# Explaining the Global Interest Rate Decline

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*By*

Nicholas Lynch

Lewiston, Maine

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Advisor: Julieta Yung, Ph.D.

# Abstract

U.S. 10-year yields have declined by over 11 percentage points from above 14% in 1982 to under 3% in February 2019. This is not only a U.S. phenomenon, but most advanced and emerging economies have experienced a similar decline in long-term yields. Yields can be decomposed into two components: the expectations component and the term premium. The expectations component is defined as the expected average short-term rate over the duration of the bond, while the term premium is the extra compensation for holding a long-term asset. In this thesis, I decompose yields of various countries into the expectations component and the term premium using a term structure model estimated through linear regressions as in Adrian, Crump, and Moench (2013). I report yield decomposition for the following 24 countries: Australia, Brazil, Canada, Chile, China, Colombia, the Czech Republic, the Euro Area, Hungary, Indonesia, Japan, Malaysia, Mexico, Norway, New Zealand, Peru, the Philippines, Poland, South Africa, Singapore, Sweden, Switzerland, the United Kingdom, and the United States; some of which are not well documented in current economic literature. Using both panel and individual data, I provide evidence that decreasing inflation expectations and inflation risk premia are major factors contributing to the decline in global yields. I also construct two global inflation indices and show that global inflation is an important factor driving the decline of long-term yields. Lastly, I provide supporting evidence that inflation targeting by monetary policy authorities is driving down inflation uncertainty and hence yields. Given the importance of long-term interest rates for the decision-making process of households and businesses, understanding the major factors behind the decline in the term premium is of paramount importance for policy makers, governments, corporations, and consumers alike.

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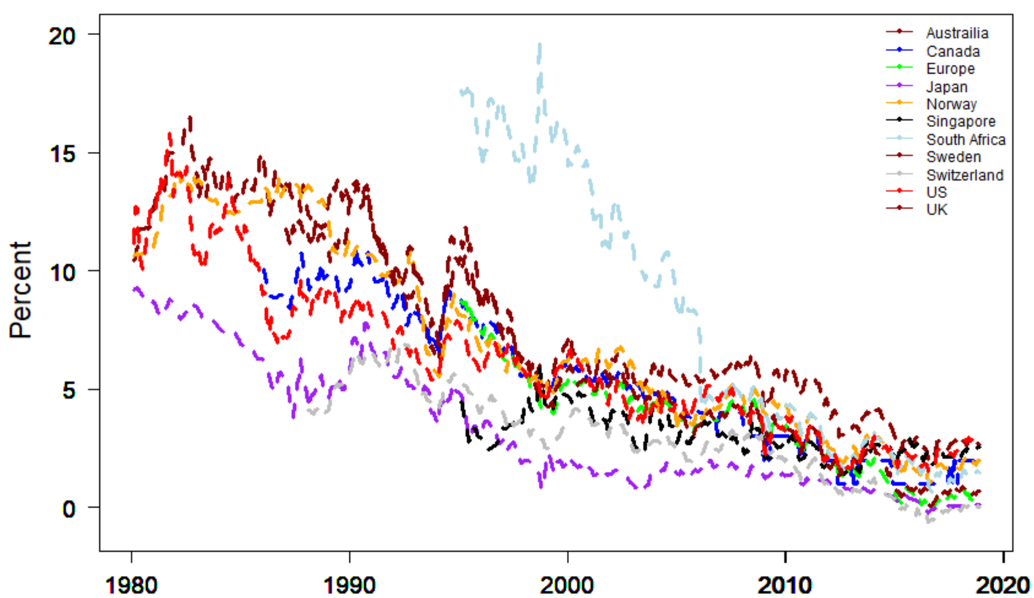
# CHAPTER I

# Introduction

Interest rates are importantdrivers of the global economy: asset cash flows are always discounted by the risk-free rate and currency fluctuations can often be attributed to interest rate differentials. Consumers depend on interest rates for mortgages or student loans and corporations rely on interest rates to make purchasing and investment decisions. Across advanced and most emerging economies, long-term interest rates have been trending lower since the 1980's (see Figure 1). The global decline in long-term interest rates is thought to be explained by a combination of many different factors, such as stable and low inflation rates across developed economies accompanied by slowing global growth. Inflation rates across the world fell as many central banks switched monetary policy regimes to target low and stable inflation of around 2--3%. There is evidence that thelong-run inflation risk premium has been trending downward as well (D'Amico et al., 2018; Grishchenko and Huang, 2013). Long run inflation expectations fell during the 1980's and 1990's and also became more stable, reflecting the introduction of credible inflation targeting by the monetary policy authority; Wright (2011). Following the global recession of 2008, central bank policies drove short-term and long-term rates even lower and many countries still are below the zero lower bound. This environment emerges from the synchronization of global interest rates to the zero lower bound and unconventional policy instruments such as quantitative easing and forward guidance, geared towards monetary accommodation.

Figure 1: Global 10-Year Yields




*Sources:* Bloomberg, FactSet, and Yung (2017).

Investors take on additional risk by holding a longer-term bond instead of a shorter-term bond. Should inflation spike to unexpected levels during the duration of the bond, the real return of that bond will fall proportionally due to the higher relative cost of goods. In addition to the drop in real bond value, investors will now require a higher yield to compensate for the increased inflation risk. Lastly, central banks may decide to hike short-term interest rates to bring inflation closer to the target rate. Theses are inflation and monetary policy risks associated with holding long-term bonds. To balance the additional risk, investors receive a "term premium". The term premium is a measure of how much extra compensation investors require for holding an asset for a longer term compared with rolling over a shorter-term asset. Term premium can eventually be linked to many different factors such as inflation risk and monetary policy uncertainty. The 10-year term premium is the difference between the 10-year yield and the amount investors expect to receive on average if they continue to buy 1-month Treasuries every month for the next ten years. This expected average short-term rate is called the "expectations component". The expectations component is highly dependent on future short-term rates and inflation expectations and is often seen as an indicator of expected monetary policy action.

This paper provides evidence that the term premium component has been falling over the last three decades for many different countries. Term premia are unobservable and therefore must be modeled and estimated. There are many different methods to estimate the term premium, but in this thesis I implement a term structure model of interest rates estimated through linear regressions, specifically presented by Adrian, Crump, and Moench (2013), henceforth ACM. I show in this thesis that term premium is also linked closely with inflation through the "risk compensation" channel. The other component of yields is the expectations component. I decompose yields into the expectations component and the term premium across 24 countries. Term premium data are scarce across developing and some developed nations and I use principal component analysis and linear regressions to infera data set of term premia and expectation components across all maturities for each country.

Next, I investigate whether the decline in term premia –and hence long-term yields– is local or global and whether this phenomenon can be attributed to structural forces or temporary factors. First, using term premia data and factor analysis, I test different hypotheses behind the decline in yields. I seek to understand if a low or negative term premium is here to stay or whether there will be a snap back in the near future, suddenly pushing long-term interest rates higher. Simalar work has been done using yield data of countries thoughout the world. Blake et al. (2015) found that inflation targeting in LATAM was sucessful in mitigating inflation uncertainty. Wright (2011) performed an analysis on the term premia of developed nations with panel data and found lower inflation unceratinty is pushing down term premia.

This thesis is organized as follows. Chapter II explains the ACM method to decompose interest rates into term premium the expectations component. I show the results of replicating their model for the U.S., extending their procedure to a longer time frame, and exploring extensions to the baseline model. Some extensions include correcting for bias, incorporating a constant, and including a different number of factors. I then apply this procedure to decompose the yield curve for 24 different countries and report the results in Chapter A.I. This includes term premia estimates across 24 countries. Local economies are explained by different outside factors and finding the different drivers of local term premia would help build a better picture of a global term premium, determine if term premia are connected, and understand how they co-move. Looking at country-specific term premia would also allow for more precise policy recommendations for local governments.

Chapter IV investigates the impact of inflation and inflation uncertainty on the term premium and expectations component. First, I begin by comparing Treasury Inflation Protected securities (TIPS) to nominal interest rates. Second, I separate and run a historical variance decomposition on U.S. term premium and expectations to determine driving factors of U.S. yields. Next, I regress term premium, expectations, and yields of 1-, 5-, and 10-year maturities on the inflation rate. Using monthly inflation data and principal component analysis, I construct my two global inflation indices to match with the "Consumer Prices for the World" measure constructed by the IMF –except with a monthly frequency. Using these indices I regress the term premium, expectations, and yields of 1- , 5-, and 10-year maturities on global inflation on all countries. Next, I group countries into three categories depending on the influence of global and local inflation on their term premium and expectations. The groups are composed of countries with a high significance of inflation on only term premium, only expectations, or both term premium and expectations. Finally, using the data of all 24 countries as a panel, I further investigate the impact of inflation and inflation uncertainty on term premium and expectations.

Chapter V summarizes the process I went through for this thesis and emphasizes my concluding thoughts on the topic. I also discuss potential caveats and possible expansions to the thesis.

CHAPTER II

# Interest Rate Decomposition

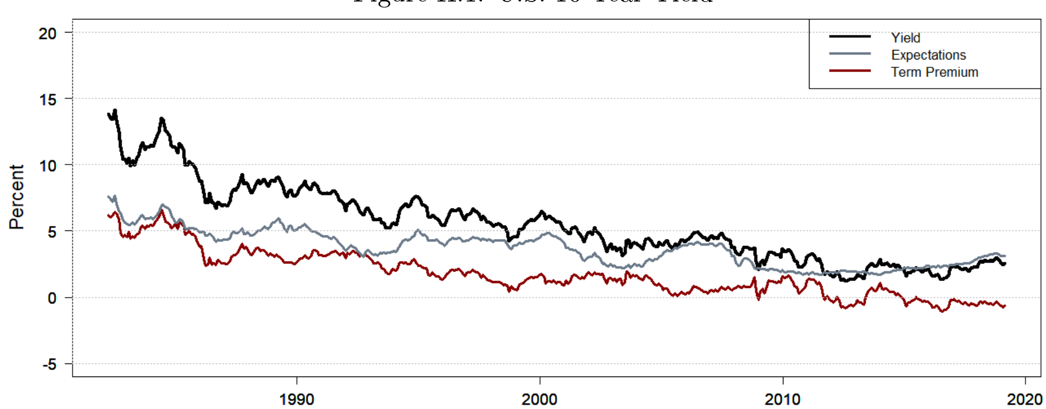
This chapter describes the general setup of term structure models in Section II.1 as well as the setup for the regression-based term structure estimation method for pricing interest rates developed by ACM (2013) outlined in Sections II.2 and II.3. The process starts by decomposing the pricing factors that drive interest rates into predictable and random components by regressing the factors on previous lags. Next, the term premium is implied from Treasury returns and the lagged pricing factors are adjusted for risk compensation.

The ACM method allows one to estimate the term premium by decomposing the yield curve of any country with simple econometric techniques that do not require enhanced computational power. This allows for flexibility in my analysis and enables exploration of different factors and trials across multiple countries. The ACM method also completely decomposes the yield curve into different terms based on the following equation:

$$y_t^{(n)} = \frac{1}{n}\sum_{i=0}^{n-1} \mathbb{E}_t[y_{t+i}^{(1)}] + TP_t^{(n)}. \tag{II.1}$$

$y_t^{(n)}$ is the $n$-year nominal yield at time $t$, $\frac{1}{n}\sum_{i=0}^{n-1} \mathbb{E}_t[y_{t+i}^{(1)}]$ is the average expected risk-free rate over the next $n$ years and $TP_t^{(n)}$ is the term premium at time $t$, or the compensation above the average expected short rate that investors demand to take on the maturity risk in an $n$-year Treasury. Figure II.1 shows the 10-year Treasury yield deconstructed into its components according to Equation (II.1). The 10-year term premium decreased by more than 6 percentage points from 6.23% in June 1984 to −0.37% in November 2018 and the expectations component decreased by more than 4 percentage points from 7.58% to 3.33% in the same period. Most of the decline in the long-term yield appears to be explained by term premia and amplified by declining expectations. Looking past 2012, the 10-year expectations surpassed the 10-year yield, hence implying a negative term premium.

Figure II.1: U.S. 10-Year Yield




*Note:* Results from the ACM model using my own R code, from June 1984 to November 2018.

The data required for the ACM method is only the yield curve. This allows for a simple model that can account for most of the variation in interest rates. Section II.4 shows the results replicating ACM's findings. Finally, I extend their analysis in Section II.5 and perform robustness checks and modifications to their model where appropriate as well as discuss some potential caveats of the estimation method.

## II.1 Term Structure Model: General Setup

In order to estimate the term premium, I use a canonical no-arbitrage Gaussian dynamic term structure model with an exponentially affine stochastic discount factor and affine prices of risk, similar to Dai and Singleton (2000), Duffee (2002), Kim and Wright (2005), and Joslin et al. (2011). The model begins with the assumptions that the risk-free rate ($r_t$) is linear in the factors ($X_t$) as in Vasicek (1977):

$$r_t = \delta_0 + \delta_1^{'} X_t. \tag{II.2}$$

Term structure models typically use at least three factors, which are commonly denoted as the level, slope, and curvature (Litterman and Scheinkman, 1991). In the ACM model the authors use the first 5 factors extracted from principal component analysis (PCA) to model the risk-free rate and all other yields. This specification allows the model to capture more variance than only the first 3;

$$X_t = \{PC_t^1, PC_t^2, PC_t^3, PC_t^4, PC_t^5\}.$$

Next, I define $X_t$ as a $K \times 1$ vector of state variables that evolves as a vector autoregressive process of order 1, VAR(1), with a variance-covariance matrix $\Sigma$, under a "risk-averse" or physical distribution and a "risk-neutral" (denoted with tilde) distribution:

$$X_{t+1} = \mu + \phi X_t + v_{t+1}, \tag{II.3}$$

$$X_{t+1} = \widetilde{\mu} + \widetilde{\phi} X_t + \widetilde{v}_{t+1}, \tag{II.4}$$

$$v_{t+1} | \{X_s\}_{s=0}^t, \ \widetilde{v}_{t+1} | \{X_s\}_{s=0}^t \sim N(0, \Sigma).$$

This specification leads to a market price of risk ($\lambda_t$) that is linear in the factors, with $\lambda_0 = \mu - \widetilde{\mu}$ and $\lambda_1 = \phi - \widetilde{\phi}$ (Duffee, 2002):

$$\lambda_t = \Sigma^{-1/2}(\lambda_0 + \lambda_1 X_t). \tag{II.5}$$

The pricing kernel or stochastic discount factor ($M_{t+1}$) is therefore exponentially affine in the factors,

$$M_{t+1} = exp(-r_t - \frac{1}{2}\lambda_t^{'}\lambda_t - \lambda_t^{'}\Sigma^{-1/2}v_{t+1}). \tag{II.6}$$

