2–3	2–3	2–3	2–3	2–3	2–3*
Floor	Par Floor	No Floor	Par Floor	Par Floor	Par Floor	No Floor	no Floor
Coupon Frequency	Semi-Annual	Semi-Annual	Annual	Annual	Semi-Annual	Semi-Annual	Semi-Annual

Table 3 – Summary Statistics for Indexed-Bond–Nominal Bond Mispricing.
This table reports summary statistics for the indexed-bond–nominal bond mispricing for all G7 countries separately, and in aggregate. The left panel reports summary statistics for the mispricing measured in dollars per $100 notional, and the right panel for the mispricing measured in basis points. The mispricing in each country is the weighted-average index-linked–nominal bond mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked bond issue. The basis-point mispricing for each country is the weighted-average index-linked–nominal Bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked bond issue.

	Dollar Mispricing				Basis-Point Mispricing				
Country	Mean	SDev	Min	Max	Mean	SDev	Min	Max	N
United States	2.23	1.79	0.18	11.77	39.81	42.36	2.31	292.72	1868
United Kingdom	1.14	2.36	−2.17	14.09	16.36	40.51	−29.24	203.66	1868
Japan	2.16	1.73	−3.24	9.63	31.46	24.67	−44.33	139.64	1187
Canada	1.02	2.95	−5.27	9.60	7.23	20.42	−39.35	67.99	1114
France	0.40	0.73	−1.04	4.01	6.87	17.23	−32.06	103.46	1868
Italy	0.56	0.96	−0.77	6.43	8.77	18.48	−37.35	114.24	1868
Germany	1.62	0.97	−0.37	5.41	28.13	22.03	−8.39	99.80	1392
G7	1.93	1.56	0.02	9.46	33.54	34.48	2.72	101.24	1868
June 2007 – September 2011									
United States	2.68	2.19	0.24	11.77	50.17	51.87	2.31	292.72	1114
United Kingdom	1.77	2.83	−2.17	16.22	28.18	48.53	−29.24	203.66	1114
Japan	2.28	1.71	−3.24	9.63	33.24	24.36	−44.33	139.64	1114
Canada	1.02	2.95	−5.27	9.60	7.23	20.42	−39.35	67.99	1114
France	0.58	0.87	−1.04	4.01	10.34	21.38	−32.06	103.46	1114
Italy	0.86	1.12	−0.77	6.43	13.05	10.32	−37.35	114.24	1114
Germany	1.71	1.12	−0.37	5.41	31.28	19.90	−8.39	99.80	1114
G7	2.08	1.86	0.02	9.46	31.72	39.19	2.91	101.24	1114
May 2006 – September 2011									
United States	2.51	1.99	0.24	11.77	46.42	47.16	2.31	292.72	1392
United Kingdom	1.45	2.62	−2.17	16.22	22.04	45.18	−29.24	203.66	1392
France	0.52	0.80	−1.04	4.01	9.10	19.38	−32.06	103.46	1392
Italy	0.75	1.03	−0.77	6.43	11.50	20.56	−37.35	114.24	1392
Germany	1.62	0.97	−0.37	5.41	28.13	22.03	−8.39	99.80	1392
G7	1.98	1.76	0.02	9.46	36.78	37.09	2.91	101.24	1392

Table 4 – **Results from the Forecasting Regression of Monthly Changes in Average BPS Mispricing on Lagged ILB Mispricing.** This table reports summary statistics for the regression of monthly changes in average basis-point ILB mispricing in each country on one-month lagged changes in average basis-point ILB mispricing in the other G7 countries. The basis-point mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. The explanatory variables correspond to the rows in the table. For each country, the left column shows the regression coefficient associated with the explanatory variable in that row, and the right column shows the corresponding Newey-West t-Statistic. The superscript ** denotes significance at the five-percent level; the superscript * denotes significance at the ten-percent level. The sample period is from June 14, 2007 to September 20, 2011.

