INFLATION EXPECTATIONS DERIVED FROM FOREIGN EXCHANGE OPTIONS

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Abstract

Inflation expectations are a key economic variable for investors in capital markets and for economic policy decision makers**.** One of the widely used sources for deriving inflation expectations are market prices of bonds. The yield differential between nominal bonds and inflation-indexed (linked) bonds is taken to be an estimate of expected inflation. The problem is however that in a risk averse world the yield differential includes an inflation risk premium and thus the yield differential provides an upward bias of inflation expectations. The novelty of our paper is that we estimate this risk premium using volatility implied in options prices. In the absence of a market in options on inflation we use prices of foreign currency options to estimate this risk premium. The theoretical foundation of our methodology is purchasing power parity theory. The Israeli financial market has both, an inflation linked and non linked bond market and an active FX options market. Using data from both markets we find a statistically and economically significant inflation risk premium.

Key Words: Inflation expectations; Inflation risk premium; Inflation-indexed bonds; foreign exchange options; Purchasing Power Parity; Error Correction Model.

JEL Classification: E31, E44, E52.

I. Introduction

Inflation expectations *are a key economic variable for decision makers in capital markets; they* play an important role in *determining* monetary policy in many countries around the globe, especially in countries with strong and independent central banks. The expectations are obtained from various sources. Expectations provided by professional forecasters, expectations derived from the prices of financial instruments and estimates based on statistical models based on the history of realized inflation. The recent emphasis on forward looking data focuses on capital assets prices as the more appropriate data to be used as predictors of inflation and output. The notion that interest rates and asset prices contain useful information about the future embodies fundamental concepts in macro economics such as the Fisher theory that the nominal interest rate is the real rate plus expected inflation. In the past years there has been considerable research on forecasting inflation and economic activity using asset *prices. (see Stock and Watson(2003) for a review).* In countries where the government issues bonds linked to inflation side by side with nominal (non-linked) bonds, the common practice has been to derive inflation expectations from these bonds. The yield differential between nominal bonds and inflation indexed bonds is used as an estimate of the market's expected inflation (referred henceforth as "break-even inflation"). For example, in the US subtracting the yield on TIPS (Treasury Inflation-Protected Securities) from the yield on a non-linked Treasury security with a similar maturity. This common practice, however, has been questioned by several researchers (e.g. Evans (1998) and Foresi et al. (1997)). It is argued that the yield differential provides an upward biased estimate of expected inflation. Evans (1998) has calculated the risk premium in the UK by modeling inflation linked bonds as a combination of "real" bonds and nominal bonds. Foresi et al. (1997) estimates the inflation risk premium on a 10 year UK government bond. Though both of these studies are unique in their attempt to estimate the inflation risk premium, they do not use an instrument that provides an exogenous forward-looking estimate of inflation risk and inflation risk premium. The main point is that in a *risk averse economy* the yield differential contains a risk premium that is a compensation for inflation uncertainty reflected in the yield on nominal bonds. In an environment of stable inflation (i.e. low volatility) like the Greenspan era in the *US*, for example, the inflation risk premium should have been very small while the risk premium in the 70s (pre Volcker) must have been very high, which was then embedded in the prices of nominal bonds.

The purpose of this research is to estimate the inflation risk premium (IRP) over time and investigate its properties. This will in turn provide unbiased inflation expectations to be used by investors and monetary policy decision makers. The novelty of the methodology described here is that in estimating the IRP we use the volatility implied in the options as a measure of risk. It is based on the linkage between inflation and the FX market and the existence of an active FX options market[1]. We are therefore able to use data from an organized options exchange and stock exchange to estimate the forward looking inflation volatility and the market price of risk (MPR) respectively from high frequency (daily) data . The product of the MPR and the proxy for inflation volatility yields an estimate of the IRP.[2]

Israel is a good candidate for research on inflation expectations since it is a country which has a long experience of high and volatile inflation and of fighting inflation as well as a well functioning capital market including a long history of inflation linked bonds. *Since* Israel is a small open economy there is a relatively significant relationship between the exchange rate and inflation. Thus, our study uses the inflation experience of Israel and its FX options market to estimate the IRP and thereby extract unbiased inflation expectations.

The methodology presented in this paper can be used to derive an IRP and inflation expectations in countries that have both, linked and non-linked government bonds, especially in open economies that are prone to high inflation uncertainty due also to the link between the exchange rate and inflation.

We use data from the Israeli bond markets and the foreign exchange market (FX). From the difference between the return on nominal bonds and real bonds, "the breakeven inflation" in the bond market, we subtract the inflation risk premium to get a pure

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[1] Options on inflation (the CPI) would have been the first best source of information in deriving the IRP, but such a market either does not exist or at best is thinly traded OTC like in Israel where it is non transparent and is controlled by the banks. In general, because of low inflation volatility, options on the CPI are thinly traded relative to FX options.