The stochastic discount factor ($M_{t+1}$) allows for the model to consistently price bonds of any maturity. I denote $P_t^{(n)}$ as the zero-coupon Treasury bond price with a maturity of $n$ years at time $t$. In this setup bonds can be priced by 3 different specifications:

$$P_t^{(n)} = \mathbb{E}_t[M_{t+1} P_{t+1}^{(n-1)}], \tag{II.7}$$

$$P_t^{(n)} = exp\left(-r_t\right) \mathbb{E}_t^{Q}[P_{t+1}^{(n-1)}]$$

$$P_t^{(n)} = exp\left(A_n + B_n X_t\right).$$

Once bonds of different maturities are priced, yields can be calculated at any point in time:

$$y_t^{(n)} = -\tfrac{1}{n} ln(P_t^{(n)}).$$

## II.2 Term Structure Model: ACM Setup

I also denote $rx_{t+1}^{(n-1)}$ as the one-period log excess holding return of a bond maturing in $n$ periods:

$$rx_{t+1}^{(n-1)} = lnP_{t+1}^{(n-1)} - lnP_t^{(n)} - r_t. \tag{II.8}$$

Thus, by combining equations (II.6) and (II.8) into equation (II.7):

$$1 = \mathbb{E}_t[exp(rx_{t+1}^{(n-1)} - \tfrac{1}{2}\lambda_t'\lambda_t - \lambda_t'\Sigma^{-1/2}v_{t+1})].$$

Next, ACM assume $\{rx_{t+1}^{(n-1)}, v_{t+1}\}$ are jointly normal distributed and thus it follows:

$$\mathbb{E}_t[rx_{t+1}^{(n-1)}] = Cov_t[rx_{t+1}^{(n-1)}, v_{t+1}'\Sigma^{-1/2}\lambda_t] - \tfrac{1}{2}Var_t[rx_{t+1}^{(n-1)}].$$

To simplify and break out different components, ACM define

$$\beta_t^{(n-1)'} = Cov_t[rx_{t+1}^{(n-1)}, v_{t+1}']\Sigma^{-1}.$$

Thus, by using Equation (II.5):

$$\mathbb{E}_t[rx_{t+1}^{(n-1)}] = \beta_t^{(n-1)'}[\lambda_0 + \lambda_1 X_t] - \tfrac{1}{2}Var_t[rx_{t+1}^{(n-1)}].$$

ACM's setup allows for the calculation of the generating process for log excess holding period returns as a function of the factors:

$$rx_{t+1}^{(n-1)} = \beta_t^{(n-1)'}(\lambda_0 + \lambda_1 X_t) - \tfrac{1}{2}(\beta^{(n-1)'}\Sigma\beta^{(n-1)} + \sigma^2 + \beta^{(n-1)'}v_{t+1} + e_{t+1}^{(n-1)}.$$

Finally, I can stack the system across maturities and time periods so $rx$ is an $N \times T$ matrix and define the following new notation:

$$X\_ = [X_0\ X_1\ X_2...X_{T-1}],$$

$$V = [v_1\ v_2...v_T],$$

$$\beta = [\beta^1\ \beta^2...\beta^N],$$

$$B^* = [vec(\beta^{(1)}\beta^{(1)'})...vec(\beta^{(N)}\beta^{(N)'})];$$

this results in the expression:

$$rx = \beta'(\lambda_0 + \lambda_1 X\_) - \frac{1}{2}(B^*vec(\Sigma) + \sigma^2) + \beta'V + e. \tag{II.9}$$

This particular proof in ACM is an important contribution, since no assumptions about serial correlation in yield pricing errors are needed. This is important because yield pricing errors are found to exhibit high autocorrelation, whereas return errors exhibit no autocorrelation; important statistical properties for the estimation of parameters by linear least square methods.

## II.3 Term Structure Model: ACM Estimation

The ACM method of estimating all the parameters and extracting the term premium from the yield curve consists of three simple steps.

1. First, use Equation (II.3) with the first 5 principal components of the yield curve to find the estimated residuals, $\hat{V}$, and residual variance-covariance matrix, $\hat{\Sigma}$, from the factor dynamics by OLS.

2. Next, use the estimated values from step 1 in the following regression, projecting excess returns onto factors and factor residuals: $rx = a + cX\_ + \beta'\hat{V} + e$.This approach results in estimates for $\hat{a}$, $\hat{c}$, $\hat{\beta}$ and $\hat{\sigma}$ (the excess return error variance).

3. From Equation (II.9), it follows that $\beta'\lambda_1 = c$ and $\beta'\lambda_0 = a + \frac{1}{2}(B * vec(\Sigma) + \sigma^2)$. This simplification yields estimates of the market price of risk terms $(\lambda_0, \lambda_1)$: $\hat{\lambda_1} = (\hat{\beta}\hat{\beta})^{-1}\hat{\beta}'\hat{c}$ and $\hat{\lambda_0} = (\hat{\beta}\hat{\beta})^{-1}\hat{\beta}'(\hat{a} + \frac{1}{2}(\hat{B}^{*}vec(\hat{\Sigma}) + \hat{\sigma}^2))$.The resulting market prices of risk can be used to calculate the term premium. Risk-free rate parameters in Equation (II.2) are finally estimated by OLS. Since the ACM method uses simple OLS regressions in all the steps, it is much more computationally efficient than traditional methods of calculating the term premium, such as maximum likelihood and Monte Carlo methods.

## II.4 Replication of ACM Results

For this thesis, I coded the ACM (2013) methodology to ensure I had a solid grasp on the methodology and could continue with the analysis for my thesis. The replication process was done using the original data source in the ACM paper provided by the Federal Reserve Bank of New York (Gürkaynak et al., 2007) and done entirely using *R Studio*. I began by limiting the data set to the period of 1987:01–2011:12 to match the ACM time period. In order to ensure I had followed the process correctly, I replicated most figures in the ACM paper with my own code.

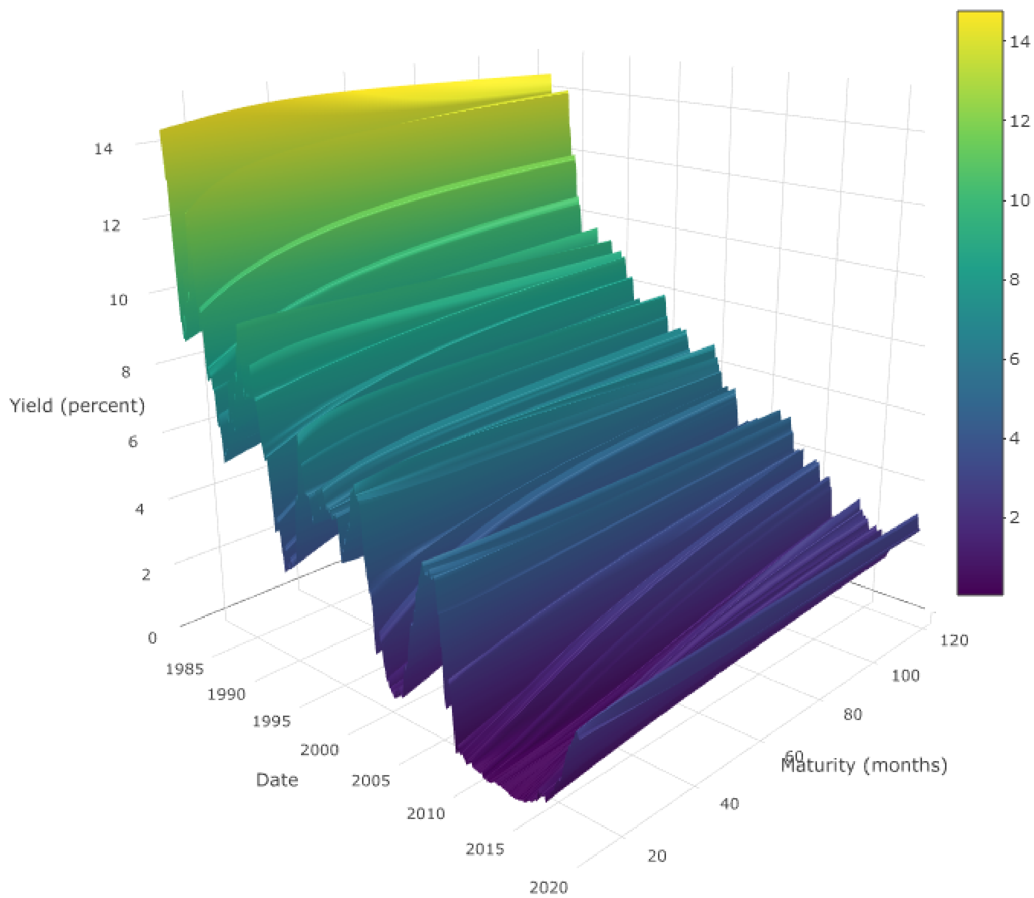
### II.4.1 Yields

To show a summary of the data used to replicate the ACM paper, Table II.1 presents summary statistics of U.S. yields during the 1987:01–2011:12 period, suggesting that, on average, long-term interest rates are higher and less variable than short-term rates. Figure II.2 shows the evolution of U.S. interest rates during this period. Looking at Figure II.2, short-term yields fluctuate quite often and, on average, have fallen lower over time. However, as the maturity increases, the decline has been relatively steady over time.

Table II.1: Summary Statistics: Yields (1987:01−2011:12)

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 300 | 4.308 | 2.421 | 0.131 | 2.177 | 4.822 | 5.919 | 9.658 |
| 24-month | 300 | 4.579 | 2.358 | 0.190 | 2.664 | 4.824 | 6.165 | 9.566 |
| 36-month | 300 | 4.811 | 2.261 | 0.387 | 3.081 | 4.909 | 6.352 | 9.459 |
| 60-month | 300 | 5.209 | 2.069 | 0.878 | 3.657 | 5.248 | 6.657 | 9.317 |
| 84-month | 300 | 5.533 | 1.915 | 1.363 | 3.994 | 5.485 | 6.954 | 9.406 |
| 120-month | 300 | 5.891 | 1.757 | 1.984 | 4.491 | 5.726 | 7.269 | 9.642 |

Figure II.2: U.S. Yield Curve




*Source:* Federal Reserve Bank of New York.

### II.4.2 Factors

Next, the ACM regression utilizes factors of interest rates. To ensure the factors used in this paper match the factors in the ACM paper, I compared the factors found through our procedure with ACM Table 2 on page 117. Looking at the factors in Figure *II*.3, the first three factors follow the structure for level, slope, and curvature. That is, the first factor loads equally across all maturities, whereas the second factor loads negatively on short-term maturities and positively on long-term maturities. Therefore, they are interpreted as "level" and "slope" factors. The third factor loads positively on both extremes of the maturity spectrum, and negatively on the mid-range of the yield curve; thus gaining the label of "curvature" factor. Loadings represent the weight that a factor places on each maturity extracted by the principal component analysis on the variance-covariance matrix of the yields. Table II.2 also shows that the means are zero and the standard deviations are one by construction.

Table II.2: Summary Statistics: Yield Curve Factors (1987:01−2011:12)

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| Factor 1 | 300 | −0.000 | 1.000 | −2.034 | −0.770 | 0.018 | 0.664 | 2.050 |
| Factor 2 | 300 | 0.000 | 1.000 | −2.000 | −0.738 | −0.069 | 0.797 | 2.214 |
| Factor 3 | 300 | −0.000 | 1.000 | −2.820 | −0.650 | −0.031 | 0.722 | 4.185 |
| Factor 4 | 300 | −0.000 | 1.000 | −2.885 | −0.606 | −0.057 | 0.557 | 3.517 |
| Factor 5 | 300 | −0.000 | 1.000 | −4.822 | −0.499 | 0.128 | 0.616 | 3.520 |

Next, looking at the histogram and autocorrelation plots in Figure *II*.4, it is clear the persistence in the factors decreases with each subsequent factor. This figure shows that the interest rate level has a lasting effect across the next year. Although not discussed in the ACM paper, this persistence can introduce bias in the autoregressive process. Bauer et al. (2012) propose a correction method to deal with the persistence of the variables. Given the multi-step approach in the ACM estimation process, bias correction methods can be implemented in the procedure. I incorporated two different bias correction methods in Section II.5.2 as a robustness check during the extension of the main model.

The Shapiro-Wilk test rejects the null hypothesis that the factors are either individually or jointly normally distributed. I also look at the residuals of the VAR for the first three factors (see Figure II.5)., Given that the null hypothesis of normality is rejected by the test on the residuals, if used for forecasting purposes, confidence intervals will require bootstrapping adjustment.

### II.4.3 Term Premium

Next, following the ACM procedure gives us the decomposed yield curve as in Equation (II.1), but with a small modification. ACM do not decompose yields by term premia and expectations, they decompose yields by term premia and risk neutral yields, the difference being a small convexity term (see ACM for details).

For replication purposes, I estimate the same term premium as in ACM by subtracting the risk neutral yield; however, for the rest of the thesis, I will estimate the term premium by the difference between the yields and the expectations component, as in equation II.1. The top row of Figure II.6 can be compared with ACM Figure 1 on page 117, showing that I have successfully replicated their findings. Figure *II*.6 shows the clear decline of the term premium from 1987 to 2012 for the 1-year yield (top) and the 2-year yield (bottom). This term premium serves as a jumping point for future analysis and testing. The U.S. is a major factor in interest rates across the world and having a tested model for U.S. term premia will help significantly in my future analysis.

