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On the Reliability of Japanese Inflation Expectations Using Purchasing Power Parity

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ON THE RELIABILITY OF JAPANESE INFLATION EXPECTATIONS USING PURCHASING POWER PARITY

Koichiro Kamada† and Jouchi Nakajima‡

Abstract

This paper shows how purchasing power parity (PPP) can be used to construct a measure for inflation expectations and discusses the properties of this measure from both a theoretical and an empirical perspective. Under the PPP hypothesis, inflation expectations in one country are equal to inflation expectations in another country plus the expected depreciation rate of the nominal exchange rate. Exploiting this formula, we calculate Japanese inflation expectations from the break-even inflation rates (BEI) and FX forward spreads for five countries (United States, United Kingdom, Australia, Canada, and Sweden). The resulting PPP-based measure of inflation expectations follows a trend that largely coincides with long-run developments in the Japanese BEI. However, we find that both levels of and variations in the new measure differ across the reference countries, and that a recent gap between the new measure and the Japanese BEI is not negligible from a short-run perspective. Consequently, there remain several issues that need to be addressed to assess the usefulness of this new formula.

Keywords: BEI; Foreign exchange forward spread; Inflation expectations; Inflation-indexed bonds; PPP

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I. Introduction

Since the Bank of Japan (BOJ) introduced the price stability target of 2 percent in early 2013, Japanese inflation expectations have attracted much attention in international financial markets. A variety of indicators are typically used to gauge policy effects on inflation expectations in Japan (Figure 1), such as indicators based on surveys of bond traders, households, and enterprises, as well as market-based indicators such as the break-even inflation rate (BEI). The latter is a commonly used measure of market participants' inflation expectations that is defined as the yield spread between the nominal yield on a fixed-rate bond and an inflation-indexed bond (IIB). Generally, the market-based indicators tend to immediately react to headline news. As can be seen in the figure, the BEI seems to have been following an accelerating upward trend in response to the BOJ's recent policy change.

However, in addition to inflation expectations, the BEI contains various distorting factors: that is, the BEI is equal to inflation expectations plus an inflation risk premium minus the market liquidity premium for IIBs. In the midst of the turmoil following the Lehman shock, foreign investors sold large volumes of bonds in the Japanese IIB market, which has attracted little buying since then. The response of the Japanese government was to stop issuing new IIBs and conduct a number of buyback operations. It is clear that under these circumstances, the market liquidity premium for IIBs must have been rather unstable, and it would be imprudent to claim that all the variation in the Japanese BEI is attributable to changes in inflation expectations.

To deal with this problem, Mandel and Barnes (2013) propose to make use of purchasing power parity (PPP). Under the PPP hypothesis, inflation expectations in one country are equal to inflation expectations in another country plus the expected depreciation rate of the nominal exchange rate. Exploiting this formula, we can infer Japanese inflation expectations from, for instance, the US BEI and the yen/dollar forward spread. If the inflation risk premium in the United States and the market liquidity premium for Treasury Inflation Protected Securities (TIPS)—inflation-indexed bonds issued by the US government— are stable, we can avoid the problem stemming from the instability of the IIB market liquidity premium in Japan.

The purpose of this paper is to evaluate how useful the PPP hypothesis is in measuring inflation expectations. First, we modify Mandel and Barnes's (2013) approach so that it is fully consistent with the PPP hypothesis. We call the resulting index the Foreign-BEI Implied Index (FBI). Second, we calculate FBIs from the BEIs and foreign exchange (FX) forward rates of five selected IIB-issuing countries, including the United States (US) and the United Kingdom (UK). Third, we explore what determines the gap between the FBIs and the BEI in the short run as well as in the long run.

The remainder of the paper is organized as follows. Section II theoretically examines the relationships between the FBI and the BEI. Section III calculates the FBIs from the BEIs and FX forward spreads for five selected countries. We also focus on the fact that the FBI has recently rapidly diverged from the BEI, and identify the driving forces responsible for this divergence. Section IV concludes the paper.

II. THE FBI: A PPP-BASED MEASURE OF INFLATION EXPECTATIONS

As mentioned above, while the BEI— the yield spread between the nominal yield on a fixed-rate bond and an inflation indexed bond— is widely used as a measure of market participants' inflation expectations, it contains not only inflation expectations, but also an inflation risk premium and an IIB market liquidity premium, i.e.:

$$\text{BEI} = \text{Inflation expectations} + \text{Inflation risk premium} - \text{IIB market liquidity premium.} \qquad (2\text{-}1)$$

Given that, as explained above, the IIB market liquidity premium likely has been quite unstable over the past few years, we therefore construct an alternative measure, the FBI.