[2] Chowdhry, Roll and Xia (2005) use stock returns to extract estimates of realized pure inflation, they purge stock returns from the risk premium of the different economic factors by using the Fama-French three factor model.

estimate of the expected change in the price level taken to be the consumer price index (CPI). The theoretical framework on the linkage between inflation and the changes in the price of foreign exchange is based on purchasing power parity between Israel and the US and the empirical estimation of short term inflation is performed using an Error Correction Model (ECM).

We find that there exists a non trivial stochastic inflation risk premium. The inflation risk premium expected a year hence was about 25 basis points during the years 2002-2005. This premium accounted for about 15% of the difference between the nominal and real rates with a one year maturity (the standard deviation was about 5%).. Analysts' estimates regarding the one year expected inflation, based largely on macro-economic models, were on average at the same period higher than the breakeven inflation which contains a risk premium.

Our findings lend support to the conjecture that the so called “break-even” inflation expectations derived from the bond market provides an upward bias of expected inflation. Investors and policy-makers should therefore take into account the risk premium embedded in this estimate. It is important to implement such a procedure especially in a period of high inflation volatility when the central bank needs reliable inputs/estimates monetary policy decisions.

II. Current and Past Research

Inflation indexed government debt exists in many countries and is an important instrument in economic policy. It helps managing the debt, increases the savings rate and the public trust in the economic policy. Countries which issue linked bonds include, among others, the United States, England, Canada, Sweden, New Zealand, Poland, Argentina, Brazil and Israel.

Though the decision in each country to link the debt happened under different circumstances, the experience shows that the inclusion of linked bonds in the capital market provides several advantages. In principal, linked bonds reduce the uncertainty about the real cost of funds for the issuer and for the investor. They reduce the cost of capital, provide the investors a hedge against inflation and expand their investment opportunity set. Finally, they also increase the efficiency and credibility of monetary policy. In countries with a relatively high rate of inflation, linked bonds help in developing the capital markets and financial intermediation (Price, 1997).

In some countries inflation expectations are derived from the prices of linked and non-linked bonds. These estimates are an important input in the decision process of the Central Banks in conducting their monetary policy (e.g. the Bank of England, the Bank of Israel). These estimates are considered superior to analysts' expectations or to estimates derived from econometric models that use past data. These estimates are attractive since they are forward looking, can be computed continuously and can provide the entire term structure of inflation expectations. Due to the importance of inflation expectations many researchers have, and are, trying to improve the quality of the estimates. Deacon and Derry (1996) and Deacon, Derry and Mirfendereski (2004) discuss various methods that can be used to extract inflation expectations from the British bond market. They devote much of their analysis to the method used by the Bank of England and discuss the theoretical as well as the practical issues in deriving inflation expectations. Woodward (1990) simply assumes that the IRP is zero, thus the yield difference between non-linked and linked government bonds for all maturities provides an unbiased “term structure” of inflation expectations. de Kock (1991) has examined the accuracy of these market expectations, in England, by comparing them to actual inflation and concludes that they are of little value since they consistently missed the realized inflation which may be true for other countries too. Nevertheless, Central Banks keep using such estimates assuming that the participants in the bond market have certain inflation expectations when they come to the market and trade and therefore these prices should reflect their expectations. Cote, Jacob, Nelmes and Wittingham (1996) discuss the estimates used by the Canadian central bank, which are derived from the bond market. Robertson and Symons (1992) have extracted inflation expectations in England in investigating the reaction of the bond market to the delinking of the British pound to the ERM. Anderson and Sleath (2003) provide the methodology that the Bank of England uses to derive inflation expectations that are published in their quarterly inflation report. An older study by Wilcox and Zervos (1994) offers a methodology to derive inflation expectations in cases where there are only partially linked, to the CPI, bonds. Sack (2000) and Emmons (2000) derive inflation expectations from nominal and inflation indexed treasury yields in the US assuming a negligable inflation risk premium.

The Bank of Israel (BOI) is deriving inflation expectations from the bond markets since 1988. It is based on work done by Yariv (2000). Alashwilli and Regev (2005) have proposed some changes in the derivation of the one year expected inflation to account for seasonality in CPI, for the delay in the announcement of actual inflation and for the fact that even holders of fully linked bonds do not get full compensation for inflation.

The need to estimate the IRP has attracted several researchers in recent years. Campbell and Shiller (1996) applied two methods to estimate the IRP in the American market and obtained an estimate in the range of 50-150 basis points for a maturity of 5 years. Gong and Remonola (1996) have found that the IPR for 5 years is 100-300 and their estimate is highly sensitive to the sampling period. These papers, however, have not used information from the TIPS market since they were written before TIPS were introduced (1997). Research that has looked at the savings of the British treasury from issuing linked bonds instead of nominal bonds incorporated the prices of linked bonds in estimating the IRP. The study by Foresi, Penati and Pennacchi (1997) arrived at an estimate of 250 basis points for a 10 year bond. A study by Brown (1998) provides a range of 100-200 basis points depending on the maturity of the bond. Breedon and Chadha (1997) estimate the difference between expected inflation and the realized one to be about 180 basis points. They claim that this mainly reflects the IRP. In a study on the Israeli bond market Kandel, Ofer and Sarig (1996) have reported that the IRP in periods of high inflation was about 34 basis point a month and only 5 b.p. in periods of low inflation. Evans (1998) examined the behavior of the inflation risk premium by relating nominal and real yields with expected inflation, his findings using UK data indicate the presence of risk premia that covary positively with the spread between nominal and real yields. Stein (2004) uses the CAPM to estimate the IRP and finds that it is only 40 b.p. per annum in the period 1996 to 2002.