	Canada		**France**		**Germany**		**Italy**		**Japan**		**UK**		**USA**	
	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat
Intercept	0.11	0.12	0.21	0.22	0.15	0.36	0.18	0.14	0.12	1.02	0.13	0.81	0.17	0.19
Canada	–	–	0.11	0.87	0.01	1.11	0.04	0.66	0.14	0.73	0.38	1.44	0.22	0.98
France	0.21	0.22	–	–	0.97	2.36^{**}	1.02	2.23^{**}	0.38	1.23	0.69	1.61^{*}	0.63	1.43
Germany	0.29	1.54	0.98	2.36^{**}	–	–	0.92	2.56^{**}	0.46	1.59^{*}	0.81	1.78^{*}	0.79	1.69^{**}
Italy	0.14	1.23	0.85	1.99^{**}	0.84	2.13^{**}	–	–	0.12	1.11	0.52	1.39	0.61	1.23
Japan	0.81	1.58^{*}	0.29	1.51	0.09	1.42	0.11	1.34	–	–	0.61	1.67^{*}	0.85	1.82^{*}
UK	0.97	1.78^{*}	0.77	1.65^{*}	0.78	1.81^{*}	0.72	1.89^{*}	0.84	1.76^{*}	–	–	0.91	2.01^{**}
USA	1.23	2.89^{**}	1.01	2.25^{**}	0.94	2.46^{**}	0.97	2.17^{**}	1.09	1.99^{**}	1.11	2.19^{**}	–	–
Adj. R^2	0.69		0.62		0.57		0.60		0.52		0.55		0.48	
N	51		51		51		51		51		51		51	

Table 5 – Results from the Forecasting Regression of Monthly Changes in Average BPS Mispricing on Lagged Stock, Bond, and Hedge Fund Returns. This table reports summary statistics for the regression of monthly changes in average basis-point ILB mispricing of each country on the indicated lagged stock, bond, and volatility index returns. Stock denotes the return on the MSCI Index for that specific country in the previous month. Bond denotes the return on the Bloomberg EFFA government bond index with maturity exceeding two years in the previous month. Hedge Fund denotes the return on Bloomberg BAIF Government and Corporate Bonds Hedge Fund Index in that specific country in the previous month. All member funds for each of the seven country indexes are incorporated in that specific country. Vola denotes the return on the JP Morgan G7 Volatility Index in the previous month. The basis-point mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. For each country, the left column shows the regression coefficient, and the right column shows the Newey-West t-Statistic. The superscript ** denotes significance at the five-percent level; the superscript * denotes significance at the ten-percent level. The sample period is from June 14, 2007 to September 20, 2011.

	Canada		**France**		**Germany**		**Italy**		**Japan**		**UK**		**USA**	
	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat
Intercept	0.63	−1.43	0.42	1.07	0.56	1.28	0.88	1.51	0.49	1.16	0.82	1.59	0.91	1.61
Stock	−1.51	-1.72^{*}	−2.07	-1.81^{*}	−2.46	-2.52^{**}	−2.61	-2.86^{**}	−2.11	-1.94^{*}	−2.81	-2.91^{**}	−2.33	-2.71^{**}
Bond	−3.67	-1.64^{*}	−3.88	-1.99^{**}	−4.22	-2.55^{**}	−3.71	-1.97^{**}	−3.11	-1.91^{*}	−4.49	-3.01^{**}	−4.39	-2.89^{**}
Hedge Fund	0.34	1.04	−3.29	-2.02^{**}	−3.58	-3.19^{**}	−2.19	−1.52	−2.88	-3.09^{**}	−3.68	-3.52^{**}	−3.41	-3.19^{**}
Vola	1.26	1.51	1.89	1.88^{*}	1.99	1.89^{*}	1.41	1.54	2.36	1.61^{*}	2.16	1.53	2.68	2.21^{**}
Adj. R^2	0.376		0.451		0.413		0.397		0.448		0.468		0.492	
N	51		86		64		86		54		86		86	

Table 6 – **Results from the Forecasting Regression of Monthly Changes in Average BPS Mispricing on Lagged HFRX Index Returns.** This table reports summary statistics for the regression of monthly changes in the basis-point mispricing on one-month lagged monthly returns of the HFRX Hedge Fund Indices. MCR denotes the HFRX Macro Strategy Index, EH the HFRX Equity Hedge Index, EDr the HFRX Event Driven, and RV the HFRX Relative Value index. Int denotes the regression intercept. G7 denotes the notional–weighted mispricing index constructed from all countries in the study. The dollar mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. The basis-point mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. For each country, the left column shows the regression coefficient, and the right column shows the Newey-West t-Statistic. The superscript ** denotes significance at the five-percent level; the superscript * denotes significance at the ten-percent level. The sample period is from July 23, 2004 to September 20, 2011.