II.1. Defining the FBI

To construct our alternative, PPP-based measure of inflation expectations, the FBI, we start by defining the real exchange rate as follows:

Real exchange rate ≡ Nominal exchange rate × Foreign price level / Japanese price level. (2-2)

Rearranging and expressing all terms as expectations yields:

Japanese inflation expectations
≡ Foreign inflation expectations + Expected change of nominal exchange rate
– Expected change of real exchange rate. (2-3)

Under the PPP hypothesis, the expected change of the real exchange rate on the right-hand side of the above equation is equal to zero. The FBI is obtained by replacing "foreign inflation expectations" by the foreign country's BEI[1] and the "expected change of nominal exchange rate" by the forward spread of the foreign exchange rate (FX), that is:

FBI ≡ Foreign BEI + (FX forward spread / spot rate). (2-4)

Mandel and Barnes (2013) in their analysis use the BEIs of the US and the UK to examine Japanese inflation expectations. It should be noted, however, that their method of calculation is not necessarily consistent with the concept of PPP, as they define the daily change in Japanese inflation expectations as the daily change in the foreign BEI plus the daily change in the FX forward rate. In contrast, we reconstruct their formula in a way that is fully consistent with the concept of PPP to make it possible to evaluate whether PPP provides a useful approach to measuring inflation expectations.

To examine the properties of the FBI, we decompose it in the following way:

FBI = Inflation expectations – Market liquidity premium of foreign IIBs
+ Inflation risk premium of foreign country
+ Expected change of real exchange rate. (2-5)

The first term on the right-hand side of equation (2-5) indicates that the FBI is an alternative measure for Japanese inflation expectations. Notice that the market liquidity premium for Japanese IIBs and the inflation risk premium in Japan do not appear in the

[1] Instead of the BEI, we can use inflation swap rates.

equation. Instead, the market liquidity premium for foreign IIBs and the inflation risk premium in the foreign country appear as the second and third terms. In addition, the expected change in the real exchange rate appears again, implying that the precision of the FBI depends on the validity of the PPP hypothesis.

To sum up, using the FBI comes at the cost of potential problems with regard to the BEI for the foreign country and depends on the validity of the PPP hypothesis, but it has the advantage of avoiding the problems involved in using the BEI for Japan.

II.2. The relationships between the FBI and the BEI

How the FBI is related to the BEI can be easily seen by decomposing the difference between the two as follows:

FBI – BEI = Spread of IIB market liquidity premium [Japan – Foreign]
+ Spread of inflation risk premium [Foreign – Japan]
+ Expected change of real exchange rate. (2-6)

The PPP hypothesis is generally considered to hold only in the long run (see Figure 2). The consensus view in the literature (see, e.g., Rogoff 1996) is that (i) the nominal exchange rate returns to its PPP level in the long run, and that (ii) the half-life of deviations from PPP— i.e., the time it takes for deviations from PPP due to a shock to halve in size— lies in a range of three to five years. In other words, the PPP hypothesis is unlikely to hold in the short run, which possibly explains the recent large FBI-BEI gap shown in Section III.2.[2]

If the PPP hypothesis holds, we can ignore the term for the expected change in

[2] We can estimate the expected change of the real exchange rate by assuming that the current real exchange rate reverts to its historical equilibrium level, instead of assuming it to be zero. As a trial, we fitted a stationary autoregressive model to a monthly series of the yen/dollar real exchange rate and estimated the expected change of the real exchange rate over five years. However, the estimated change of the real exchange rate was so large that we could not obtain realistic inflation expectations based on equation (2-3). The time-series properties of the real exchange rate vary considerably depending on the data frequency, sample size, and events which occurred during the sample period. If we assume that the real exchange rate is explained by a random-walk process without a trend, the current real exchange rate is an unbiased estimator of the future real exchange rate, which supports the assumption that the expected change of the real exchange rate equals zero. We conducted a unit-root test for the monthly real exchange rate and found that the null of the series being a random-walk process was not rejected at the 5 percent significance level.

the real exchange rate. In this case, the FBI-BEI gap comprises two kinds of spreads between two countries: the Japan-foreign spread in IIB market liquidity premiums, and the spread in inflation risk premiums.

To identify the short-term driving forces that generate the FBI-BEI gap, we employ the following interest rate parity condition:

$$\text{FX forward spread / spot rate} \equiv \text{Spread of nominal interest rates [Japan – Foreign]} - \text{FX forward basis}, \quad (2\text{-}7)$$

where the FX forward basis is the cost difference between the following two ways of foreign fund raising. First, we can borrow foreign currency directly in the foreign money market. Second, we can borrow domestic currency in the domestic money market and convert it into the foreign currency in the FX swap market. Note that equation (2-7) is the definition of the FX forward basis. In principle, the FX forward basis would be driven to zero by arbitrage. In practice, however, the basis sometimes significantly deviates from zero. As pointed out by Baba and Packer (2009) and Goldberg et al. (2011), funding conditions in the dollar market were extremely tight during the recent financial crisis. As a result, funding euros and converting them into dollars in the swap market was more costly than funding dollar directly in the dollar funding market.

Substituting equation (2-7) into (2-6), we obtain the following relationship:

$$\text{FBI} - \text{BEI} = \text{Spread of IIB interest rates [Japan – Foreign]} + \text{FX forward basis}. \quad (2\text{-}8)$$

The FBI-BEI gap is decomposed into the Japan-foreign spread in IIB yields and the FX forward basis (Appendix B). Since these factors are all observable, we can use equation (2-8) to identify the driving forces generating the FBI-BEI gap.