III. The Methodological Framework; Estimation and Results

The Fisher equation is the basis for the current practice employed by central banks and investors in deriving inflation expectations from the prices of real (inflation linked) bonds and nominal bonds assuming that there is no inflation risk premium. If we assume, however, that the consumers/investors utility is stated in real terms, risk-averse investors will demand a premium that will compensate them for inflation risk and this premium should be reflected in bond prices.[3] The hypothesis is that the volatility of inflation is non trivial so is the volatility of the real rate. Though it is reasonable to assume that the current estimate which uses the yield differential between nominal and real bonds ("breakeven" inflation) is correlated with market expectations of future inflation, it is biased upward and moves around. In this paper we adjust this 'breakeven' inflation expectation by an estimate of the IRP and thus obtain an unbiased estimate of inflation expectations. Our hypothesis is based on well known results of standard financial theory assuming a single factor model (CAPM for example) namely the risk premium is a product of risk (volatility) and the market price of risk that is a market compensation per unit of risk (volatility)[4]

IRP=inflation risk * MPR

and

Expected Inflation = Break-even inflation - IRP

In this study we propose a methodology that uses current market information to estimate the IRP on a daily basis. We subtract the IRP from the 'breakeven' inflation to obtain unbiased inflation expectations for the period October 2002 to May 2005. A basic premise of the analysis rests on the fact that in a small open economy, like Israel, there is a strong link between exchange rates and inflation. In such economies changes in the

[3] The analysis in this paper assumes that such a risk premium is present but we are not developing any theoretical model that will tell us precisely how it is generated and what it should be. We are focusing on the proper empirical methodology to extract unbiased inflation expectations from the bond market (???)

[4] Mayfield (2004) estimation of market risk premium is based on estimates of market volatility.

exchange rate translate into changes in commodity prices including locally produced commodities which are affected by changes in inputs (oil, for example).[5]

We start with an analysis of purchasing power parity in the long run. We then estimate the short run inflation relationship using an Error Correction Model. This enables us to arrive at an ex-ante estimate of inflation and the risk premium.

a. Purchasing Power Parity (PPP) in the Long Run (Israel and the U.S.)

PPP simply says that the exchange rate reflects the relative price levels of two countries. By and large, empirical studies have rejected PPP in the short run. However, several researchers have found that it holds in the long run. For example, Rogoff (1996) states that there is a consensus that, in the long run, the real exchange rate is approaching PPP. Two other studies, Cheung and Lai (1993) and Ramirez and Khan (1999), which use co-integration tests, show that there is a stable long run relationship between exchange rates and consumer prices. In this study we also use co-integration to examine the long run relationship after Israel moved to a fully floating exchange rate in May 1997.

We start with the simple model for testing Absolute PPP between the dollar exchange rate and relative consumer prices (Israel and the U.S.):

$$s_t = \alpha_1 p_t + u_t \qquad (1)$$

where s_t is the Shekel/Dollar (ILS/\$) exchange rate, p_t is the ratio of Israel CPI and the U.S. CPI, u_t is an error term. For Absolute PPP to hold we need $\alpha_1 = 1$.

In order to analyze the factors that affect consumer prices in Israel we rewrite (1) in logarithmic terms as:

$$P_t(ISR) = \beta_0 + \beta_1(S_t + P_t(US)) + v_t \qquad (1a)$$

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[5] The effect of the exchange rate on consumer prices was investigated and reported in many studies. To mention just a few; Bruno and Sussman (1979), Bruno and Fischer (1986), Azoulay and Elkayam (2001) Elkayam (2001). For example, Azoulay and Elkayam (2001) examined the effect of monetary policy on inflation in Israel and found that devaluation of the currency coupled with world wide inflation has a significant effect on domestic inflation.

Where $P_t(ISR)$ is log of the price level in Israel, $P_t(US)$ is the log of consumer price level in the U.S., S_t is log of the *exchange rate* (ILS/$) and v_t is the error term.

The common approach is to assume that local prices change with a change in the exchange rate or as a result of a change in the foreign country's prices. In (1a) we only require that local prices adjust when the product of both changes. Thus the Absolute PPP hypothesis can be stated as: H_0: $\beta_0=0$, $\beta_1=1$. Using monthly observations, for the period 5/1997 – 4/2005 we obtained the following regression results

$$P_t(ISR) = \underset{(40.4)}{1.81} + \underset{(61.1)}{0.42}(S_t + P_t(US)) + v_t \qquad (1b)$$

$R^2=0.98$ DW = 0.38 N = 96

(t statistic values are in parenthesis)

The coefficients are significantly different from 0 and 1 respectively. Thus, the null hypothesis, H_0, is rejected. This result, however, comes at no surprise, it is consistent with most studies which have tested PPP in other countries.