	Canada		**France**		**Germany**		**Italy**		**Japan**		**UK**		**USA**		**G7**	
	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat
Int	−1.18	−0.53	0.28	0.36	0.59	0.70	1.04	0.83	−0.36	-0.19	0.35	0.24	1.06	0.57	0.56	0.46
MCR	−1.24	−1.75*	−1.06	−1.93*	−0.94	−1.71*	−1.61	−2.15**	−1.18	−1.92*	−0.98	−1.93*	−1.15	−2.63**	−1.09	−2.02**
EH	−0.15	−0.84	−0.53	−0.54	−0.24	−1.60	−0.88	−1.04	−0.95	−0.51	−0.75	−0.49	−0.94	−0.83	−0.88	−0.79
EDr	0.08	0.70	−0.15	−0.39	0.03	0.11	−0.54	−0.87	0.44	0.66	0.05	0.99	−0.78	−0.85	−0.46	−1.09
RV	−1.92	−1.99**	−1.79	−2.09**	−1.64	−2.17**	−2.13	−2.71**	−2.13	−1.97**	−2.85	−2.51**	−3.73	−2.72**	−3.02	−3.26**
Adj. R^2	0.356		0.432		0.394		0.381		0.424		0.457		0.471		0.428	
N	52		86		65		86		55		86		86		86	

Table 7 – Results from the Forecasting Regression of Monthly Changes in Average BPS Mispricing on Lagged Substrategy Index Returns of the HFRX Relative Value Index. This table reports summary statistics for the regression of monthly changes in the average basis-point mispricing on one-month lagged monthly returns on the substrategy indices of the HFRX Relative Value Hedge Fund Index. Conv. denotes the HFRX Fixed-Income Convertible Arbitrage Index, Vola denotes the HFRX Volatility Strategies Index, M.Str. denotes the HFRX Multi-Strategy Index, Corp. denotes the HFRX Fixed Income Corporate Index, AB denotes the HFRX Fixed Income Asset Backed Securities Index, Sov. denotes the HFRX Fixed Income Sovereign Index, RE denotes the HFRX Real Estate Index, A.Yld. denotes the HFRX Fixed Income Alternative Yield Index, and Enrgy denotes the HFRX Energy Index. G7 denotes the notional–weighted mispricing index constructed from all countries in the study. The dollar mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. The basis-point mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. For each country, the left column shows the regression coefficient, and the right column shows the Newey-West t-Statistic. The superscript ** denotes significance at the five-percent level; the superscript * denotes significance at the ten-percent level. The sample period is from July 23, 2004 to September 20, 2011.

	Canada		**France**		**Germany**		**Italy**		**Japan**		**UK**		**USA**		**G7**	
	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat
Int.	0.40	0.85	−0.61	−0.23	−0.59	−0.35	0.51	1.36	−0.57	−0.24	−0.77	−0.16	0.39	−0.26	0.03	0.17
Conv.	−2.07	−2.37**	−1.01	−1.75*	−0.83	−1.84*	−2.13	−3.06**	−1.71	−1.98**	−1.95	−2.63**	−2.83	−3.05**	−2.11	−2.65**
Vola	−1.60	−2.04**	−1.91	−1.97**	−1.79	−1.91*	−1.82	−2.02**	−1.85	−1.81*	−1.96	−2.04**	−1.77	−2.19**	−1.83	−1.98**
M.Str.	−0.79	−0.46	−0.82	−0.33	−0.68	−0.40	−0.72	−0.81	−1.31	−0.86	−1.02	−0.64	−0.98	−0.74	−0.94	−1.60
Corp.	0.30	0.67	0.26	0.56	0.12	0.67	0.27	0.58	0.17	0.71	−0.90	0.64	0.39	0.74	0.26	0.88
AB	0.09	0.57	0.13	0.97	0.18	0.88	0.11	0.97	0.22	1.11	0.08	0.44	0.14	0.61	0.13	0.58
Sov.	−2.74	−3.03**	−1.91	−2.52**	−1.80	−2.77**	−2.86	−3.20**	−2.73	−2.02**	−2.79	−3.09**	−2.99	−3.22**	−2.89	−3.11**
RE	−0.31	−0.38	−0.90	−0.41	−0.56	−0.59	−0.75	−0.69	−0.31	−0.66	−0.57	−0.77	−0.47	−0.51	−0.50	−0.76
A.Yld.	−1.79	−1.75*	−1.36	−1.79*	−1.57	−1.82*	−1.49	−1.94*	−1.52	−1.72*	−1.59	−1.70*	−1.63	−1.80*	−1.58	−1.75*
Enrgy	0.18	0.97	0.29	1.01	0.11	0.88	−0.46	−0.86	0.43	0.65	0.42	0.53	−0.51	−0.71	0.47	0.52
Adj. R^2	0.345		0.423		0.381		0.372		0.414		0.445		0.461		0.409	
N	52		86		65		86		55		86		86		86	