Looking at equations (2-4) and (2-7), we can see why the FX forward spread is meaningful in measuring inflation expectations. Suppose that nominal interest rates perfectly reflect inflation expectations for Japan and the United States in the bond markets and that the yen/dollar forward spread perfectly reflects the Japan-US spread in nominal interest rates. When both conditions are satisfied, the forward spread is a perfect reflection of the Japan-US inflation expectations gap, so that Japanese inflation expectations can be obtained by adding US inflation expectations to the FX forward spread.[3]

III. Japanese Inflation Expectations Measured Using the FBI

IIBs are issued in many countries (see, e.g., Deacon et al. 2004). As shown in Table 1, the US IIB market (TIPS) is the largest in terms of the current market value of the outstanding stock of IIBs. The UK IIB market is the oldest, with the first IIB issued in 1981, and is about 15 times as large as the Japanese IIB market. Other major countries such as France, Italy, Australia, and Canada have also issued IIBs. Canada has issued 30-year IIBs and the average duration to maturity of these IIBs is likely to be longer than that of IIBs of other countries.

In several countries, such as the US, Australia, and Sweden, IIBs have floor protection, but this is not the case in Japan and the UK. Sweden started issuing IIBs without floor protection in 1994, but after the country experienced deflation for several months in 1998, the government began issuing IIBs with floor protection. Currently, both IIBs with and without floor protection are traded in the Swedish market. If IIBs have such protection, the BEI is higher than would otherwise be the case, namely by the option premium for the floor protection. However, the probability of deflation is negligible in most of these countries, so that we can safely ignore this option premium in the analysis below. Japanese IIBs have not provided floor protection so far, although there are plans for a new issue of IIBs in October 2013 providing floor protection. In general, the option premium tends to increase in line with the level and volatility of expected inflations, which needs to be borne in mind when we gauge the expected inflations from the BEI (Appendix C).

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[3] This implies that the “Expected change of nominal interest rate” in equation (2-3), which is required for the FBI, is preferable as a measure of inflation expectations when the “Expected change of nominal interest rate” more accurately reflects the gap of inflation expectations between two countries. As a trial analysis, we calculated the FBI index using the Blue Chip Economic Indicators survey for the nominal exchange rate forecast (end of next year) as the expected change of nominal interest rates. However, we could not obtain realistic inflation expectations, since the forecasting horizon is too short for the analysis.

III.1. Japanese inflation expectation estimates using the FBI

To measure inflation expectations for Japan, we calculate five FBIs, with the US, the UK, Australia, Canada, and Sweden as reference countries. The FBIs obtained are plotted in Figure 3. As can be seen, both the levels of and variations in the calculated FBIs differ across the reference countries, reflecting differences in the IIB market liquidity premium, the inflation risk premium, and the expected change of the real exchange rate implied by the FX forward spread. Note that recently the order of FBI levels is in line with that of the current market values in Table 1, except for the positions of the US and the UK. This suggests that the FBI is influenced by the IIB market liquidity premium. It is challenging to empirically estimate the liquidity premium and the inflation risk premium in the FBI. We leave this interesting issue as work for the future.

FBIs may be distorted by country-specific factors. To mitigate the effects of such country-specific factors in the estimation of Japanese inflation expectations, we take the weighted average of the five FBIs obtained above. Figure 4 plots the (weighted) mean of the five FBIs and the one-standard-deviation interval of the five FBIs. The five-country-average FBI has been on an upward trend since 2010 and turned positive in early 2012. Note also that the average FBI and the Japanese BEI follow similar secular trends and that for the most part the Japanese BEI falls within the one-standard-deviation interval of the average FBI (about ± 0.5 percent). Recall the discussion in Section II that the PPP hypothesis holds in the long run. If this is the case, we can conclude that the Japan-foreign spreads in the IIB market liquidity premium and the inflation risk premium are also small.

III.2. The recent divergence of the FBI from the BEI

In the short run, however, we find that the gap between the average FBI and the Japanese BEI is not negligible. Figure 5 shows daily series of the BEI for Japan and the FBI employing daily data. The figure indicates that the FBI-BEI gap was positive in 2010 and around zero in 2011 and 2012. At the beginning of 2013, this gap turned negative and declined further from January to March. While it temporarily returned to zero in April, it then turned substantially negative towards June 2013, the end of the observation period.

Below, we use the interest rate parity condition to interpret the recent short-run divergence between the FBI and the BEI for Japan. As discussed in Section II, the FBI-BEI gap can be decomposed into the contribution of IIB interest rates in Japan, those in the foreign country, and the FX forward basis. Figure 6 provides an example of such a decomposition for the gap between the FBI using the US as the reference country and the BEI for Japan and shows the contribution of each factor to the changes from the beginning of 2013. As shown in the figure, from January to March, the decline in Japanese IIB interest rates (i.e., Japanese real interest rates) increased the FBI-BEI gap in a negative direction. From April, the rise in US TIPS interest rates (i.e., US real interest rates) further increased the negative gap. In June, Japanese real interest rates started to rise, but US real interest rates increased even more, thus more than canceling out the rise in Japanese real interest rates. Market participants point out that another factor that contributed to the rise in the US TIPS interest rate is the rise in the market liquidity premium. It is imprudent to claim that the recent decline in the FBI is attributable to changes in the Japanese inflation expectations. Meanwhile, the FX forward basis has been quite stable and made only a relatively small contribution to the FBI-BEI gap during this period.