Figure II.3: Yield Curve Factors and Loadings (1987:01–2011:12)

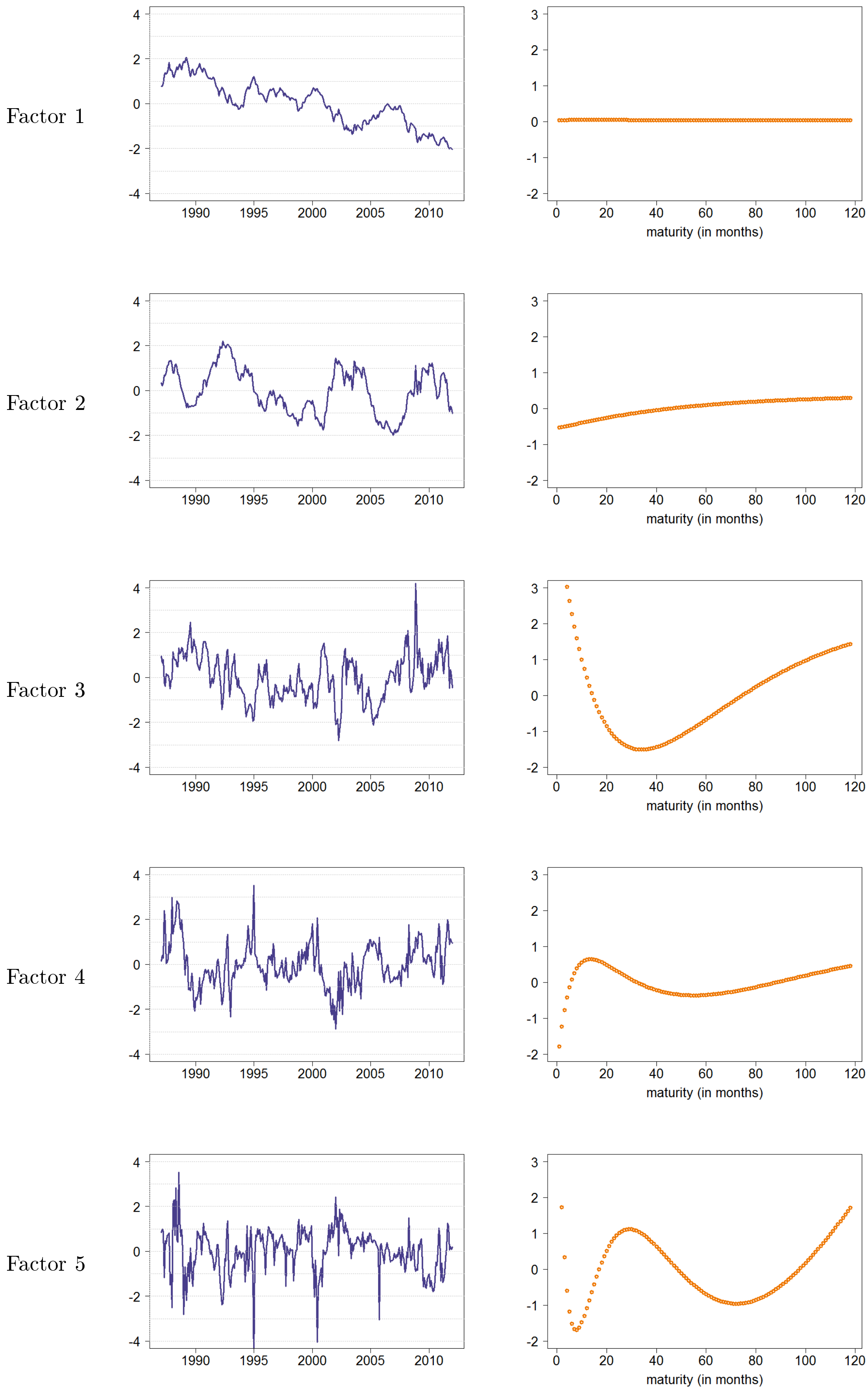


Figure II.4: Yield Curve Factors Distribution and Autocorrelation (1987:01–2011:12)

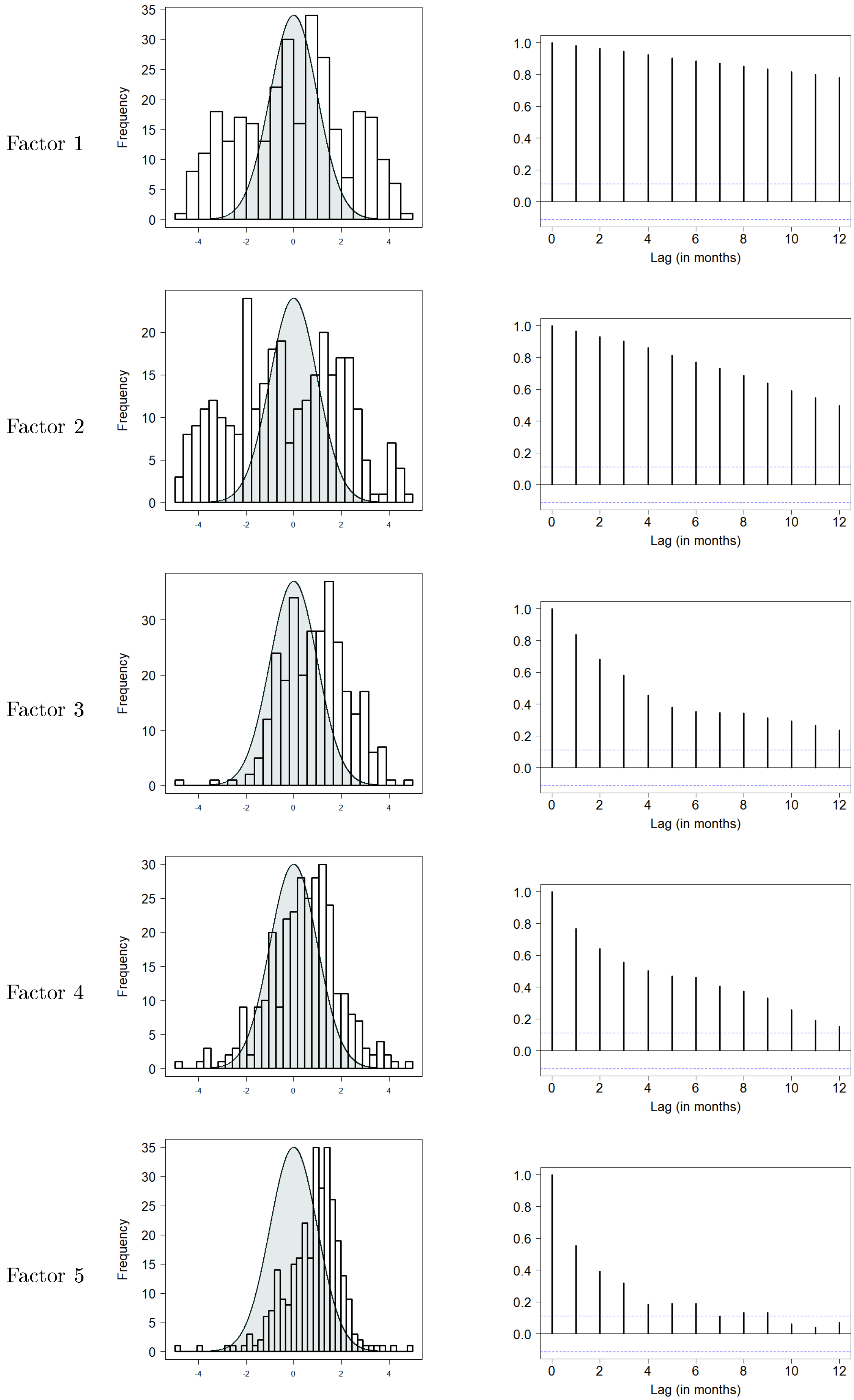


Figure II.5: Residual Histograms

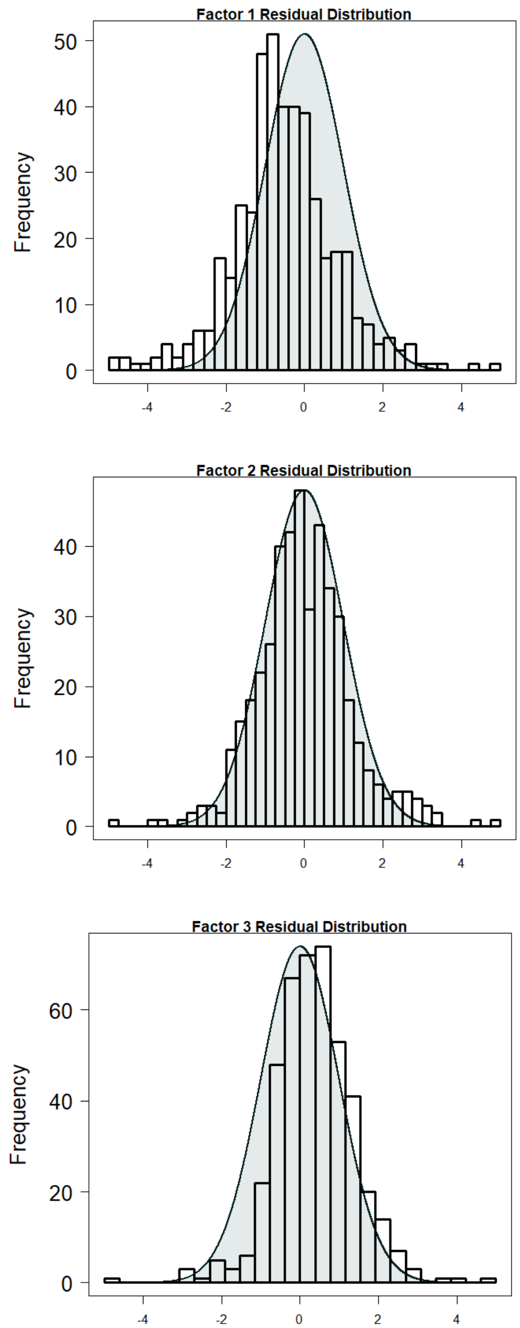
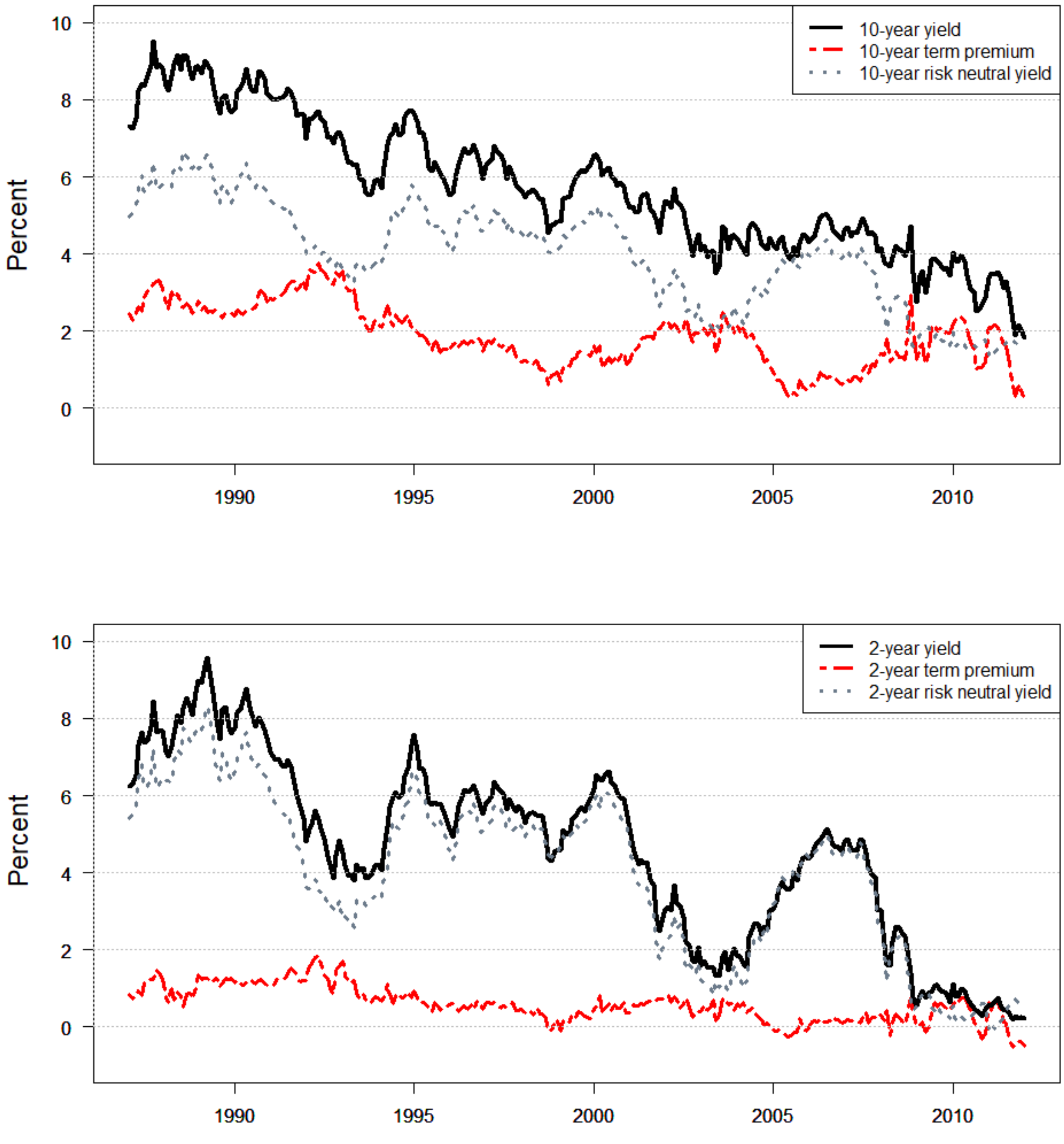


Figure II.6: Yield Curve Decomposed (1987:01–2011:12)




*Note:* Results from the ACM model using my own R code to match ACM Figure 1 on page 117.

### II.4.4 Model Fit

A very important aspect of the analysis is the fit of the model. First, looking at an overview of the yield pricing errors in the 5 factor model in Table II.3, the mean error is quite small (less that 0.004% in absolute value), regardless of the tenor of the bond with a standard deviation slightly higher for the 10-year yield (0.008%) relative to lower maturities (0.004%–0.006%). This can also be viewed graphically in Figure *II*.4.4. It is important to note that pricing error does not change significantly in times of crisis and the model is robust across the full timeline.

Table II.3: Fit Diagnostics: Yield Pricing Errors of 5-Factor Model (%) (1987:01−2011:12)

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 300 | −0.001 | 0.004 | −0.014 | −0.004 | −0.0005 | 0.002 | 0.010 |
| 24-month | 300 | −0.00001 | 0.006 | −0.016 | −0.004 | −0.001 | 0.003 | 0.015 |
| 36-month | 300 | −0.001 | 0.006 | −0.015 | −0.005 | −0.001 | 0.003 | 0.011 |
| 60-month | 300 | −0.003 | 0.005 | −0.013 | −0.007 | −0.002 | −0.0001 | 0.008 |
| 84-month | 300 | −0.003 | 0.004 | −0.014 | −0.006 | −0.003 | 0.001 | 0.010 |
| 120-month | 300 | −0.004 | 0.008 | −0.030 | −0.010 | −0.003 | 0.002 | 0.015 |

Finally, Table II.4 shows the replication of the market prices of risk ($\lambda$) that matched the results in ACM Table 3 on page 118. This replication exercise shows with confidence that I am able to follow the ACM process and decompose yields for the United States. Using the same procedure would allow me to explore more countries and investigate important questions using the estimates I generate.

Table II.4: Market Prices of Risk (1987:01−2011:12)

| 5-Factor Model* | $\lambda_0$ | $\lambda_{1,1}$ | $\lambda_{1,2}$ | $\lambda_{1,3}$ | $\lambda_{1,4}$ | $\lambda_{1,5}$ |
|---|---|---|---|---|---|---|
| Factor 1 | -0.019 | -0.003 | -0.016 | -0.005 | 0.012 | 0.030 |
| Factor 2 | 0.013 | 0.028 | -0.011 | -0.003 | -0.012 | 0.015 |
| Factor 3 | -0.029 | -0.075 | 0.001 | -0.093 | -0.134 | -0.056 |
| Factor 4 | 0.041 | 0.065 | -0.007 | 0.015 | -0.058 | -0.085 |
| Factor 5 | 0.006 | -0.106 | 0.012 | -0.003 | -0.073 | -0.325 |

*Note:* Results from the ACM model using my own R code to compare to ACM Table 3 on page 118.