Table 8 – **Results from the Forecasting Regression of Monthly Changes in Average ILB Mispricing on Lagged Percentage Changes in HFRX Total Hedge Fund Assets.** This table reports summary statistics for the regression of monthly changes in ILB Mispricing on one-month lagged percentage changes in total Hedge Fund assets of the HFRX reference hedge fund indices. MCR denotes the HFRX Macro Strategy Index, EH the HFRX Equity Hedge Index, EDr the HFRX Event Driven, and RV the HFRX Relative Value index. Int denotes the regression intercept. The first row for each regressor presents results for the basis-point mispricing, and the second row for the mispricing per $100 notional. G7 denotes the notional–weighted mispricing index constructed from all countries in the study. The dollar mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. The basis-point mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. For each country, the left column shows the regression coefficient, and the right column shows the Newey-West t-Statistic. The superscript ** denotes significance at the five-percent level; the superscript * denotes significance at the ten-percent level. The sample period is from July 23, 2004 to September 20, 2011.

	Canada		**France**		**Germany**		**Italy**		**Japan**		**UK**		**USA**	
	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat
Int	−0.640	−0.223	0.676	0.236	0.694	0.243	−0.605	−0.211	0.626	0.218	0.648	0.226	0.726	0.253
	−0.073	−0.325	0.078	0.343	0.080	0.352	−0.069	−0.307	0.072	0.317	0.074	0.328	0.083	0.368
EQ	0.016	1.333	0.014	1.195	0.011	0.907	0.017	1.387	0.018	1.493	0.012	0.800	0.016	1.355
	0.006	1.470	0.005	1.317	0.004	0.998	0.006	1.529	0.007	1.646	0.003	0.882	0.006	1.493
EDr	−0.103	−1.527	−0.093	−1.416	−0.057	−0.878	−0.092	−1.049	−0.084	−1.332	−0.074	−1.055	−0.108	−1.404
	−0.013	−1.474	−0.017	−1.327	−0.072	−0.893	−0.006	−0.982	−0.011	−1.256	−0.008	−0.994	−0.030	−1.447
MCR	−7.732	−1.549*	−8.339	−1.604*	−9.805	−1.804**	−9.013	−1.808*	−10.736	−2.156**	−8.765	−1.755*	−7.904	−1.554
	−0.333	−1.704*	−0.351	−1.842*	−0.426	−2.187**	−0.387	−1.940*	−0.465	−2.374**	−0.366	−1.935*	−0.337	−1.715*
RV	−8.179	−1.678*	−19.846	−4.569**	−21.629	−4.916**	−16.687	−3.790**	−20.758	−4.711**	−22.580	−5.121**	−21.264	−4.837**
	−0.234	−1.797	−1.007	−6.598**	−1.101	−7.196**	−0.850	−5.533**	−1.056	−6.897**	−1.144	−7.494**	−1.081	−7.076**
Adj. R^2	0.321		0.441		0.481		0.381		0.415		0.519		0.478	
	0.313		0.430		0.469		0.371		0.411		0.489		0.469	
N	52		86		65		86		55		86		86	