IV. Concluding Remarks

In this paper, we developed a new measure for inflation expectations in Japan, the Foreign-BEI Implied Index (FBI), which is calculated from foreign inflation expectations and the expected change of exchange rates.

We showed that, from a theoretical perspective, the FBI is subject to various distortions, such as variations in the market liquidity premium for foreign IIBs and the inflation risk premium in the foreign country. In the short run, the FBI suffers from even further noise. For instance, changes in domestic and/or foreign real interest rates affect the FX forward spread and thus the level of the FBI through interest rate parity.

Furthermore, the FBI relies on the validity of the PPP hypothesis, which needs to be borne in mind when interpreting the results.

Next, we empirically applied the newly developed measure to calculate FBIs based on five selected countries and showed that in recent years the FBIs have been following a secular upward trend, which is generally in line with the long-run developments of the BEI for Japan. The results also indicated, however, that the FBI has diverged considerably from the BEI since the beginning of 2013. Decomposing the FBI-BEI gap into the contribution of the interest rates on Japanese IIBs and on US TIPS as well as the FX forward basis, we find that it is developments in Japanese and US real interest rates that primarily account for the recent divergence between the FBI and the BEI.

Overall, our view is that there remain many issues that need to be considered with regard to the FBI. It is particularly important to develop approaches to gauge the impact of the market liquidity premium and the inflation risk premium on the BEI. This challenging task remains as work for the future.

Appendix A. Data and FBI indices

(i) Single-country-based FBI

The FBI index is defined as the sum of the foreign country's BEI and the FX forward spread divided by the spot rate. Generally speaking, for the analysis in this paper, we focus on BEIs and FX forward spreads with a maturity of 5 years. For Australia and Canada, we use BEIs with a maturity of 7 and 10 years respectively due to data limitations.

(ii) Five-country-average FBI

The five-country-average FBI is the weighted average of the FBIs based on the five countries. The weights are based on the market value of the outstanding stock of IIBs (as of June 2013, estimates provided by Barclays Capital). Specifically, the weights are as follows: US, 59 percent; UK, 34 percent; Australia, 2 percent; Canada, 4 percent; and Sweden, 2 percent. The one-standard-deviation interval in Figure 3 is based on the weighted variance of the five FBIs.

(iii) Principal-factor-based FBI

Figure 7 plots the first principal component of the daily series of the five FBIs (from the beginning of January 2010 to the end of June 2013). The mean and variance of the index are adjusted equal to those of the five-country-average FBI. Although the principal component analysis does not take account of each country's weight, the trajectory of the common-factor FBI is quite similar to the five-country-average FBI.

Appendix B. Details on the gap between the FBI and the BEI

This appendix provides details for the decomposition of the gap between the FBI and the BEI. Define i as the nominal interest rate, r as the real interest rate, Δp as inflation expectations, R as the IIB interest rate, MLP as the market liquidity premium for IIBs, and IRP as the inflation risk premium. Variables for the foreign country are denoted by an asterisk ($*$). Further, define $\mathrm{E}\Delta s_h$ as the expected change of the nominal exchange rate (that is, the FX forward spread divided by the spot rate), and $\mathrm{E}\Delta q_h$ as the expected change of the real exchange rate, where h indicates the time horizon. We have the following definitions of variables:

$$BEI = \Delta p - MLP + IRP,$$

$$\mathrm{E}\Delta s_h = \mathrm{E}\Delta q_h + \Delta p - \Delta p^*,$$

$$i = r + \Delta p + IRP,$$

$$R = i - BEI = r + MLP.$$

The definition of the FBI implies

$$\begin{aligned} FBI &= BEI^* + \mathrm{E}\Delta s_h \\ &= (\Delta p^* - MLP^* + IRP^*) + (\mathrm{E}\Delta q_h + \Delta p - \Delta p^*) \\ &= \Delta p - MLP^* + IRP^* + \mathrm{E}\Delta q_h. \end{aligned}$$

The difference between the FBI and the BEI is given by:

$$\begin{aligned} FBI - BEI &= (\Delta p - MLP^* + IRP^* + \mathrm{E}\Delta q_h) - (\Delta p - MLP + IRP) \\ &= (MLP - MLP^*) - (IRP - IRP^*) + \mathrm{E}\Delta q_h. \end{aligned}$$

This implies that the FBI-BEI gap can be decomposed into the spreads of the IIB market liquidity premium and of the inflation risk premium, as well as the expected change of the real exchange rate. Note that the PPP hypothesis implies that $\mathrm{E}\Delta q_h = 0$.