## II.5 Extension: Model and Estimation Strategy Robustness

In order to ensure the ACM Model and the yield estimations are appropriate for expansion into more countries, I conducted two different tests to account for bias and compare the results with different data sources.

### II.5.1 Data

Ideally, yield curve data would span from 1 month to 10 years for all countries, filling every single possible maturity. In practice, only data for a few maturities along the yield curve are available over time. This data limitation needs to be overcome with an interpolation technique that consistently fills in for the missing gaps in maturity. There are different parametric and non-parametric approaches to estimate the yield curve cross-sectionally; however, the most commonly used method is an extension to the (Nelson and Siegel, 1987) approach by (Svensson, 1995), which estimates the parameters that help fit the yield curve at each point in time,

$$y_t^{(n)} = \beta_0 + \beta_1 \frac{1 - exp\left(-\frac{n}{\tau_1}\right)}{\left(\frac{n}{\tau_1}\right)} + \beta_2 \left[\frac{1 - exp\left(-\frac{n}{\tau_1}\right)}{\left(\frac{n}{\tau_1}\right)} - exp\left(-\frac{n}{\tau_1}\right)\right] + \beta_3 \left[\frac{1 - exp\left(-\frac{n}{\tau_2}\right)}{\left(\frac{n}{\tau_2}\right)} - exp\left(-\frac{n}{\tau_2}\right)\right] \quad \text{(II.10)}$$

The Svensson method consists of estimating the parameters $\{\beta_0, \beta_1, \beta_2, \beta_3, \tau_1, \tau_2\}$ from equation (II.10) to be able to recreate any yield of maturity $n$. This technique allows one to estimate yields, for example, from 1 to 120 months at every point in time and therefore have a consistent and complete data set for each country.

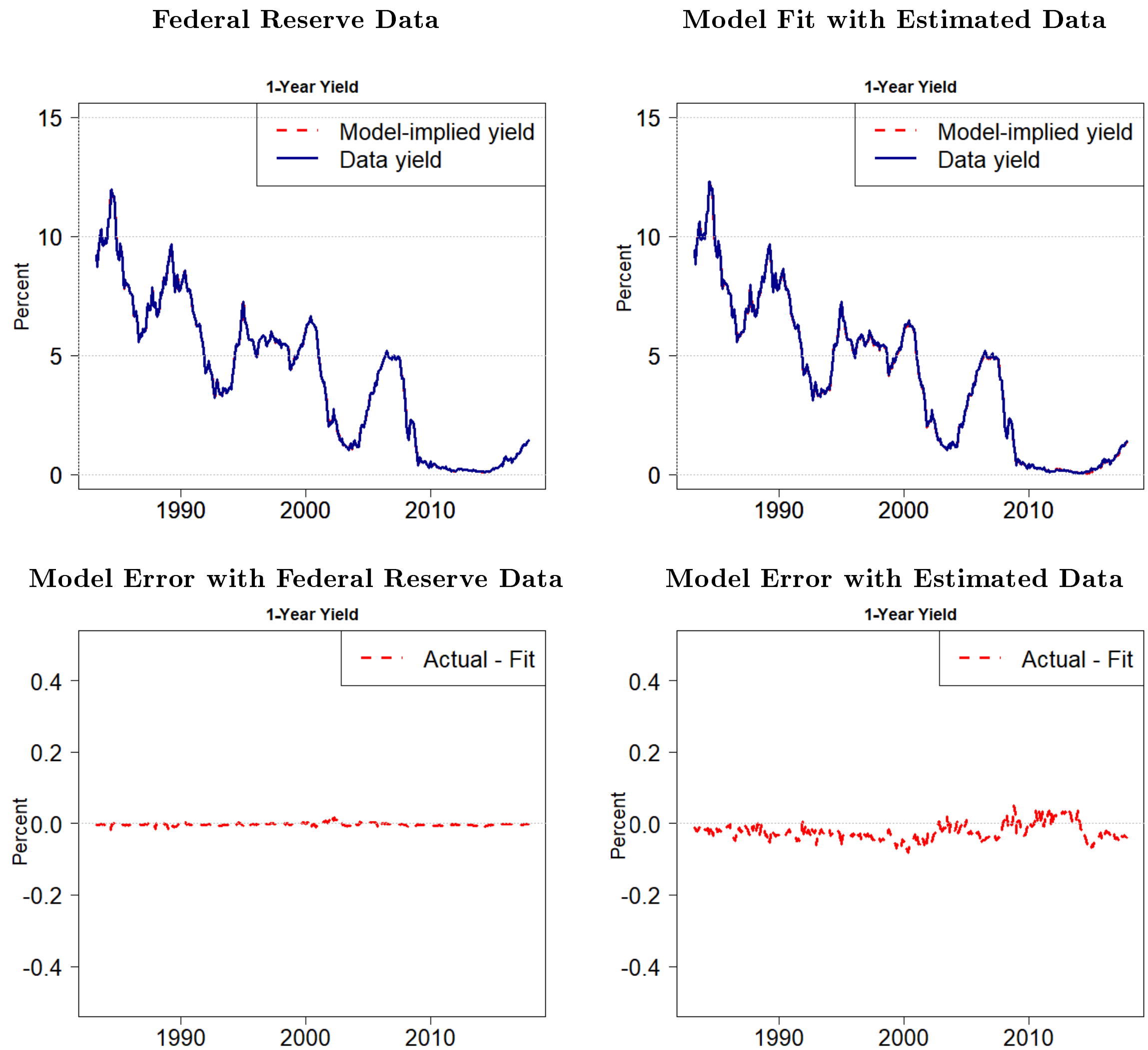
Gürkaynak et al. (2007) have collected Treasury yield data for any maturity available and estimated yields for all maturities using interpolation techniques. ACM utilized the Gürkaynak et al. (2007) data, publicly available at the Federal Reserve Bank of New York website, which I refer to as "Federal Reserve Data". Although these data are the best resource for U.S. yields, the purpose of this thesis is to implement the ACM estimation technique for different countries. This means that when collecting data for other countries, the yield data will have to be inferred from a scarce number of bonds issued on a monthly basis. Therefore, I collect bond data and create a consistent set of yields using interpolation methods for the U.S., which I call "Estimated Data." In order to verify whether the data estimation procedure I implement resembles the estimates produced by the New York Fed, I compare the results of ACM when using my Estimated Data to the model results when using the Federal Reserve Data for the U.S..

I extend the ACM sample period to cover a longer time frame,from March 1982 to October 2017, and find that the results for the model are similar (Figures II.7, II.8, II.9 and II.10); suggesting that when estimating yields for other countries, this method is likely to produce good quality proxies for missing yields.

The results from Figures II.7, II.8 and II.9 show a clear similarity between the model estimated with data from the Federal Reserve and the model estimated with data constructed with interpolation methods. This implies the model has a high accuracy in estimating yields regardless of the data source. The fit for the model estimated with Federal Reserve data is slightly better across all yields and especially in the 1-year yield.

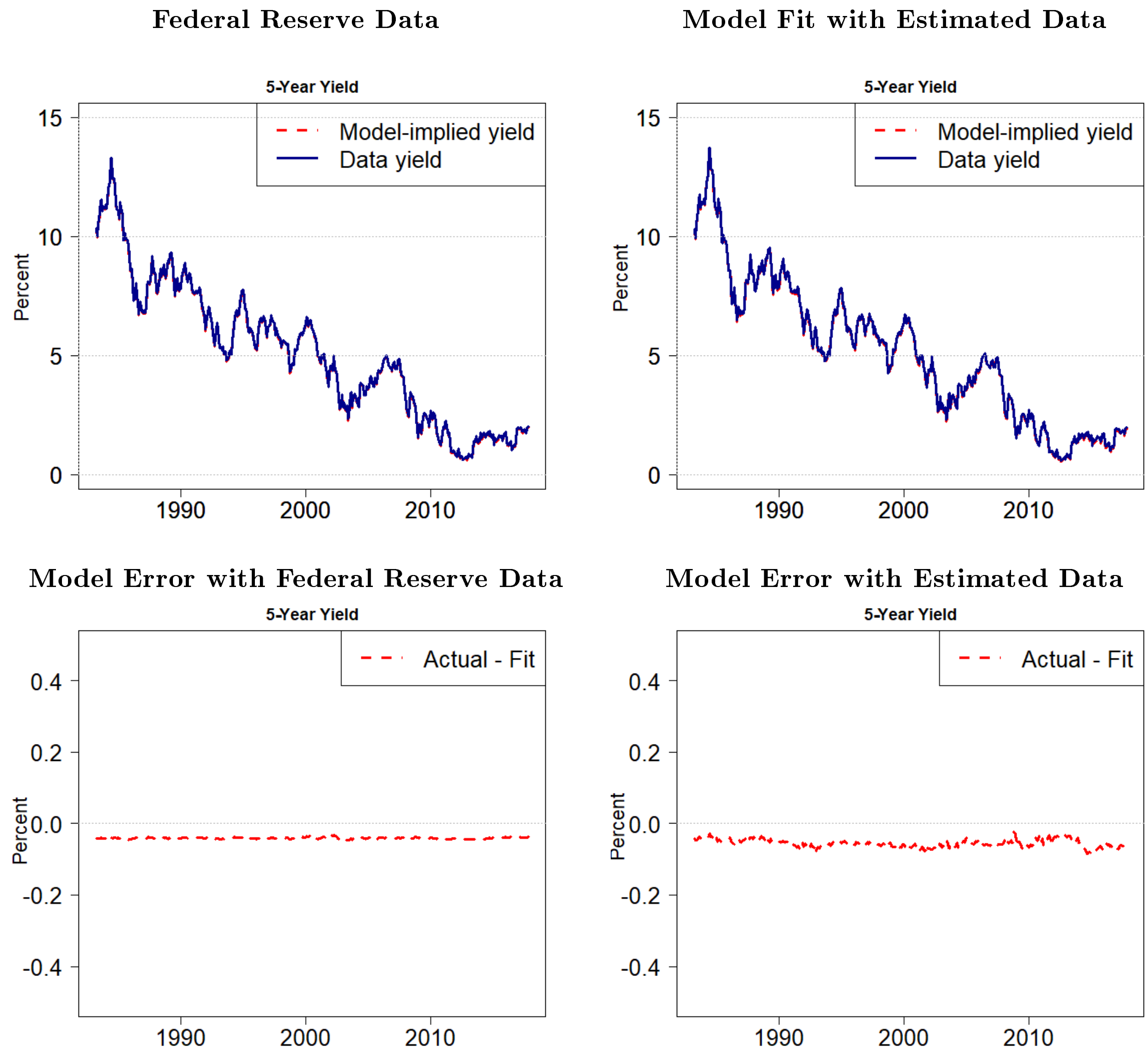
Next, it is important to determine the accuracy of the calculation of the U.S. term premium. Figure II.10 shows the U.S. term premium calculated using the Federal Reserve data versus the term premium calculated using my estimated data. The two figures appear to be very close for all maturities. The results using the Federal Reserve data show a slightly lower term premium, but overall, these results appear to be robust and thus acceptable to continue using the data as estimated from this paper. The Federal Reserve data are likely more accurate, but in order to best compare the results of many different countries, it is best to use the same calculations across countries. For the remaining of this paper, it is assumed that the yield estimated data from this paper will be used and not the Federal Reserve data.

Figure II.7: Model Fit 1 Year Yield



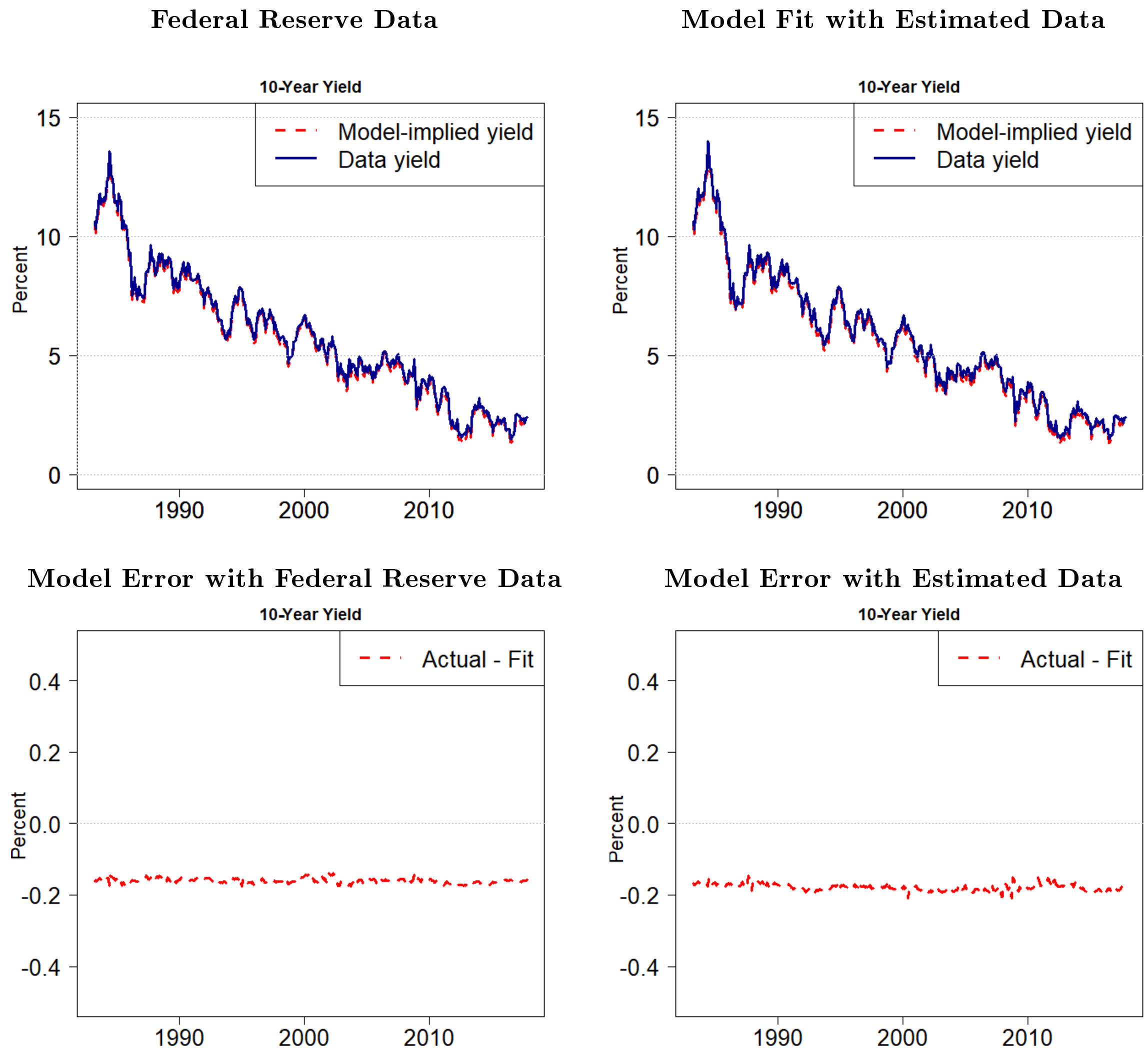

*Note:* Results are from 1982-2017.