Three main reasons are given for the empirical results that reject the existence of absolute PPP and are relevant in the context of Israel. First, like in other countries, CPI includes non tradable assets, housing for example, which adjust infrequently. Second, about 20 percent of the tradable items, included in the CPI in Israel, are affected by changes in the Euro and not the dollar. Third, the sampling period which starts immediately after the move from a band controlled FX market to a free floating, is not long enough to properly test such a relationship. Moreover, within the sample period there was a recession, 2002-2003, when producers could not afford to adjust prices *upwards*.

Though absolute PPP was rejected we turned to tests of non-stationarity and co-integration, as was done for other countries, to see if a long run relationship between consumer prices and exchange rates does exist. For the two variables, $P_t(ISR)$ and (S_t + $P_t(US)$), to be co-integrated we need the following *two conditions to hold* : a. the two variables exhibit non-stationarity of the same order. b. the two variables exhibit, at least, one co-integration relationship.

We first use the Augmented Dickey-Fuller Test (ADF) to test for non-stationarity of the two variables. We use a constant term and two lags.

Table 1a: A Unit Root Test

VARIABLES		ADF	Critical values for a Unit Root Test: Signif.Level 1%	Signif.Level 5%
Levels:	$S_t + P_t(US)$	-1.72	-3.50	-2.89
	$P_t(ISR)$	-1.88	"	"
First differences:	$\Delta(S_t + P_t(US))$	-7.27	-3.50	-2.89
	$\Delta P_t(ISR)$	-6.17	"	"

In Table 1a we cannot reject the hypothesis of a unit root in the *level (in log form)* variables, the variables are non-stationary. When the test is applied to first differences, *the rate of change of the exchange rate (ΔS) and the inflation rates (ΔP),* we reject the existence of a unit root. I.e. the time series of first differences are stationary and integrated in the first order. These results are consistent with the findings in other developed countries (see, for example, Cheung and Lai (1993) and Corbae and Ouliaris (1988)). The next step is to test for co-integration using the approaches of Johansen (1988) and Engle and Granger (1987). The purpose of the analysis is to see whether the results in 1b represent a long-run relationship that will assist us in understanding the short run dynamics of inflation in Israel.

According to Engle and Granger (1987) a necessary condition for co-integration is that the error term is a stationary series. An ADF test of v_t shows that the series is stationary and we can reject the hypothesis of a unit root at the 5% level. The two variables are co-integrated. The Johansen co-integration test was applied to lags of 2, 4 and 7. In Table 1b we present the co-integration coefficients of the long run, for each lag. The results show that there is, at least, one co-integration relationship, at the 1% level.

These results are consistent with the Engle and Granger results that there is a long run relationship between the two variables in equation 1b; consumer prices in Israel and consumer prices in the U.S. multiplied by the exchange rate.

Table 1b: Tests of Co-integration

Engle and Granger			
Error Term	ADF		
v_t	-4.00*	Critical val. -3.37	
Johansen			
Max. Lags	β_0	β_1	Trace Statistic
2	1.92	0.40	26.04**
4	1.94	0.40	30.32**
7	2.02	0.38	30.23**

* Significant at the 1% level
** Significant at the 5% level

b. Estimation of the Error Correction Model (ECM)

The co-integration tests which point to a long term relationship enable us to examine the short term behavior of these variables. Engle and Granger (1987) have suggested that, for variables that are co-integrated, it should be possible to find a process that is Error Correcting, a process that describes the convergence of the short term deviations to the long run relationship. Basically, the long run and short run come together by the inclusion of the lagged error term from 1b in the short term equation. In equation (2) we *specify* the short run behavior and the convergence process by an ECM.

$$\Delta P_t(ISR) = \theta_0 \cdot \Delta\left[S_t + P_t(US)\right] + \theta_1 \cdot \Delta P_{t-1}(ISR) + \theta_2 \cdot EC_{t-1} + x_t \qquad (2)$$

Where EC_{t-1} is the error correction component and is derived from equation 1b. x_t is the error term in (2). The basic idea here is that any short term deviation from the long run relationship would be reversed so there is a convergence in the long run. Thus, the coefficient θ_2, which is an estimate of the speed of convergence, should be negative and significantly different from zero.