Interest rate parity condition implies

$$\mathrm{E}\Delta s_h = (i - i^*) - b,$$

where b is the FX forward basis, defined as the nominal interest rate spread between

Japan and the foreign country minus $E\Delta s_h$. This implies

$$
\begin{aligned}
E\Delta q_h &= E\Delta s_h - (\Delta p - \Delta p^*) \\
&= (i - i^*) - b - (\Delta p - \Delta p^*) \\
&= (r - r^*) + (\Delta p - \Delta p^*) + (IRP - IRP^*) - b - (\Delta p - \Delta p^*) \\
&= (r - r^*) + (IRP - IRP^*) - b.
\end{aligned}
$$

Hence,

$$
\begin{aligned}
FBI - BEI = &\ (MLP - MLP^*) - (IRP - IRP^*) \\
&+ (r - r^*) + (IRP - IRP^*) - b \\
= &\ (MLP - MLP^*) + (r - r^*) - b \\
= &\ (R - R^*) - b.
\end{aligned}
$$

Consequently, the FBI-BEI gap can be decomposed into the spread of IIB interest rates and the FX forward basis.

Appendix C. Option premium for the floor protection

The option of the floor protection in IIBs is equivalent in its property to a European put option on foreign exchange (FX) rates. Thus, the value of the floor premium can be calculated using the Black model (Black 1976).

Black model is a formula to evaluate the value of the option using the forward price as an underlying asset. The value of the FX options depends mainly on the following parameters: (1) the FX forward rate, (2) volatility of the forward rate, and (3) the strike price. To calculate the value of the floor protection in IIBs, we replace these parameters in the following way. Let the reference price index be 100 at issuance of the IIB, and its face value be 100. Then, (1) the FX forward rate is replaced by the expected reference price index at time of redemption implied by the current expected inflation; (2) the volatility of the FX forward rate is replaced by that of the expected inflation; and (3) the strike price is set at 100.

With other parameters fixed, the floor premium has the following properties: the lower the expected inflation and/or the higher the volatility of the expected inflation, the higher the premium is.

The floor premium gives the following two biases to the BEI, which needs to be borne in mind when we gauge the expected inflation from the BEI. One is an upward bias in BEI: the premium adds on to the BEI. The other is a smaller-variation bias: the premium changes inversely with inflation expectations, which results in a smaller variation in the BEI than the actual expected inflation.

As a hypothetical example, suppose that the expected inflation is 1%, the volatility of the expected inflation is 3%, the nominal interest rate is 0.8%, and the maturity is 10 years. Then, the value of the option premium, which adds on to the BEI, would be 6 basis points in yield. Under the same conditions, but with the expected inflation at 0.2%, the value of the option premium would be 24 basis points.

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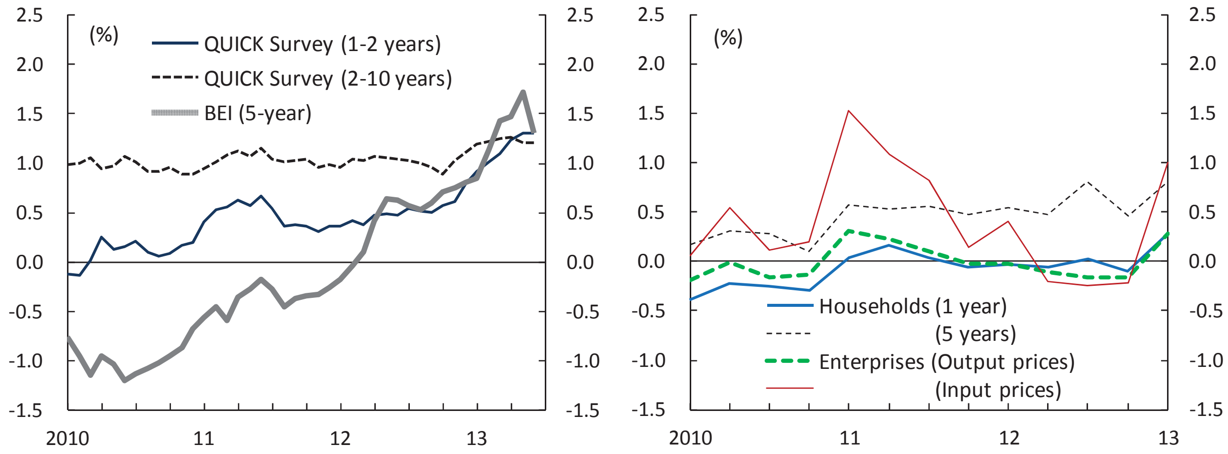
Table 1. Major international inflation indexed bond markets

	Market values[*1]	First issue	Inflation index	Floor protection
United States	925.7	1997	CPI All urban	Yes
United Kingdom	540.0	1981	UK RPI	No
France	245.5	1998	French CPI ex-tobacco Euro HICP ex-tobacco	Yes
Italy	162.9	2003	Euro HICP ex-tobacco	Yes
Germany	75.7	2006	Euro HICP ex-tobacco	Yes
Canada	56.8	1991	CPI All Items	No
Japan	35.3	2004	CPI All items less fresh food	No[*2]
Sweden	33.9	1994	Swedish CPI	No/Yes
Australia	24.8	1985	All groups CPI	Yes