Table 9 – Results from the Regression of Changes in BPS Mispricing on Monetary Policy Announcements. The table reports summary statistics for the regression of changes in the ILB mispricing on indicator variables representing monetary policy announcements by central banks using daily data. These announcements reflect quantitative easing programs by central banks such as purchases of government bonds, changes in interest rates, and the establishment of liquidity facilities. Europe comprises France, Germany, and Italy. For each regressor, the first row presents results for the dollar mispricing (labeled USD), the second row for the basis-point mispricing (labeled BPS). The dollar mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. The basis-point mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. For each country/ region, the left column shows the regression coefficient, and the right column shows the Newey-West t-Statistic. The superscript ** denotes significance at the five-percent level; the superscript * denotes significance at the ten-percent level. The two rows for each R^2 statistic correspond to the dollar and basis-point mispricing, respectively. The sample period is from July 23, 2004 to September 20, 2011.

	Canada		**Europe**		**Japan**		**UK**		**USA**	
	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat
USD	0.493	1.252	0.761	2.361**	−0.895	1.591*	1.098	2.803**	0.947	3.077**
BPS	9.892	1.343	17.032	2.216**	−12.588	1.627*	18.716	2.951**	21.016	3.091**
Adj. R^2	0.1193		0.2864		0.3087		0.2912		0.3205	
	0.1250		0.2981		0.3206		0.3010		0.3379	
N	1114		1868		1187		1868		1868	

Table 10 – **Results from the Regression of Daily Changes in 10-year Breakeven Rates on Changes in Basis-Point Mispricing.** This table reports summary statistics for the regression of daily changes in ten-year breakeven inflation rates on changes in ILB mispricing measured in basis-points for all G7 countries using daily data. The basis-point mispricing index for each country is constructed as the weighted-average index-linked–nominal Bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. For each country, the left column shows the regression coefficient, and the right column shows the Newey-West t-Statistic. The superscript ** denotes significance at the five-percent level; the superscript * denotes significance at the ten-percent level. The sample period is from July 23, 2004 to September 20, 2011.

	Canada		**France**		**Germany**		**Italy**		**Japan**		**UK**		**USA**	
	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat
	−0.761	−22.94**	−0.465	−21.59**	−0.283	−20.08**	−0.246	−18.63**	−0.271	−21.28**	−0.189	−25.12**	−0.885	−26.76**
Adj. R^2	0.6285		0.6519		0.686		0.6047		0.6582		0.7013		0.7107	
N	1114		1868		1392		1392		1187		1868		1868	

Table 11 – **ILB Arbitrage Strategy Returns.** This table reports summary statistics for the monthly percentage excess returns on the ILB arbitrage strategy for all G7 countries. Each day during the sample, the arbitrage trade is implemented if ILB mispricing is positive and the trade is unwound after a one-month holding period. The returns on the ILB arbitrage strategy are calculated from the average monthly mispricing in dollar terms. The dollar mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. SDev denotes the standard deviation of the monthly returns, ρ denotes the serial correlation of the monthly returns, and SR represents the annualized Sharpe Ratio. RN is the proportion of negative excess returns. Gain/loss is the Bernardo and Ledoit (2000) gain/loss ratio for the strategy. The sample period is from July 23, 2004 to September 20, 2011.

	Canada	**France**	**Germany**	**Italy**	**Japan**	**UK**	**USA**
Mean	0.501	0.486	0.524	0.437	0.519	0.523	0.558
SDev	3.875	2.987	3.121	3.013	3.645	2.998	2.571
Min	−8.878	−6.365	−8.307	−9.223	−5.667	−6.994	−7.264
Max	9.011	10.557	11.464	14.571	11.329	11.965	12.678
Skewness	0.569	1.112	0.984	2.156	1.112	1.548	1.995
Kurtosis	4.552	3.172	4.036	4.953	6.269	8.451	7.778
RN	0.301	0.337	0.281	0.401	0.347	0.346	0.327
ρ	−0.059	−0.088	−0.121	−0.158	−0.084	−0.108	−0.112
Gain/Loss	1.887	1.645	2.102	2.525	1.798	2.257	2.336
SR	0.448	0.564	0.582	0.502	0.493	0.604	0.752
N	1084	1838	1362	1838	1157	1838	1838