Equation (2) was estimated for the period July 1997 to April 2005 and the results are given in equation (2a).

$$\underset{}{\Delta P_t(ISR)} = \underset{(10.4)}{0.20\, \Delta (S_t + P_t(US))} + \underset{(4.3)}{0.27\, \Delta P_{t-1}(ISR)} - \underset{(-\,4.3)}{0.19\, EC_{t-1}} + x_t \qquad (2a)$$

$R^2 = 0.67 \quad DW = 2.15 \quad N = 94$

(t statistic values are in parenthesis)

Equation (2a) is well specified as evidenced by the R^2 and by the DW statistic. Foreign inflation (U.S.), the exchange rate and lagged domestic inflation explain most of the variation in current domestic inflation. The ECM seems to work well, the Error Correction component is negative and significantly different from zero; about 19 percent of the deviation from the long run relationship is "corrected" in the following month.

At this point we would like to elaborate on the transmission process, from changes in the exchange rate to consumer prices. The immediate channel is the prices of imported goods which also affects the prices of domestic substitutes. The other channel is the prices of imported raw materials and services used in the production of domestic goods. The effect of this price increases on the CPI will depend on their part in the consumer's basket.

The transmission coefficient found here is similar to findings in other countries. Gagnon and Ihrig (2002) have examined a sample of industrialized countries and have found that during 1972 to 2000 the one year transmission coefficient is, on the average, about 20 percent. Canada, for example, has a 20 percent transmission coefficient. By the end of the above period this coefficient was only 5% despite the fact that world trade has increased markedly and there are more imported goods in every consumer's basket. The increase in imported goods, however, came along with lower prices due to a reduction in import taxes, cheap goods from the emerging markets and credible monetary policies in the developed countries[6]. Another study by Elkayam(2001) who examined the 1992-2000 period in Israel has obtained an estimate of 0.19 which is virtually identical to ours.[7]

Since 2a imposes the same, .2, coefficient on U.S. prices and the exchange rate we released this restriction and reran 2a to find out what are the individual effects of U.S. prices and the exchange rate.

$$\Delta P_t(ISR) = \underset{(9.8)}{0.20}\, \Delta S_t + \underset{(1.8)}{0.24}\, \Delta P_t(US) + \underset{(4.1)}{0.27}\, \Delta P_{t-1}(ISR) - \underset{(-4.3)}{0.19}\, EC_{t-1} + x_t \qquad (2b)$$

$R^2 = 0.67$ DW = 2.15 N = 94

(t statistic values are in parenthesis)

Though the power of this specification is the same as (2a) it seems that the effect of U.S. inflation is less significant ~~marginal~~ while changes in the exchange rate are the dominant factor and they carry the same coefficient as before (0.2).

To simplify our analysis of the Inflation Risk Premium, which we do next, we drop the U.S. inflation and use the following equation:

$$\Delta P_t(ISR) = \underset{(10.1)}{0.21}\, \Delta S_t + \underset{(4.7)}{0.30}\, \Delta P_{t-1}(ISR) - \underset{(-4.0)}{0.18}\, EC_{t-1} + x_t \qquad (2c)$$

$R^2 = 0.66$ DW = 2.09 N = 94

(t statistic values are in parenthesis)

The power of this equation remains the same.

[6] See Bailliu and Bouakez (2004) for a discussion on the link between the decline in exchange rate pass-through and the low inflation rate achieved in the last decade in most industrialized economies.

[7] Azoulay and Elkayam (2001) have examined the period 1988-1996 and obtained a higher coefficient, 0.29, which again points to the changes that have occurred in the Israeli economy during the 90s.

c. Estimating Inflation Volatility and the IRP

1. The Volatility of Inflation

We use equation (2c) to derive the relationship between the volatility (variance) of the exchange rate and the volatility of inflation. Rewriting (2c) such that the inflation terms are on the left hand side and the exchange rate on the right hand side results in:

$$\mathrm{var}(\Delta P_t - 0.30\Delta P_{t-1}) = \mathrm{var}(0.21\Delta S_t + (-0.18)EC_{t-1} + x_t) \qquad (3)$$

Where ΔP_t is the monthly rate of inflation in Israel, ~~ΔP_t(ISR)??~~ and ΔS_t is the monthly rate of change in the exchange rate[8].

Since ΔP_t and ΔP_{t-1} come from the same distribution we can rewrite (3) as:

$$\begin{aligned}(1-0.30)^2\cdot\sigma^2_{\Delta P_t} &= 0.21^2\cdot\sigma^2_{\Delta S_t} + (-0.18)^2\cdot\sigma^2_{EC_{t-1}} + \sigma^2_{x_t}\\ &+ 2\cdot(-0.18)\cdot\sigma_{x_t}\cdot\sigma_{EC_{t-1}}\cdot\rho_{x_t,EC_{t-1}}\\ &+ 2\cdot 0.21\cdot\sigma_{\Delta S_t}\cdot\sigma_{x_t}\cdot\rho_{\Delta S_t,x_t} + 2\cdot 0.21\cdot(-0.18)\cdot\sigma_{\Delta S_t}\cdot\sigma_{EC_{t-1}}\cdot\rho_{\Delta S_t,EC_{t-1}}\end{aligned} \qquad (3a)$$

where $\mathrm{var}\equiv\sigma^2$ and ρ denote the variances and correlation terms respectively .