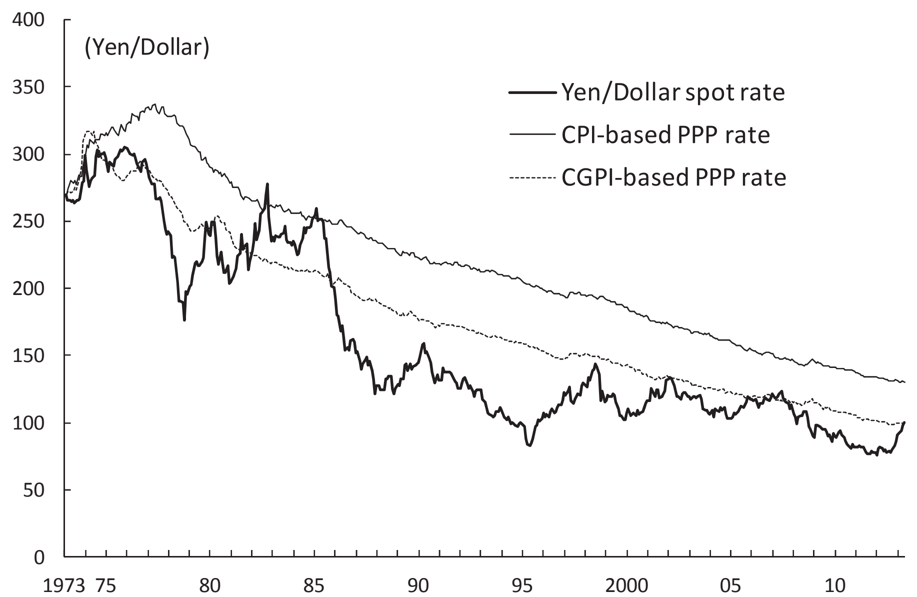
Notes: 1. Market values (billions of USD) are estimates of Barclays Capital (as of June 2013).
2. There are plans for a new issue of IIBs in October 2013 providing floor protection.

Figure 1. Various measures for inflation expectations



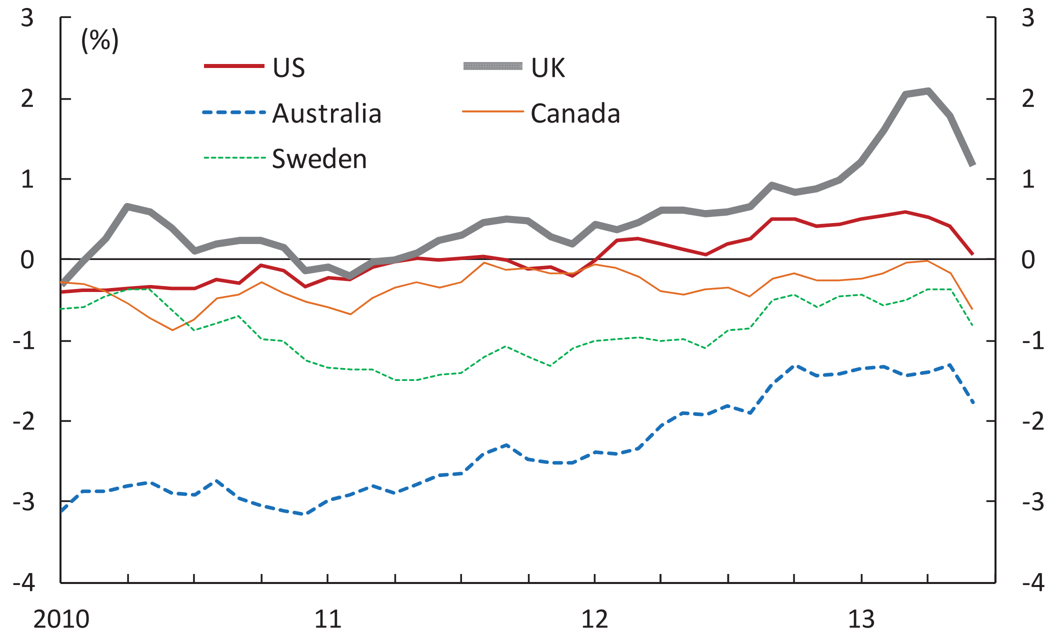
Note: In the left panel, "QUICK Survey" refers to the expectations of bond market participants obtained from the "QUICK Bond Monthly Survey." The solid line denotes the expectations for 1 to 2 years ahead, while the dotted line denotes those for 2 to 10 years ahead. In the right panel, expectations are estimated using the modified Carlson-Parkin method (see Sekine et al. 2008). "Households" refers to households' expectations estimated based on the "Opinion Survey on the General Public's Views and Behavior" (expectations over the coming year and the next 5 years), while "Enterprises" refers to the expectations based on the "Tankan" (expectations for the next quarter).