Figure II.8: Model Fit 5 Year Yield



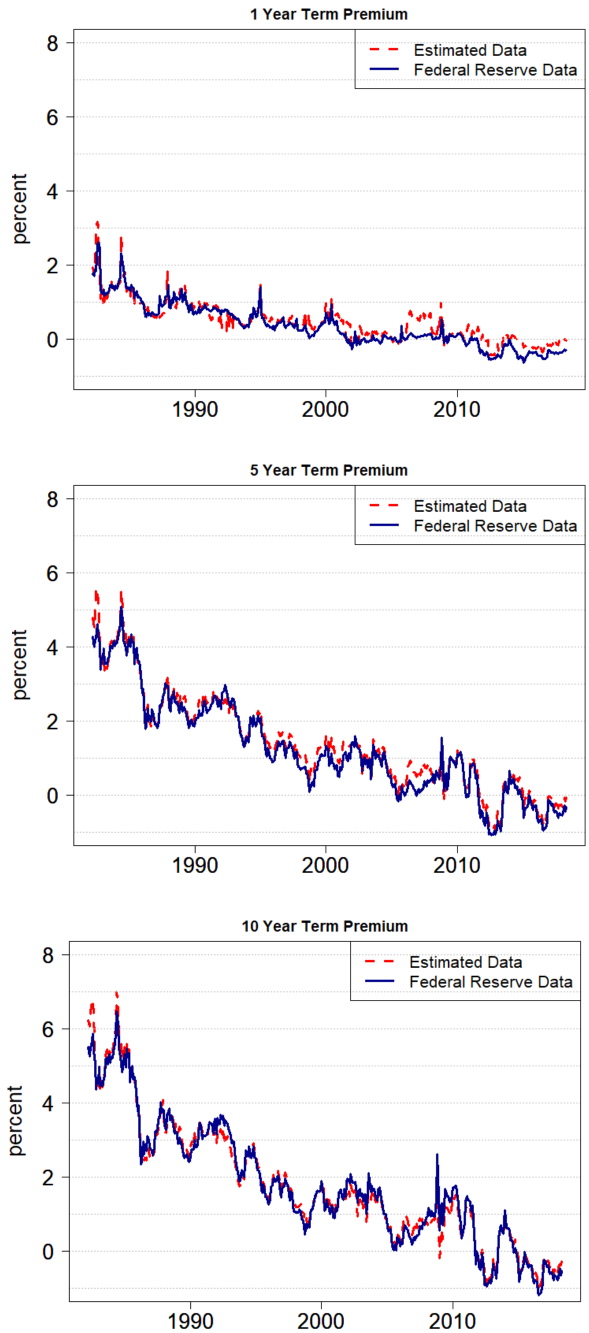

*Note:* Results are from 1982-2017.

Figure II.9: Model Fit 10 Year Yield




*Note:* Results are from 1982-2017.

Figure II.10: Term Premium Estimates



### II.5.2 Bias Correction

As explained in Bauer et al. (2012), henceforth BRW, dynamic term structure models like ACM may suffer from small-sample bias. This implies that interest rates may be estimated to be less persistent than they actually are, implying future short-term interest rates will appear to revert to their unconditional mean too quickly (Bauer et al., 2012).

To correct for the bias, I incorporate two techniques that use Monte Carlo methods to correct for bias. The methods are outlined in BRW. Despite a high level of persistence across the factors, the bias correction methods did not change the resulting term premia estimates significantly.

#### II.5.2.1 Bootstrap Bias Correction (BRW Appendix A)

This method begins with finding the initial non-corrected $\hat{\Phi}$ ($\hat{\theta}$ in BRW) by running the regression and calculating the residuals ($\hat{V}$). Next, I choose a number of trials ($Z$) and for each trial, generate a random initial set of factors. In all cases for bootstrap bias correction I used 1,000 trials. Using an original $\hat{\Phi}$, I therefore generate $Z$ bootstrap samples. Using the same process to find the initial $\hat{\Phi}$, I calculate the mean of the $Z$ trials. Next, I calculate the bias corrected estimates as $\hat{\Phi}^B = \hat{\Phi} - [\bar{\Phi} - \hat{\Phi}]$. Finally, the process ensures that the newly constructed $\hat{\Phi}^B$ has eigenvalues less than 1 to ensure stationarity.

#### II.5.2.2 Indirect Inference Bias Correction (BRW Appendix B)

This method utilizes the same bootstrap bias correction method except that adds an additional adjustment step. The method starts the same way and runs the full bootstrap bias correction approach as described in II.5.2.1. However, after the first run of $Z$ trials, it adjusts the $\hat{\Phi}^B$ (see BRW for details).

#### II.5.2.3 Comparing Bias Correction Methods

Tables II.5, II.6 and II.7 show the $\Phi$ values produced from both bias correction models as well as without any bias correction. The $\Phi$ values do not change significantly, thus it follows that the bias correction for the U.S. may not be necessary.

Next, Figure II.11 examines the difference in term premia across the bias correction methods to help determine if the results are robust to correct for bias. The results show that there is very little change in the term premium estimates for all maturities. This result implies that the U.S. data do not contain any significant bias that once corrected materially alters the results. More research needs to be done in order to understand why the bias correction does not change the estimates of the term premium, contrary to the findings in BRW. The next step to address this would be to replicate the estimates in the BRW paper, which I leave for future research.

### II.5.3 Constant in Model

The ACM model did not include a constant term $\mu$ in their analysis. This is because they assumed $\mu = 0$; however,I would like to know if allowing $\mu$ to be non zero changes the term premium estimates. Table II.8 shows the value of $\mu$ when allowed to be non-zero along with the standard errors. The first factor $\mu$ is statistically significant at the 1% level and the second factor $\mu$ is statistically significant at the 5% level. The remaining 3 factors are not statistically significant. Although the constant is small in every case, an extension of this model for future iterations can re-consider whether this assumptions needs to be relaxed.

Table II.5: $\Phi$ without Bias Correction

| Model | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Factor 1 | 0.99 | 0.00 | 0.01 | 0.00 | -0.01 |
| Factor 2 | 0.00 | 0.97 | -0.01 | 0.02 | 0.03 |
| Factor 3 | 0.00 | 0.05 | 0.85 | 0.04 | -0.03 |
| Factor 4 | -0.01 | -0.03 | -0.01 | 0.80 | 0.06 |
| Factor 5 | 0.03 | -0.01 | 0.05 | -0.05 | 0.60 |

Table II.6: $\Phi$ with Bootstrap Bias Correction

| Model | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Factor 1 | 0.99 | 0.00 | 0.01 | 0.00 | -0.01 |
| Factor 2 | 0.00 | 0.97 | -0.01 | 0.01 | 0.03 |
| Factor 3 | 0.00 | 0.05 | 0.85 | 0.04 | -0.02 |
| Factor 4 | 0.00 | -0.03 | -0.01 | 0.81 | 0.05 |
| Factor 5 | 0.02 | -0.01 | 0.05 | -0.06 | 0.61 |

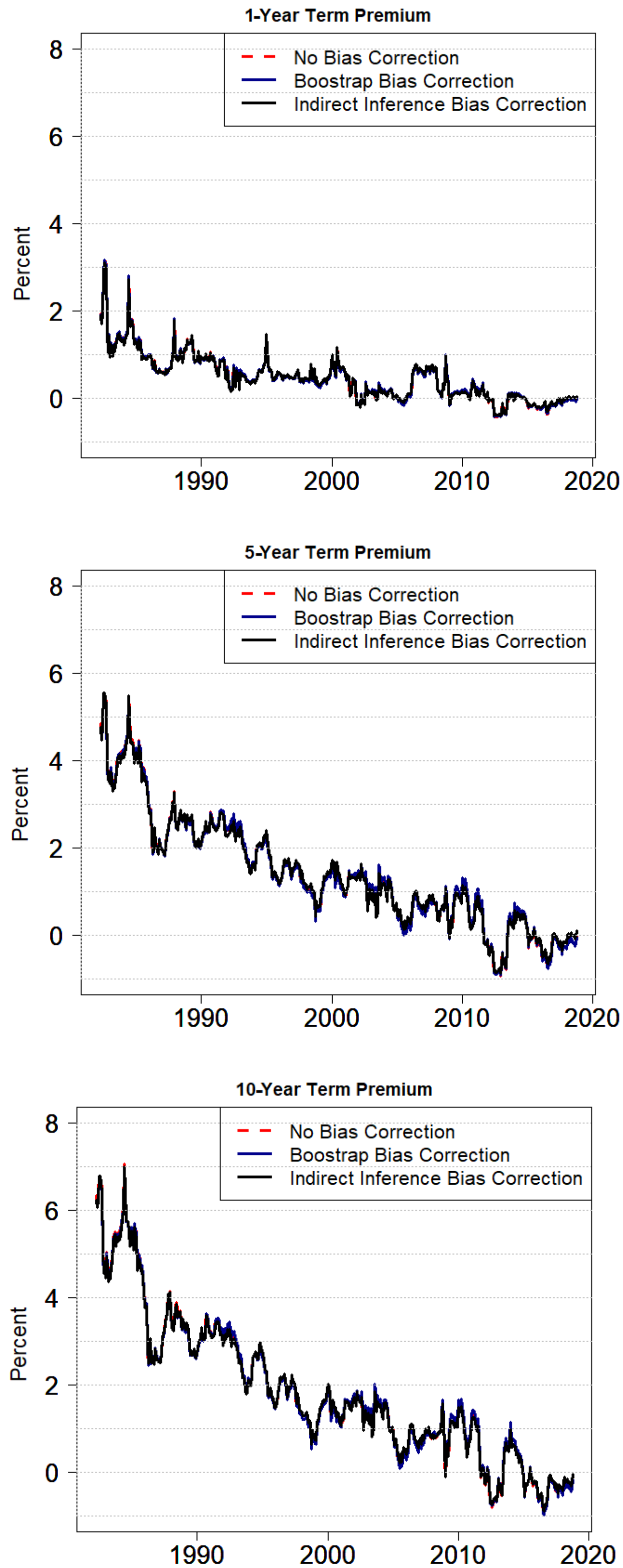
Table II.7: $\Phi$ with Indirect Inference Bias Correction

| Model | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| Factor 1 | 0.99 | 0.00 | 0.02 | 0.00 | -0.02 |
| Factor 2 | 0.00 | 0.96 | -0.01 | 0.02 | 0.03 |
| Factor 3 | 0.00 | 0.05 | 0.83 | 0.04 | -0.03 |
| Factor 4 | -0.01 | -0.04 | -0.01 | 0.79 | 0.06 |
| Factor 5 | 0.03 | -0.01 | 0.05 | -0.05 | 0.59 |

Table II.8: Non-Zero $\mu$

| Model | $\mu$ | Standard Error |
|---|---|---|
| Factor 1 | -0.008 | 0.002 |
| Factor 2 | -0.001 | 0.013 |
| Factor 3 | -0.009 | 0.089 |
| Factor 4 | 0.001 | 0.254 |
| Factor 5 | -0.002 | 0.606 |

Figure II.11: Term Premium Estimates



### II.5.4 Selecting Factors

Figure II.12 shows the estimate of the term premium after adding more factors to the model. There appears to be little change in the term premium after three factors. While two factors provide a similar term premium estimate, Table II.9 shows that mean, median, and max error are much higher across all maturities when you leave out the third factor. The results support traditional literature which implies three factors will provide a strong fit when modeling yields. Since ACM estimation is fitted to excess returns instead of yields, adding additional factors to the model does not necessarily imply a better fit for yields (Malik and Meldrum, 2016).

Table II.9: 2-Factor Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 441 | 0.200 | 0.256 | −0.209 | −0.009 | 0.220 | 0.370 | 1.046 |
| 24-month | 441 | 0.230 | 0.264 | −0.189 | 0.002 | 0.213 | 0.398 | 1.076 |
| 36-month | 441 | 0.226 | 0.223 | −0.237 | 0.054 | 0.224 | 0.377 | 0.921 |
| 60-month | 441 | 0.185 | 0.116 | −0.082 | 0.108 | 0.187 | 0.255 | 0.459 |
| 84-month | 441 | 0.158 | 0.043 | 0.062 | 0.126 | 0.154 | 0.192 | 0.253 |
| 120-month | 441 | 0.193 | 0.098 | −0.119 | 0.124 | 0.189 | 0.258 | 0.457 |

Table II.10: 3-Factor Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 441 | 0.098 | 0.093 | −0.095 | 0.031 | 0.100 | 0.157 | 0.448 |
| 24-month | 441 | 0.072 | 0.065 | −0.063 | 0.025 | 0.060 | 0.101 | 0.325 |
| 36-month | 441 | 0.063 | 0.043 | −0.005 | 0.032 | 0.054 | 0.089 | 0.184 |
| 60-month | 441 | 0.099 | 0.053 | −0.054 | 0.069 | 0.107 | 0.137 | 0.252 |
| 84-month | 441 | 0.162 | 0.048 | 0.053 | 0.125 | 0.170 | 0.192 | 0.311 |
| 120-month | 441 | 0.236 | 0.060 | 0.100 | 0.191 | 0.228 | 0.279 | 0.440 |

Table II.11: 4-Factor Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 441 | 0.089 | 0.083 | −0.066 | 0.024 | 0.091 | 0.144 | 0.401 |
| 24-month | 441 | 0.072 | 0.057 | −0.013 | 0.018 | 0.065 | 0.110 | 0.244 |
| 36-month | 441 | 0.072 | 0.042 | −0.002 | 0.034 | 0.070 | 0.100 | 0.195 |
| 60-month | 441 | 0.110 | 0.045 | 0.043 | 0.075 | 0.106 | 0.132 | 0.275 |
| 84-month | 441 | 0.169 | 0.063 | 0.074 | 0.120 | 0.162 | 0.202 | 0.389 |
| 120-month | 441 | 0.254 | 0.057 | 0.161 | 0.212 | 0.248 | 0.290 | 0.425 |

### II.5.5 Standard Errors

To test the precision of the market price of risk ($\lambda$), I use standard errors converted into t-statistics (see Table II.14). During the replication phase, these t-stats did not perfectly match the calculations in ACM, however the results held similar significance levels and is likely due to rounding errors.