Using the estimates provided in Table 1b and equation (3a) we can write the expression for the variance of inflation as:

$$\sigma^2_{\Delta P_t} = 0.09\cdot\sigma^2_{\Delta S_t} + 0.0001656\cdot\sigma_{\Delta S_t} + 2.9674\cdot 10^{-5} \qquad (3b)$$

This equation enables us to use the volatility of the exchange rate as a proxy for the volatility of inflation. We can now use the one month forward looking implied volatility from options on the Dollar, traded on the Tel-Aviv stock exchange, as a proxy for the one month forward looking volatility of inflation. This estimate can be computed daily from the traded options.

[8] Based on monthly average exchange rates.

Table 1b: Standard Deviations and Correlation of the Exchange Rate and the Error Correction Term

	ΔS_t	EC_{t-1}	x_t
ΔS_t	0.18250		
EC_{t-1}	-0.189217	0.009228	
x_t	-0.035316	-0.002669	0.003428

2. The Market Price of Risk and the IRP

We now turn to the estimation of the second component of the IRP: the market price of risk (MPR). *Following standard finance theory (CAPM)* we define the MPR in real terms:

$$\begin{aligned} MPR &= \left[(R_m - \Delta P) - (R_f - \Delta P)\right] / \sigma(R_m - \Delta P) \\ &= (R_m - R_f) / \left(\sigma_m^2 + \sigma_{\Delta P}^2 - 2\sigma_m \sigma_{\Delta P} \rho_{m,\Delta P}\right)^{1/2} \end{aligned} \tag{3c}$$

in our study R_m is the *average nominal* return on the TA100, an index of the largest 100 companies on the Tel – Aviv Stock Exchange, R_f is the nominal risk free rate, using the interest rate charged by the central bank. Table 1c presents the parameter estimates used in the computation of the MPR and of the IRP.

Table 1c: Parameter Estimates (Percentage points, in Monthlys terms)

$\overline{R}_m$	$\overline{R}_f$	σ_m	σ_π	$\rho_{m,\pi}$	$\overline{\pi}$
1.155	0.716	5.5	0.6	-0.265	0.21

The IRP is the product of the MPR and the risk of inflation, as measured by the implied standard deviation of inflation, estimated from FX options (see 3b)

$$IRP_t = \sigma_{\Delta P_t} \cdot MPR \tag{3d}$$

Where $\sigma_{\Delta P_t}$ is the implied volatility of inflation

Estimation of the IRP enables us to extract the inflation expectations from the yield on nominal bonds minus the yield on the CPI linked bonds, the so called "real Bonds".

$$E(\Delta P_t) = (RN_t - RP_t) - IRP_t \tag{3e}$$

Where $E(\Delta P_t)$ is expected inflation at time t, RN is the yield on nominal bonds and RP is the yield on the indexed ("real") bond. These are one year forward looking expectations estimated on a daily basis. Currently, central banks (e.g. the BOI) use the raw number, $(RN_t - RP_t)$ as an estimate of expected inflation.

Our findings, presented in Table 2, point to a sizable IRP which was about 25 basis point during our estimation period , October 2002 to May 2005. The IRP accounted, on the average, for 15 percent of the yield difference between RN and RR. Inflation expectations during that period were, on the average, about 1.62 percent with a standard deviation of 0.64 percent. Since the volatility of the exchange rate is our proxy for the volatility of inflation we find, Table 2 columns 2 and 4, that the range of IRP is correlated with the range of FX volatility. It was the lowest in May 2005, 19 b.p. and the highest in March 2003, 35 b.p. (the most volatile month in the FX market). The proportion of IRP in the "breakeven" inflation, $(RN_t - RP_t)$, is rather volatile. It ranged from 9% in March 2005 to 31% in December 2003.

The Implied Volatility in Table 2 was computed from FX options with 1 month to maturity, assuming that the variance is linear in time such that the $\underline{IV}$ extends to one year estimates. There is, however, evidence that the variance is not linear in time to maturity so we have estimated the slope of the term structure of volatility using the BOI 3 and 6 month options and applied it to the 1 year estimates. As can be observed in Table 2a column 2, the $\underline{IV}$ has declined but the volatility of $\underline{IV}$ has increased. This shows up in the

IRP which has declined but its volatility increased (see Table 2 column 3). Due to the volatility of IV the risk premium varies too which makes estimation harder but necessary. In Tables 3 and 4 we have aggregated the monthly data and have presented the findings on an annual basis. It is interesting to note that, like in other markets, the IV derived from the FX options was mostly larger than the realized volatility of inflation mainly due to a the probability of a jump.

IV. Summary and Conclusions

Central banks, financial institutions and other investors increasingly use forward looking financial market data to obtain unbiased expectations of forthcoming inflation. The standard approach has been to subtract the yield on a real bond, a CPI linked bond, from a nominal bond. Such an estimate is biased upwards since it includes an inflation risk premium (IRP).