Figure 2. Yen/Dollar exchange rate and PPP rate



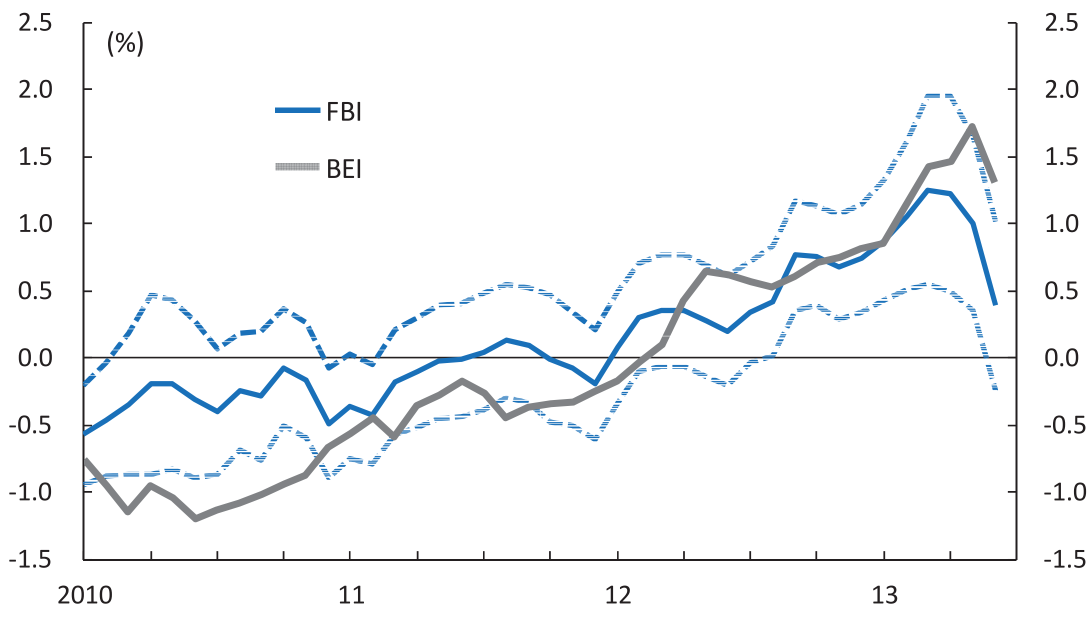
Note: "CPI-based PPP rate" refers to the PPP rate based on the consumer price index. "CGPI-based PPP rate" refers to the PPP rate based on the corporate goods price index (CGPI). The rate is calculated using the CGPI for Japan and the producer price index (PPI) for the United States.

Figure 3. Japanese FBI inflation expectations (5-year)



Note: Monthly average of daily series of the FBI. See Appendix A for more details.

Figure 4. The FBI and the BEI for Japan (5-year)



Note: The FBI index is the weighted average of the FBIs based on the five countries. The weights are the market values of each country's IIB market (as of June 2013, estimates by Barclays Capital). The dotted lines denote the one-standard-deviation interval.

Figure 5. The FBI and BEI for Japan (5-year, daily)