Table 12 – **ILB Arbitrage Returns Regression on Fama–French Factors.** This table reports summary statistics for the regression of monthly percentage excess ILB arbitrage returns on the Fama-French Factors denoted by SMB, HML, and WML, and on the excess return on the market, denoted by R_m. Each day during the sample, the arbitrage trade is implemented if ILB mispricing is positive and the trade is unwound after a one-month holding period. The dollar mispricing index for each country is constructed as the weighted-average Index-Linked–Nominal Bond mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. The superscript ** denotes significance at the five-percent level; the superscript * denotes significance at the ten-percent level. The sample period is from July 23, 2004 to September 20, 2011.

	Canada	**France**	**Germany**	**Italy**	**Japan**	**UK**	**USA**
Alpha	0.3761	0.5105	0.5348	0.5944	0.6038	0.6438	0.6910
t-Stat	1.4364	2.0972**	2.5608**	2.7126**	3.1712**	2.7878**	3.5805**
				***t*-Statistics**			
R_m	-1.8019	-2.4914	-2.882	-2.4752	-2.9201	-3.0876	-3.2521
SMB	1.2375	0.9114	1.0766	0.5544	1.1009	1.0868	-0.6068
HML	-0.2475	0.2156	-0.3201	0.0693	-0.0505	-0.34848	-0.0761
WML	0.1584	0.1372	0.8342	0.2079	0.2525	0.90816	0.2284
Adj. R^2	0.0564	0.0735	0.0911	0.1158	0.0979	0.0712	0.0892
N	1084	1838	1362	1838	1157	1838	1838

Table 13 – **Liquidity Factors Regression.** This table reports summary statistics for the regression of changes in the average monthly basis-point ILB mispricing on liquidity factors. NORTH AMERICA comprises the United States and Canada, EUROPE consists of the United Kingdom, France, Germany and Italy, EUROPE EX. UK represents France, Germany, and Italy. Swap Spread denotes the difference between the current ten-year Interest Rate Swap yield and the yield of the current reference ten-year Bond Future. Swap Rate denotes the current ten-year interest rate swap rate for a period ending at the maturity of the bond underlying the next-expiring ten-year Bond future. Vola denotes the index of implied volatilities on index options (VIX in the United States). Swaption denotes a one-year straddle on ten-year interest rate swaps with the strike price reset to the current at-the-money swap rate at the beginning of every roll period. CDX index denotes the current five-year CDX index by Markit. The dollar mispricing index for each country is constructed as the weighted-average index-linked–nominal bond mispricing, expressed in units of dollars per $100 notional, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. The basis-point mispricing index for each country is constructed as the weighted-average Index-Linked–Nominal Bond mispricing, expressed in basis points, across the pairs included in the sample for that country, where the average is weighted by the notional amount of the index-linked issue. For each country/ region, the left column shows the regression coefficient, and the right column shows the Newey-West t-Statistic. The superscript ** denotes significance at the five-percent level; the superscript * denotes significance at the ten-percent level. The sample period is from July 23, 2004 to September 20, 2011.

	USA		**Europe**		**Europe w/o UK**		**Japan**		**UK**	
	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat	Coeff.	t-Stat
Intercept	3.592	1.099	1.077	1.350	−0.248	−0.338	−0.097	−0.068	−0.317	−0.187
Swap Spread	0.356	1.104	0.221	1.024	0.293	1.143	0.372	1.015	0.362	1.234
Swap Rate	1.385	1.691*	1.433	1.736*	1.747	1.709*	1.936	1.563	1.481	1.802*
Vola	0.004	1.983**	0.005	2.086**	0.007	1.986**	0.008	2.315**	0.006	2.189**
Swaption	0.085	1.927*	0.076	1.993**	0.077	1.947*	0.129	1.918*	0.065	2.039**
CDX	0.249	1.001	0.162	0.232	0.168	1.276	0.268	0.822	0.195	0.678
Adj. R^2	0.140		0.171		0.281		0.326		0.150	
N	87		87		87		55		87	