The objective of this paper has been to provide a methodology that will derive estimates of inflation risk premiums and enable forecasters to extract “pure” inflation expectations from financial market data. We subtract an estimate of the IRP from the biased estimate, nominal yield minus real yield, to obtain unbiased inflation expectations.

We found that the IRP for a year ahead is about 25 basis points during the estimation period, 2002-2005, and accounted for 15% of the difference between nominal and real yields. Another empirical observation that supports our findings of a positive IRP is the positive gap between the yield differential, the ”breakeven” yield, and the realized inflation which was about 100 basis points lower than this differential in the past 8 years.

Given that monetary authorities use inflation expectations as an important input in their policy decisions, the findings reported here should be taken into consideration.

Table 2: Inflation Expectations Net of Risk Premium
(Pct., avg. of daily observations)

Year	Month	Inflation breakeven point	Implied S.D. of NIS/$ exchange rate	Annual inflation S.D.	Inflation risk premium	Inflation expectations	Share of risk premium in break-even inflation
		(1)	(2)	(3)	(4)	(5)=(1)-(4)	(6)=(4)/(1)
2002	10	3.02	11.75	4.09	0.32	2.71	10.43
	11	2.82	11.86	4.12	0.32	2.50	11.28
	12	2.20	12.02	4.17	0.32	1.88	14.61
2003	1	2.72	12.31	4.24	0.33	2.39	12.02
	2	3.79	13.24	4.49	0.35	3.44	9.14
	3	3.05	13.60	4.59	0.35	2.69	11.61
	4	1.87	10.23	3.69	0.28	1.58	15.23
	5	1.39	12.11	4.18	0.32	1.07	23.15
	6	1.45	11.35	3.98	0.31	1.15	21.11
	7	2.45	10.04	3.64	0.28	2.17	11.44
	8	1.72	9.98	3.62	0.28	1.44	16.29
	9	1.49	9.12	3.41	0.26	1.23	17.64
	10	1.69	8.19	3.18	0.25	1.44	14.54
	11	1.11	8.10	3.16	0.24	0.87	21.87
	12	0.74	7.60	3.03	0.23	0.51	31.46
2004	1	0.88	7.54	3.02	0.23	0.65	26.39
	2	1.11	7.16	2.93	0.23	0.88	20.44
	3	1.17	5.73	2.62	0.20	0.97	17.23
	4	1.58	6.12	2.71	0.21	1.37	13.20
	5	1.96	6.61	2.81	0.22	1.75	11.05
	6	1.75	6.06	2.69	0.21	1.54	11.86
	7	1.49	5.60	2.60	0.20	1.28	13.49
	8	1.85	5.02	2.48	0.19	1.66	10.30
	9	1.96	4.85	2.44	0.19	1.77	9.62
	10	2.04	5.65	2.60	0.20	1.84	9.84
	11	1.87	6.92	2.88	0.22	1.64	11.90
	12	1.38	7.41	2.99	0.23	1.15	16.69
2005	1	1.56	7.50	3.01	0.23	1.33	14.87
	2	2.01	6.01	2.68	0.21	1.80	10.29
	3	2.18	5.87	2.65	0.20	1.98	9.36
	4	1.98	5.22	2.52	0.19	1.79	9.80
	5	1.69	4.63	2.40	0.19	1.50	10.97
Avg.		1.87	8.29	3.24	0.25	1.62	14.66
S.D.		0.67	2.77	0.68	0.05	0.64	5.42

(1) The difference between the nominal yield on one-year Treasury bills and the real yield on a CPI-indexed bond to a term of approx. one year. The result is an indicator of the capital market's one-year forward-looking inflation expectations, calculated in accordance with the methodology applied by the BOI Monetary Department.

(2) Implied standard deviation from one-month NIS/$ options traded on the Tel Aviv Stock Exchange. Generated from data processed by BOI Monetary Department.

(3) Calculated on the basis of Equation 3b from daily data. We substitute into Equation 3b the daily figure from Column (2) in monthly terms. To obtain the figure in annual terms, we multiplied the result by the square root of 12.

(4) Based on Equation 3d. The figure is the product of the market price of risk and the daily volatility of inflation, from Column 3. The market price of risk is constant and calculated based on the definition in 3c. The estimated market price of risk is 0.08, calculated from a sample of monthly averages from May 1997–May 2005, based on the yield of a market portfolio composed of 100 leading shares on the Tel Aviv Stock Exchange and the Bank of Israel Monetary rate, which represents the yield on a risk-free asset.

(5) Inflation expectations net of risk premium, using daily data.

(6) Proportion of risk premium in breakeven inflation.