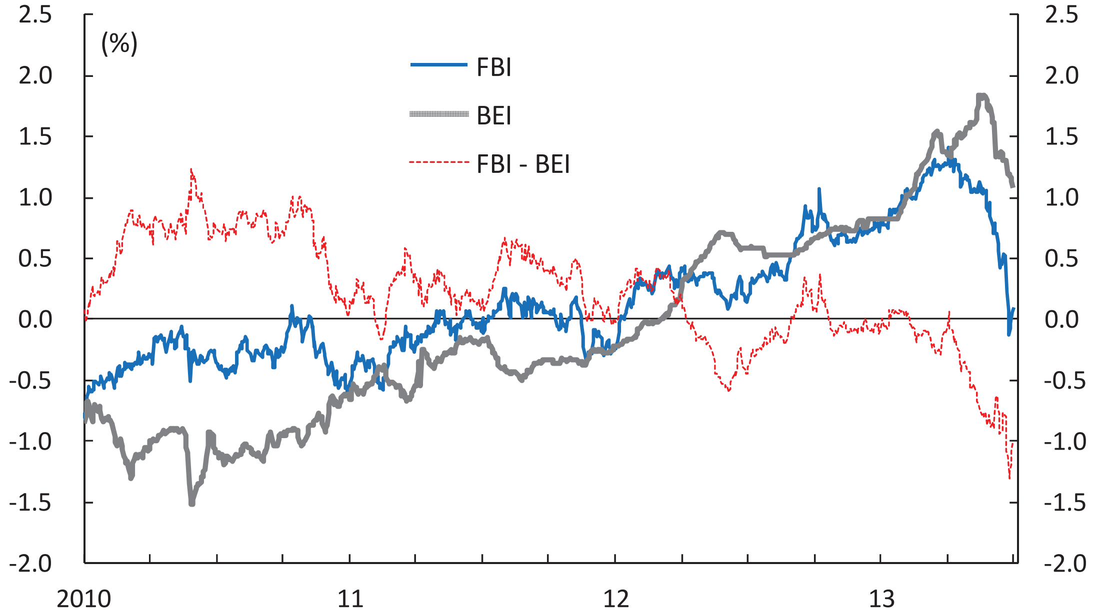
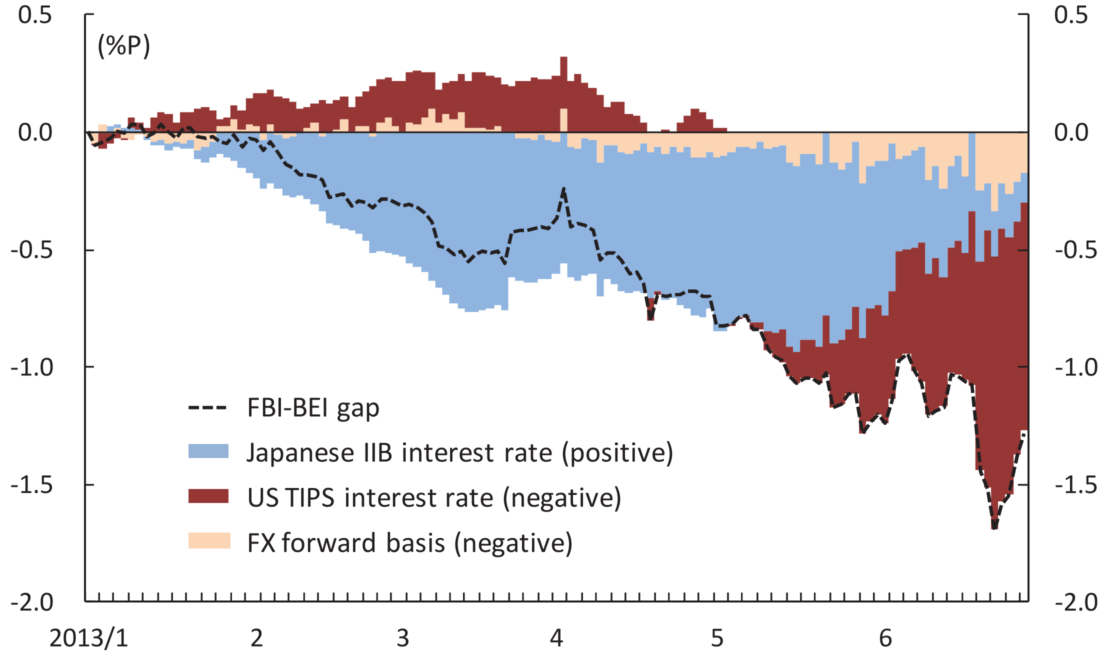
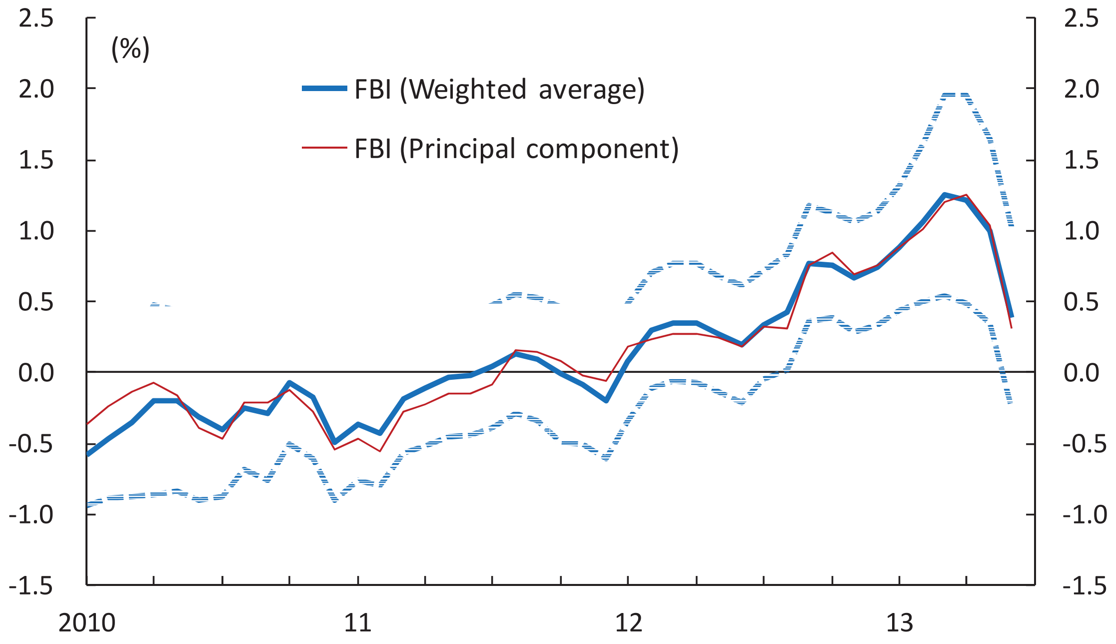


Figure 6. FBI-BEI gap and factor decomposition
(change from the beginning of January 2013)



Note: An increase in the US TIPS interest rate and in the FX forward basis has a negative effect on the FBI-BEI gap. All variables are for 5-year maturities.

Figure 7. FBI index: Weighted average and principal component



Note: The dotted lines denote the one-standard-deviation interval.