Table II.12: 5-Factor Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 441 | 0.054 | 0.055 | −0.063 | 0.010 | 0.057 | 0.092 | 0.283 |
| 24-month | 441 | 0.047 | 0.036 | −0.038 | 0.019 | 0.052 | 0.070 | 0.195 |
| 36-month | 441 | 0.063 | 0.040 | −0.020 | 0.031 | 0.068 | 0.088 | 0.246 |
| 60-month | 441 | 0.094 | 0.037 | 0.018 | 0.067 | 0.097 | 0.117 | 0.219 |
| 84-month | 441 | 0.130 | 0.028 | 0.070 | 0.109 | 0.129 | 0.147 | 0.212 |
| 120-month | 441 | 0.218 | 0.031 | 0.157 | 0.191 | 0.217 | 0.235 | 0.352 |

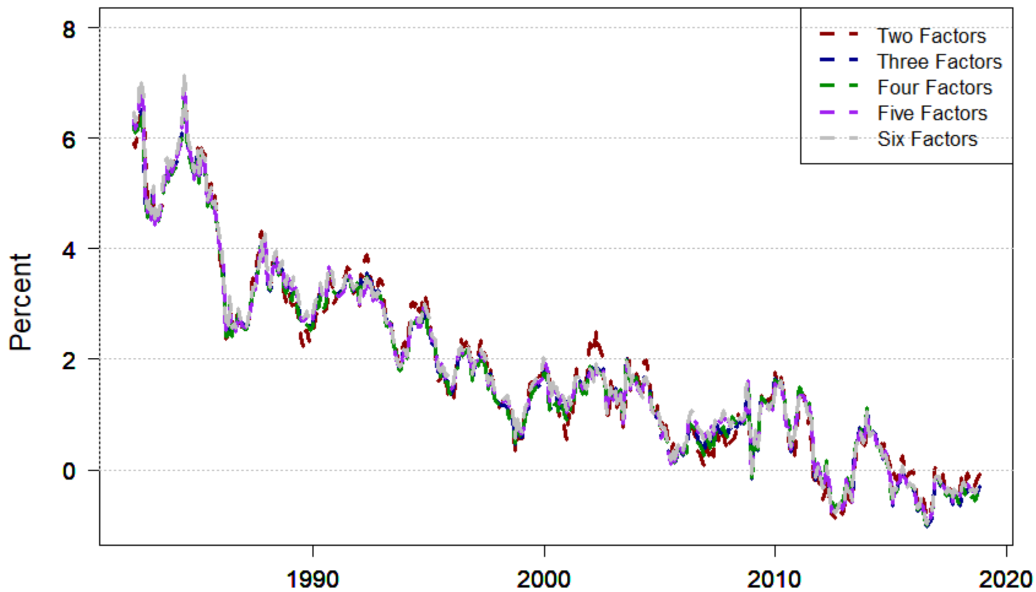
Table II.13: 6-Factor Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 441 | 0.0001 | 0.010 | −0.026 | −0.007 | −0.0002 | 0.005 | 0.030 |
| 24-month | 441 | 0.005 | 0.008 | −0.039 | 0.001 | 0.005 | 0.010 | 0.025 |
| 36-month | 441 | 0.014 | 0.006 | −0.008 | 0.010 | 0.014 | 0.018 | 0.030 |
| 60-month | 441 | 0.043 | 0.005 | 0.026 | 0.040 | 0.043 | 0.046 | 0.055 |
| 84-month | 441 | 0.086 | 0.005 | 0.062 | 0.083 | 0.086 | 0.089 | 0.096 |
| 120-month | 441 | 0.171 | 0.006 | 0.150 | 0.168 | 0.172 | 0.175 | 0.188 |

Table II.14: Market Prices of Risk T-Stats

| Model* | $\lambda_0$ | $\lambda_{1,1}$ | $\lambda_{1,2}$ | $\lambda_{1,3}$ | $\lambda_{1,4}$ | $\lambda_{1,5}$ |
|---|---|---|---|---|---|---|
| Factor 1 | −8.94 | −3.68 | −2.30 | 0.25 | −1.69 | 6.04 |
| Factor 2 | 4.17 | 4.70 | −1.94 | 1.64 | −0.63 | −3.20 |
| Factor 3 | −0.72 | −4.26 | 2.59 | −4.14 | −6.00 | 6.48 |
| Factor 4 | 0.20 | 0.81 | −1.38 | 1.86 | −3.21 | −6.32 |
| Factor 5 | 0.02 | 1.12 | 1.49 | −1.92 | 0.83 | −5.34 |

Figure II.12: U.S. Term Premium Estimates




*Source:* Author's Calculations.

### II.5.6 Extracting Illiquidity Measures from Noise Estimates

My model also allows me to extract a "noise" measure as in Hu et al. (2013). HPW (2013) found that the "noise" or difference between data and model estimates had predictive properties. HPW defined noise as:

$$Noise_t = \sqrt{\frac{1}{N_t}\sum_{i=1}^{N_t}[y_t^{(n)} - \hat{y_t}^{(n)}]^2}, \tag{II.11}$$

where $y_t^{(n)}$ is yield at time $t$ with a maturity of $n$, $\hat{y_t}^{(n)}$ is the model-implied yield at time $t$ with a maturity of $n$, and $N_t$ denotes the number of maturities included in the noise. I would like to utilize the noise found from the model to make conjectures as well. Noise is a new emerging data source that often contain predictive properties and could be helpful as a measure of illiquidity or market distress. The Appendix Chapter A.II shows noise measures for 24 countries.

## CHAPTER III

# Decomposing Interest Rates for 24 Countries

To better understand why interest rates have declined in the United States, it is important to first learn whether interest rates are declining in other countries as well. Given the lack of yield curve data availability, this chapter describes the data collection process for as many countries as possible and decomposes each country's yield curve into term premia and expectations with the term structure model. The final sample includes 24 countries across six continents for the longest possible time frame, as permitted by data availability, detailed in Section III.1. Section III.2 describes the final results for the U.S., while all other countries are detailed in Appendix Chapter A.I. For each country, a 3D plot of all yields for maturities 3--120 months shows the change in yields across time and maturities. In each case, 3 factors were obtained by principal component analysis to reduce the dimensionality of the data set, with some exceptions when needed. I show a standardized plot of the 3 factors to visualize the variables that explain yield curve variation across maturities. Next, a table representing the fit of the model is shown in order to provide a measure of the model's accuracy in describing the yield curve. This diagnostic is followed by a plot showing the decomposition of 2-year yields and 10-year yields to provide a visual representation of short- and long-term interest rates. These plots show whether the variation or decline in yields can be explained by a change in the term premium, the expectations component, or both. Lastly, a 3D plot showing the term premium for 12--120 month maturities and the expectations component for the same maturities provides a comprehensive representation of the yield curve.

## III.1 Data Summary

The data for each country come from various sources. Data for each country prior to 2006 originate from Yung (2017) and details on these data can be found in Data Appendix A. After 2006, the data originate from FactSet. In every case, data are end of month, in local currency, and expressed in percentage. Dates for the period of the data used in this paper can be found in Table III.1.

The model specified by ACM utilized 5 principal components as factors. These factors were generated using Principal Component Analysis –henceforth PCA. PCA is the eigenvalue-eigenvector decomposition of the covariance of yields, allowing for a large dataset to be reduced to a smaller set of factors, capturing the common movements across all maturities. I estimate the ACM model for every country using the first 3 factors extracted with PCA. There are several reasons why I choose 3 factors. First, the first three factors alone can account for the majority of the cross-sectional movement in yields. For example, the first factor extracted by PCA from the U.S. yield curve explains 98.81% of movements during the February 1975 to February 2019 period, the second factor accounts for 1.11%, and the third factor explains 0.06%, for a combined 99.97% of cross-sectional movements with only 3 factors. Second, many papers tend to favor a parsimonious approach and choosing 3 factors is consistent with other models in the literature (e.g., Diebold et al., 2007). Finally, Litterman and Scheinkman (1991) have provided interpretation to these factors, according to the effect they have on the yield curve, making the factors easier to relate to the shape of the yield curve.

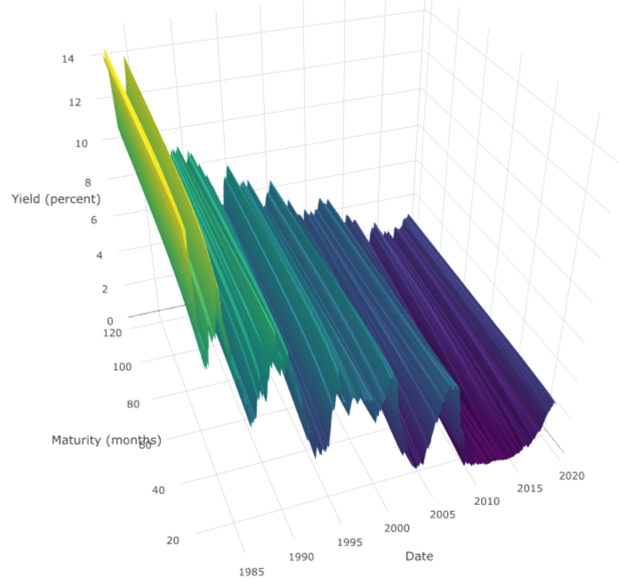
Table III.1: Country Data Summary

| Country | Start | End |
|---|---|---|
| Australia | March 1983 | February 2019 |
| Brazil | April 2007 | February 2019 |
| Canada | February 1986 | February 2019 |
| Chile | May 2005 | February 2019 |
| China | May 2004 | February 2019 |
| Colombia | June 2006 | February 2019 |
| Czech Republic | January 2001 | February 2019 |
| Euro Area | January 1995 | February 2019 |
| Hungary | April 2001 | February 2019 |
| Indonesia | June 2003 | February 2019 |
| Japan | September 1974 | February 2019 |
| Malaysia | October 2001 | February 2019 |
| Mexico | September 2003 | February 2019 |
| New Zealand | January 1995 | February 2019 |
| Norway | January 1995 | February 2019 |
| Peru | June 2006 | February 2019 |
| Philippines | June 2006 | February 2019 |
| Poland | January 2001 | February 2019 |
| Singapore | February 1995 | February 2019 |
| South Africa | February 1995 | February 2019 |
| Sweden | February 1987 | February 2019 |
| Switzerland | February 1988 | February 2019 |
| United Kingdom | February 1975 | February 2019 |
| United States | Febuary 1975 | February 2019 |

## III.2 United States

U.S. government bond data for this thesis are from February 1975 to February 2019. This time period contains data on 3- and 6-month yields and 1-, 2-, 3-, 5-, 7-, 10- and 30-year bonds. The U.S. has a consistent decline in long-term interest rates as seen in Figure III.1. The 10-year yield decreased by more than 11 percentage points from 14.2% in March 1982 to 2.74% in February 2019.

Figure III.1: United States: Yield Curve (left) and Yield Curve Factors (right)



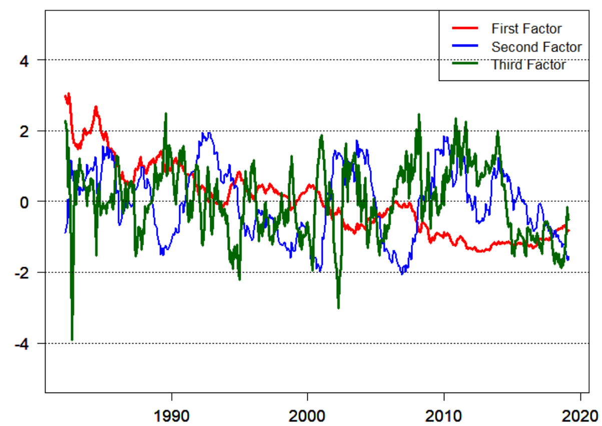




Table III.2: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 444 | 0.098 | 0.092 | −0.094 | 0.032 | 0.100 | 0.156 | 0.447 |
| 24-month | 444 | 0.071 | 0.065 | −0.063 | 0.025 | 0.060 | 0.100 | 0.324 |
| 36-month | 444 | 0.062 | 0.043 | −0.011 | 0.031 | 0.053 | 0.088 | 0.184 |
| 60-month | 444 | 0.098 | 0.054 | −0.056 | 0.067 | 0.105 | 0.137 | 0.254 |
| 84-month | 444 | 0.161 | 0.049 | 0.050 | 0.123 | 0.168 | 0.192 | 0.315 |
| 120-month | 444 | 0.235 | 0.061 | 0.099 | 0.190 | 0.227 | 0.278 | 0.441 |

Figure III.2: United States: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

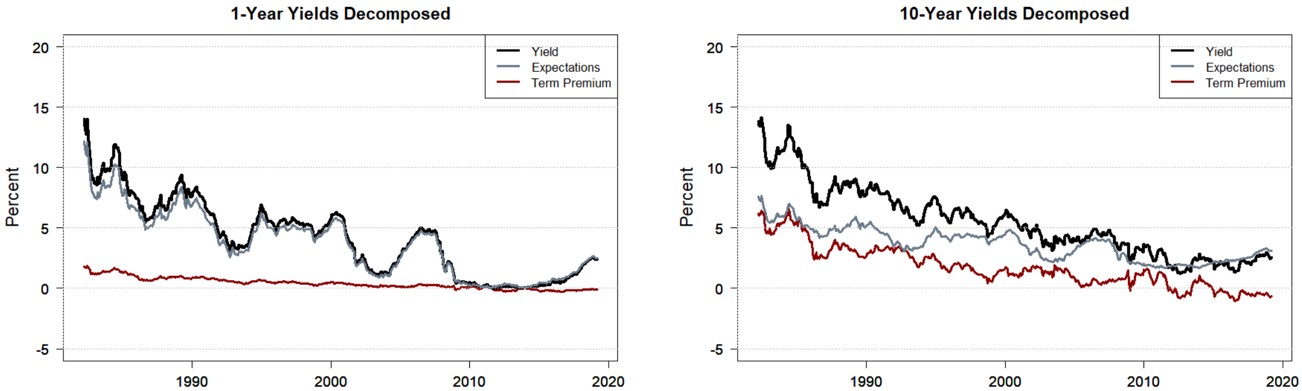



Figure III.3: United States: Term Premium Curve (left) and Expectations Yield Curve (right)