Table 2a: Inflation Expectations Taking Into Account the Implied S.D. Term Structure

(Pct., avg. of daily observations)

Year	Month	Implied S.D. of NIS/$ exchange rate	Annual inflation S.D.	Inflation risk premium	Inflation expectations	Share of risk premium in break-even inflation
		(1)	(2)	(3)	(4)	(5)
2002	10	12.64	4.33	0.33	2.69	11.05
	11	11.07	3.94	0.30	2.52	10.78
	12	10.98	3.91	0.30	1.90	13.70
2003	1	14.74	4.91	0.38	2.34	13.91
	2	15.27	5.05	0.39	3.40	10.28
	3	15.08	5.00	0.39	2.66	12.67
	4	9.72	3.57	0.28	1.59	14.74
	5	13.47	4.55	0.35	1.04	25.19
	6	13.29	4.51	0.35	1.11	23.93
	7	10.64	3.81	0.29	2.16	11.98
	8	11.11	3.92	0.30	1.41	17.63
	9	8.42	3.24	0.25	1.24	16.75
	10	6.16	2.73	0.21	1.48	12.44
	11	4.69	2.43	0.19	0.93	16.84
	12	5.58	2.60	0.20	0.54	26.91
2004	1	6.35	2.76	0.21	0.67	24.08
	2	6.07	2.70	0.21	0.90	18.79
	3	3.33	2.19	0.17	1.00	14.41
	4	3.17	2.18	0.17	1.41	10.65
	5	4.63	2.41	0.19	1.78	9.48
	6	3.72	2.25	0.17	1.57	9.92
	7	2.55	2.07	0.16	1.33	10.78
	8	1.89	2.00	0.15	1.70	8.32
	9	1.80	1.99	0.15	1.81	7.84
	10	1.69	2.02	0.16	1.88	7.64
	11	5.78	2.63	0.20	1.66	10.89
	12	7.53	3.02	0.23	1.15	16.87
2005	1	7.51	3.02	0.23	1.33	14.90
	2	4.81	2.45	0.19	1.82	9.42
	3	4.43	2.36	0.18	2.00	8.37
	4	3.37	2.19	0.17	1.81	8.53
	5	2.06	2.02	0.16	1.53	9.22
Avg.		7.30	3.09	0.24	1.64	13.72
S.D.		4.33	1.00	0.08	0.63	5.32

(1) Implied volatility from approx. one-month NIS/$ options traded on the Tel Aviv Stock Exchange, calculation made by BOI Monetary Department. The annual volatility is based is extrapolated from the term structure of the implied volatility from three- and six-month Bank of Israel options. The difference between the implied volatility from BOI six-month options and that implied from three- month options serves as an estimate of the slope of the term-structure curve. Based on this slope, the implied volatility from short term options traded in the TASE is extrapolated to annual estimates.

(2) Calculated on the basis of Equation 3b from daily data. We substitute into Equation 3b the daily figure from Column (2) in monthly terms. To obtain the figure in annual terms, we multiplied the result by the square root of 12.

(3) Based on Equation 3d. The figure is the product of the market price of risk and the daily volatility of inflation, from Column 3. The market price of risk is constant and calculated in view of the definition in 3c. The estimated market price of risk is 0.08, calculated from a sample of monthly averages from May 1997–May 2005, based on the yield of a market portfolio composed of 100 leading shares on the Tel Aviv Stock Exchange and the Bank of Israel Monetary rate, which represents the yield on a risk-free asset.

(4) Inflation expectations net of risk premium, calculated on the basis of daily data—Column (1) in Table 2 less Column (3) in Table 2a.

(5) Proportion of risk premium in breakeven inflation — Column (4) in Table 2a divided by Column (1) in Table 2.

Table 3: Standard Deviation of Inflation
(Pct., from monthly observations)

Year	Historical	Expected, based of foreign-exchange option prices	Expected, based on foreign-exchange options with term structure taken into account
	(1)	(2)	(3)
1998	3.22		
1999	1.51		
2000	1.68		
2001	1.45		
2002	2.45	4.13	4.06
2003	1.24	3.77	3.86
2004	1.28	2.73	2.35
2005	1.92	2.65	2.41
Entire period			
Avg.	1.84	3.24	3.09
S.D.	0.68	0.68	1.00

(1) Standard Deviation of monthly rate of change in Consumer Price Index, in annual terms (multiplied by square root of 12).

(2) Annual average of Column (3) in Table 2.

(3) Annual average of Column (2) in Table 2a.

Table 4: Inflation Risk Premium
(Pct. points, avg. of monthly observations)

Year	Based on the difference between annual breakeven inflation and actual inflation	Based on the prices of foreign-exchange options	Based on prices of foreign-exchange options with term structure of implied S.D. taken into account
	(1)	(2)	(3)
1998	2.68		
1999	0.31		
2000	3.56		
2001	0.77		
2002	-4.48	0.32	0.31
2003	1.96	0.29	0.30
2004	2.36	0.21	0.18
2005	0.78	0.20	0.19
Entire period			
Avg.	0.99	0.25	0.24
S.D.	2.47	0.05	0.08

(1) Calculated as an annual average of the difference between annual “breakeven” inflation from the bond market (at a 12-month lag) and the annual actual inflation rate.

(2) Annual average of Column (4) in Table 2.

(3) Annual average of Column (3) in Table 2a.

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