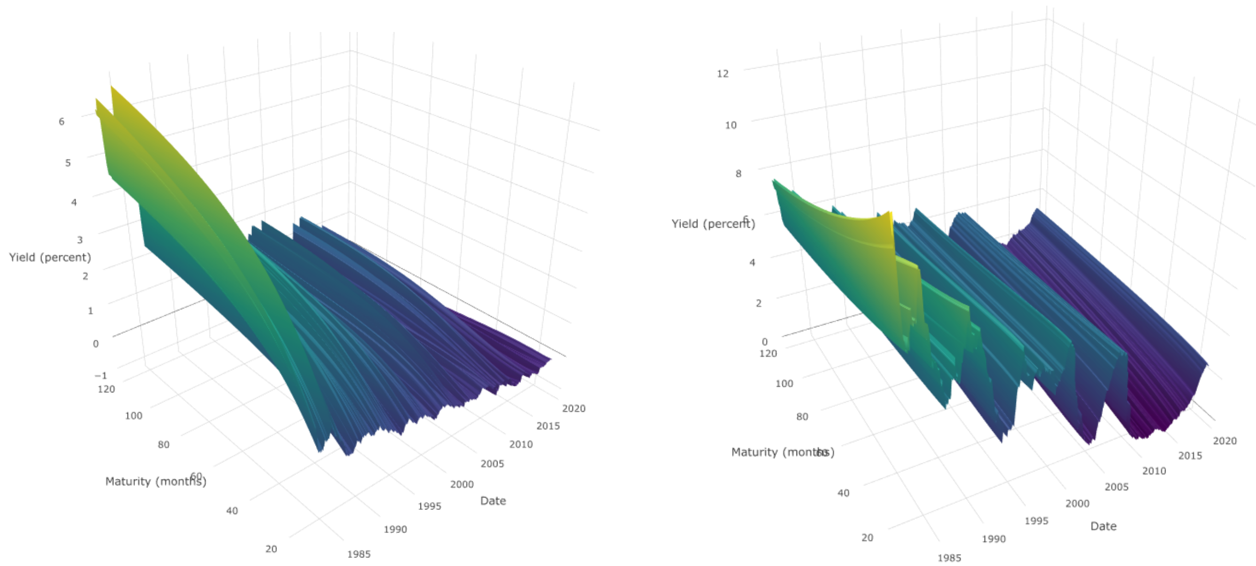



Figure III.2 shows a 10-year yield decomposition which contains both a declining 10-year expectations term and 10-year term premium. The 10-year term premium decreased by almost 7 percentage points from 6.19% in March 1982 to --0.64% in February 2019 and the 10-year expectations component decreased by 4.49 percentage points from 7.62% to 3.13% during the same period. Most of the decline in long term rates appears to be explained by term premia and amplified by declining expectations.

CHAPTER IV

# Effect of Inflation on Term Premium and Expectations

## IV.1 U.S. Focus

This section focuses on the U.S. due to the ample availability of data and major relevance to the global economy. From 1970's to the mid 1990's, inflation tended to be high even when consumption growth was low. However, after the 1990's demand-side type of shocks that simultaneously lowered inflation and consumption growth have been increasingly important (Campbell et al., 2017). This finding implies a lower and possibly negative risk premium in bonds. The low and negative term premium throughout many of the developed nations in this thesis support this theory. Historically, the most important factor affecting nominal term premia has been the risk of unexpected inflation because unexpected inflation erodes the purchasing power of fixed nominal bond payments (Piazzesi et al., 2007). The declining importance of inflation risks changed the characteristics of bonds to more of a hedge instead of a risky asset (Campbell et al., 2017).

### IV.1.1 Real vs Nominal Yield Curve Decomposition

The U.S. Treasury Inflation Protected securities, commonly referred to as TIPS, were first issued in 1999 and are hedged to monthly CPI with a 2.5 month delay. These TIPS are used by investors and economists as a proxy for real or inflation-adjusted U.S. interest rates. Using all available TIPS for every maturity between 5 and 20 years, I use the Svennson method to estimate yields across the entire maturity spectrum, as described in Section II.5.1. I therefore built an entire set of TIPS yields for all maturities between 1--120 months for the period of January 1999 to February 2019. Treasury yields at maturity $n$ in years $\left(y_{t,N}^{(n)}\right)$ can be decomposed into the real yields of the same maturity $\left(y_{t,R}^{(n)}\right)$, the expected inflation over $n$ years $\left(\pi_{t,e}^{(n)}\right)$, the inflation risk premium that compensates for holding an inflation-sensitive asset $\left(IRP_t^{(n)}\right)$, and a liquidity premium component $\left(\alpha_{t,liquidity}^{(n)}\right)$. Investors of nominal yields must be compensated for expected inflation as well as the risk that expectation is wrong. Given the worldwide high demand of U.S. dollar denominated safe assets, U.S. Treasuries are a very liquid market. However TIPS are not as liquid and investors must be compensated for this extra liquidity risk. Multiple sources acknowledge that ignoring this risk causes incorrect estimates and that the premium is not constant (e.g. (D'Amico et al., 2018) & Abrahams et al., 2013):

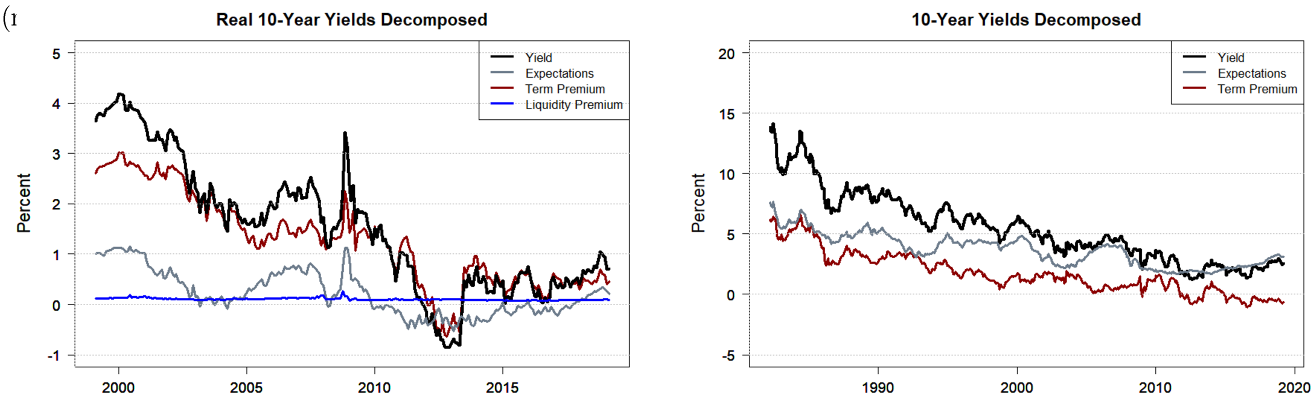
$$y_{t,N}^{(n)} = y_{t,R}^{(n)} + \pi_{t,e}^{(n)} + IRP_t^{(n)} + \alpha_{t,liquidity}^{(n)}. \tag{IV.1}$$

Abrahams et al. (2013) outline a method similar to ACM to decompose real yields into expected inflation, inflation risk premium, and liquidity. Looking at the results of this analysis, Abrahams et al. (2013) also use the ACM method as described in Chapter II with some small modifications to account for the illiquidity of TIPS. The modification involves adding an unspanned factor in the model –a factor that is not already explained (or spanned) by the yield curve. Unspanned factors were also proposed in Adrian et al. (2013) and allow for outside variables that will factor into risk averse estimates and not to risk neutral estimates. The modification of ACM involves adjusting Equation (II.3) to include spanned factors ($X_t^s$) and the new unspanned factors ($X_t^u$).

$$\begin{bmatrix} X^s_{t+1} \\ X^u_{t+1} \end{bmatrix} = \mu + \phi \begin{bmatrix} X^s_t \\ X^s_t \end{bmatrix} + \begin{bmatrix} v^s_{t+1} \\ v^u_{t+1} \end{bmatrix} \tag{IV.2}$$

In order to extract the additional illiquidity premium, I use the noise estimates described in Section II.5.6. Since this liquidity premium is only relative to nominal yields, I assume nominal yields of U.S. Treasuries have no illiquidity premium. Following Abrahams et al. (2013), I first calculated the nominal yield fit for the U.S. using 3 factors from the joint data and the same for TIPS. Next, I found the noise from each model and took the difference to calculate the illiquidity factor. Figure IV.1 shows that both real and nominal yields are experiencing a decline. The decline and variation of real yields can be explained mostly by the term premium. However, the decline in nominal yields is driven by both the term premium and the expectations component, suggesting that inflation is a major factor in explaining expectations for the U.S. Contrary to my findings, literature suggests that the spike in value during 2008 was not driven by expectations, but instead by illiquidity and an embedded floor in yields that increased in value due to fears of deflation (D'Amico et al., 2018).

Figure IV.1: United States: 10-Year TIPS Yields Decomposed (left) and 10-Year Treasury Yields Decomposed (




Starting with the U.S., the term premium and inflation have a strong relationship. The difference between U.S. nominal yields and TIPS yields is the breakeven inflation rate $\left(\pi^{(n)}_{t,B}\right)$. This rate is comprised of the expected inflation throughout the maturity of the bond, the compensation for additional inflation uncertainty $\left(E[\pi^{(n)}_{t,unc}]\right)$, and a liquidity premium due to a lower relative supply $(\alpha_{t,liquidity})$,

$$y^{(n)}_{t,N} - y^{(n)}_{t,R} = \pi^{(n)}_{t,B} = \pi^{(n)}_{t,e} + E[\pi^{(n)}_{t,unc}] + \alpha_{t,liquidity}. \tag{IV.3}$$

This measure of breakeven inflation decomposition is very similar to the term premium decomposition. The term premium captures more risk and uncertainty than breakeven inflation; however, inflation is a main factor in term premium as well. Wright (2011) finds strong evidence that term premium is strongly linked with long-term inflation uncertainty. The next question would be, how much of the term premium is driven by inflation and inflation uncertainty? Across most countries, some main risk factors include inflation uncertainty, monetary policy uncertainty $\left(E[MP^{(n)}_{t,unc}]\right)$, probability of default $\left(P(Default^{(n)}_t)\right)$, political uncertainty $(E[Political_{t,unc}])$ and exchange rate or currency uncertainty $(E[Currency_{t,unc}])$. While this is not the entire risk spectrum included in the term premium, I believe these represent some major risks for most countries:

$$TP_t^{(n)} = \beta_0 + \beta_1 E[\pi_{t,unc}^{(n)}] + \beta_2 E[MP_{t,unc}^{(n)}] + \beta_3 P(Default_t^{(n)}) + \beta_4 E[Political_{t,unc}] + \beta_4 E[Currency_{t,unc}]. \quad \text{(IV.4)}$$

Klein (2017) and the Federal Reserve Bank of New York find that there is a strong correlation between the first difference of the breakeven inflation rate and the first difference of the term premium. Figure IV.2 shows the strong relationship between the two measures. Taking the first difference of Equations (IV.3) and (IV.4), yields the following:

$$\Delta TP_t^{(n)} = \beta_1 \Delta E[\pi_{t,unc}^{(n)}] + \beta_2 \Delta E[MP_{t,unc}^{(n)}] + \beta_3 \Delta P(Default_t^{(n)}) + \beta_4 \Delta E[Policy_{t,unc}] + \beta_4 \Delta E[Currency_{t,unc}]. \quad \text{(IV.5)}$$

The U.S. and many other developed nations have a near zero probability of default, hence it is a reasonable assumption to assume this is zero. I decided to test this assumption using credit default swap data (CDS). Looking at U.S. CDS as a regressor on term premium in Table IV.1, the coefficient on the U.S. is insignificant, supporting the assumption that default risk is not a major risk factor for the U.S.[1]

Next, government policy uncertainty likely has some effect on risk via the term premium. To test this, I regress term premium on the Economic Policy Uncertainty index and report results in Table IV.1. This regression did not result in a statistically coefficient for the U.S. The result loses its significance and turns positive when expected inflation is added into the regression. Government policy uncertainty may also be a factor within inflation and monetary policy uncertainty. For the U.S., the lack of significance leads me to believe this risk may either be low or near constant, hence taking the first difference brings this to zero.

Lastly, currency uncertainty is mainly a factor for developing nations, given that the U.S. has the world's largest reserve currency and typically does not interfere in currency markets, there is a near zero risk of devaluing the currency. After imposing all of these assumptions, $\Delta TP_t^{(n)} = \Delta E[\pi_{t,unc}^{(n)}] + \beta_2 \Delta E[MP_{t,unc}^{(n)}]$. The Move index is the implied volatility of 10-year yields over the next 30 days, the Move index serves as an indicator for interest rate and therefore monetary policy uncertainty. Table IV.1 shows that the Move index has a positive and significant influence on the term premium.

Looking at Equation (IV.3), I assume the liquidity factor increasing the value of TIPS is constant. This assumption holds true in most circumstances with the exception of the 2008 financial crisis. This assumption is also made in (Abrahams et al., 2016). Therefore, taking the first difference in yields $\Delta\pi_{t,B}^{(n)} = \Delta\pi_{t,e}^{(n)} + \Delta E[\pi_{t,unc}^{(n)}]$, Table IV.1 shows the strong relationship between the first difference of 10-year term premium and the breakeven inflation. This strong relationship implies $\Delta\pi_{t,B}^{(10y)} \approx \beta \Delta TP_t^{(10y)}$; the $R^2$ of the regression in Table IV.1 is 0.27, indicating a strong fit over a long period. Following this assumption,

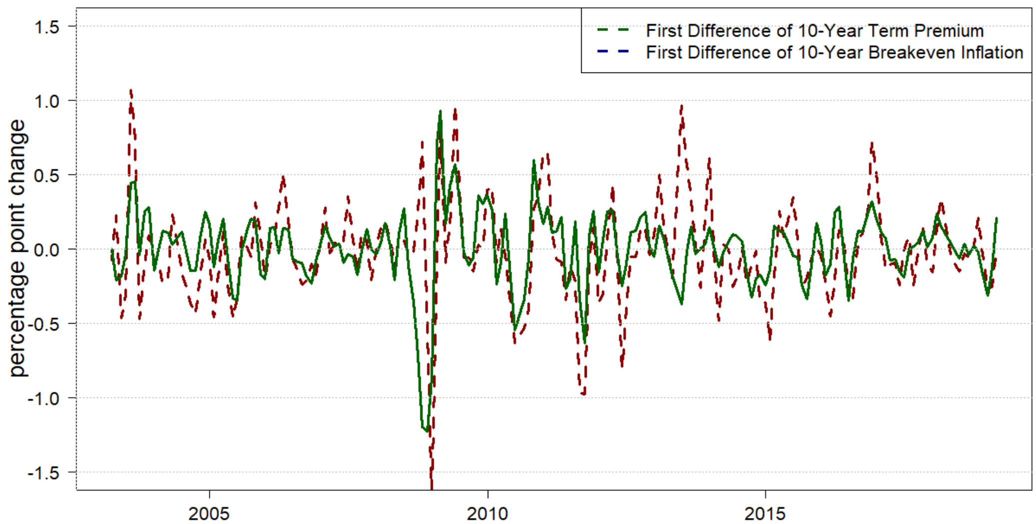
$$\Delta\pi_{t,B}^{(10y)} \approx \Delta TP_t^{(10y)} \implies \Delta\pi_{t,e}^{(n)} + \Delta E[\pi_{t,unc}^{(n)}] \approx \beta_1 \Delta E[\pi_{t,unc}^{(n)}] + \beta_2 \Delta E[MP_{t,unc}^{(n)}]. \quad \text{(IV.6)}$$

Equation (IV.6), therefore implies some different outcomes.

It is often hypothesized that longterm inflation expectations have remained constant since the nineties Abrahams et al. (2016). This assumption implies the term $\Delta\pi_{t,e}^{(10y)} = 0$.

[1] The first difference is trailing 1-month due to the delay for TIPS to be compensated for inflation in the prior month.

Figure IV.2: First Difference of 10-Year Term Premium and Breakeven Inflation




*Sources:* Author's calculations & FactSet.

Table IV.1: U.S. First Difference Regression Results on 10-Year Term Premium

| Regressor | | | | | | |
|---|---|---|---|---|---|---|
| Break even Inflation Rate | 0.68 | | | | | 0.86 |
| | (0.08) | | | | | (0.07) |
| Credit Default Swap Yield | | 1.57 | | | | |
| | | (1.14) | | | | |
| Economic Policy Uncertainty Index | | | -0.00 | | | |
| | | | (0.00) | | | |
| Monetary Policy Uncertainty Index | | | | -0.00 | | |
| | | | | (0.00) | | |
| Move Index | | | | | 0.36 | 0.80 |
| | | | | | (0.08) | (0.10) |
| $R^2$ | 0.27 | 0.03 | 0.01 | 0.01 | 0.05 | 0.46 |

### IV.1.2 Historical Variance Decompositions

In order to understand which factors contribute to explaining variation over time, Figure IV.3 shows the decomposition of the 10-year expectations component and the 10-year term premium. To perform a historical variance decomposition, first I ran a VAR(4) on either the term premium or the expectations component, along with potential factors that can affect each of them. I followed the methods laid out by Kilian (2017) to decompose the variation. I scaled all of the variables and calculated the cumulative effect of flow from a shock from each variable onto another. This process involves computing the magnitude of shocks to the dependent variable from each regressor using impulse response functions, then taking that information to calculate the expected variation caused from shocks in the data.

The VAR for expectations included, in the following order, the global short interest rate, the inflation rate, the standard deviation of inflation, the economic policy uncertainty index, the monetary policy uncertainty index, the debt uncertainty index, the trade uncertainty index, the Move index, and the expectations component. The global short rate is estimated as the first principal component of the 1-month yields of the U.S., the U.K., Europe, and Japan. Short-term interest rates from these advanced economies are highly correlated and can explain variation in U.S. 10-year expectations. (Kaminska et al., 2013) show there exist global factors that account for a significant proportion of the variation in bond yields across countries, including the U.S. Next, different uncertainty indices give the ability to connect movement in expectations to a real world situation. Lastly, the Move index can help account for expected future variation in yields, hence interest rate uncertainty.

Figure IV.3: Historical Variance Decomposition of the 10-Year Expectations Component

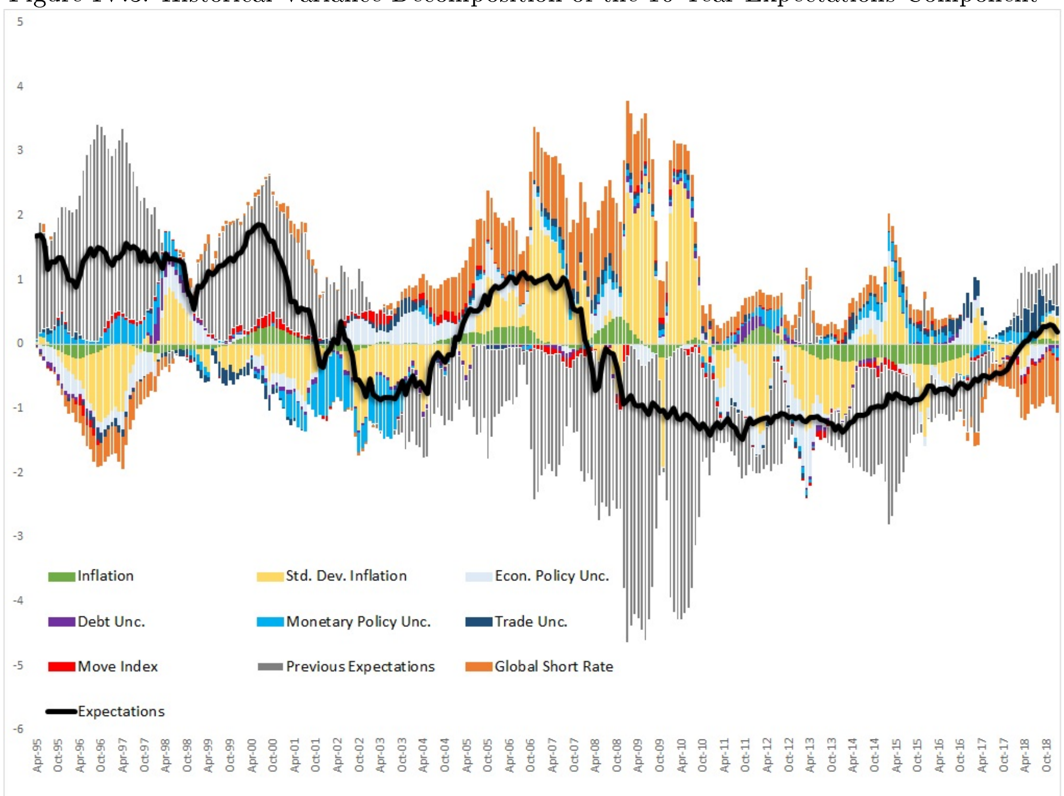



*Figure is scaled.*

*Source: FRED, EPU, FactSet, & author's calculations.*

Figure IV.3 shows that a vast majority of the movement in expectations' historical variance is driven by the global short-term interest rate (in orange) and the inflation uncertainty (in yellow). Both of these measures are linked to inflation and shows there exists a clear strong relationship between inflation and the variation in the expectations component. Inflation and the standard deviation of inflation play a major role in the variation mostly dragging down yields over the last 8 years. This lower inflation (in levels and variability) may be causing inflation expectations to fall as well, hence moving expectations significantly. It is also interesting to note that trade uncertainty (dark blue) has been driving expectations upward over the past few years. Trade wars often raise prices, raising inflation expectations and hence the expectations component.

The VAR(4) for the term premium consists of variables that relate to uncertainty and risk in the economy. In this order, these variables include the unemployment rate, the inflation rate, the standard deviation of inflation, the economic policy uncertainty index, the monetary policy uncertainty index, the debt uncertainty index, the trade uncertainty index, the Move index, and the term premium.

Figure IV.4: Historical Variance Decomposition of the 10-Year Term Premium

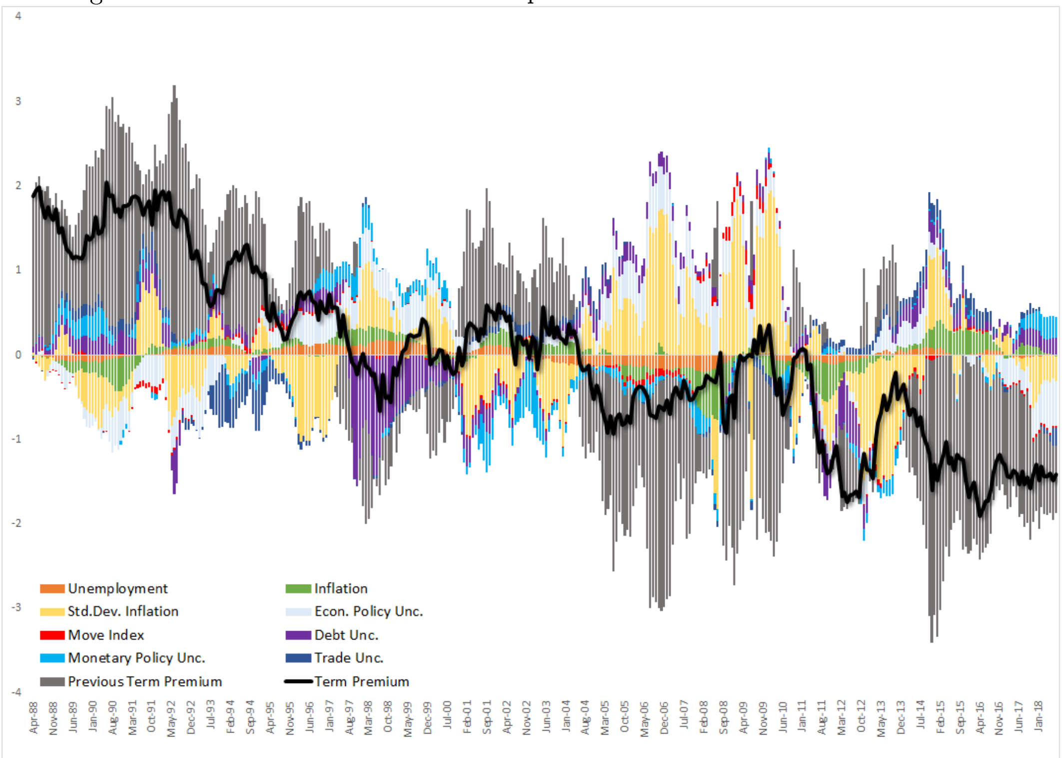



*Figure is scaled.*

*Source: FRED, EPU, FactSet, & author's calculations.*

This decomposition shows that inflation (in green) and the inflation uncertainty (in yellow) remain factors that account for term premium variation throughout the entire decomposition. It is clear that inflation is not only a major factor in expectations, but also in term premium variability. Debt uncertainty (in purple) and monetary policy uncertainty (in light blue) also play a major role in accounting for the variation in the term premium, which is consistent with previous findings. Notably absent from explaining significant variation is the Move index (in red). The Move index and 10-year term premium share a strong correlation and Table IV.1 shows the Move index is easily statistically significant and positively related to the 10-year term premium. It is important to note that this identification relies on Cholesky decompositions, which depend on the ordering of the variables. Further robustness needs to be performed in order to assess whether the order of the variables in the VAR change the main findings of the historical variance decompositions.

## IV.2 International Evidence on Inflation and Yields

It is common knowledge in economic literature that there is a strong correlation between yields and inflation. When inflation is higher than target inflation, Central Banks will increase interest rates. Inflation can also be a major risk factor of yields and investors in long-term bonds are exposed to inflationary risk. Therefore, inflation plays a crucial role in both shaping the expectations component and the term premium. To further investigate this relationship, I regress the term premium, expectations, and yields on the inflation of each country. I also utilize an unbalanced fixed effects panel regression on all of the countries to see the results for all countries as a group.

Table IV.2: Regression Coefficients on Inflation

| | 10y TP | 10y Exp. | 10y Yield | 5y TP | 5y Exp. | 5y Yield | 1y TP | 1y Exp. | 1y Yield |
|---|---|---|---|---|---|---|---|---|---|
| Australia | -0.01 | 1.16*** | 1.08*** | -0.12*** | 1.43*** | 1.31*** | -0.15*** | 1.77*** | 1.5*** |
| Brazil | 0.31*** | 0.15*** | 0.44*** | 0.2*** | 0.29*** | 0.52*** | 0.06*** | 0.75*** | 0.91*** |
| Canada | 0.12*** | 1.08*** | 1.18*** | -0.01 | 1.32*** | 1.32*** | -0.01*** | 1.65*** | 1.59*** |
| Chile | -0.21*** | -0.05*** | -0.27*** | -0.09*** | -0.1*** | -0.19*** | 0.1*** | -0.08 | 0.12 |
| China | 0.04*** | 0.02*** | 0.06*** | 0.05*** | 0.03*** | 0.08*** | 0.03*** | 0.09*** | 0.11*** |
| Colombia | 0.28*** | 0.31*** | 0.58*** | 0.18*** | 0.5*** | 0.69*** | 0.08*** | 0.84*** | 0.94*** |
| Czech Republic | 0.27*** | 0.21*** | 0.49*** | 0.24*** | 0.33*** | 0.56*** | 0.07*** | 0.53*** | 0.62*** |
| Euro Area | 0.45*** | 0.44*** | 0.88*** | 0.32*** | 0.63*** | 0.95*** | 0.08*** | 0.9*** | 0.97*** |
| Hungary | -0.1 | -0.04 | -0.11 | -0.11 | -0.05 | -0.18 | -0.03 | -0.07 | -0.07 |
| Indonesia | 0.42*** | 0.07*** | 0.51*** | 0.39*** | 0.14*** | 0.52*** | 0.14*** | 0.4*** | 0.54*** |
| Japan | 0.19*** | 0.98*** | 1.12*** | 0.13*** | 1.16*** | 1.31*** | 0.03*** | 1.35*** | 1.37*** |
| Malaysia | 0 | 0*** | 0.02 | 0.02 | 0.01*** | 0.02 | 0.03*** | 0.03*** | 0.07*** |
| Mexico | 0.06 | 0.47*** | 0.5*** | -0.07 | 0.67*** | 0.62*** | 0.01*** | 0.9*** | 0.91*** |
| New Zealand | -0.01 | 0.1 | 0.05 | 0.01 | 0.15 | 0.14 | 0.02 | 0.28*** | 0.35*** |
| Norway | 0.09*** | 0.08*** | 0.14*** | 0.06*** | 0.11*** | 0.16*** | 0.03*** | 0.12*** | 0.13*** |
| Peru | 0.61*** | 0.04*** | 0.3*** | 0.39*** | 0.08*** | 0.4*** | 0.16*** | 0.32*** | 0.49*** |
| Philippines | 1.09*** | 0.43*** | 1.56*** | 0.82*** | 0.63*** | 1.49*** | 0.25*** | 0.97*** | 1.34*** |
| Poland | 0.01 | -0.29*** | -0.24 | -0.05 | -0.52*** | -0.58 | -0.18*** | -1.15*** | -1.34*** |
| South Africa | -0.13*** | -0.29*** | -0.44*** | -0.11*** | -0.33*** | -0.43*** | -0.02*** | -0.34*** | -0.35*** |
| Singapore | -0.1*** | -0.04*** | -0.13*** | -0.13*** | -0.06*** | -0.2*** | -0.04*** | -0.1*** | -0.13*** |
| Sweden | 0.12*** | 0.89*** | 1.01*** | 0.07*** | 1.04*** | 1.11*** | 0.04*** | 1.22*** | 1.27*** |
| Switzerland | -0.11*** | 1.02*** | 0.91*** | -0.15*** | 1.19*** | 1.04*** | -0.06*** | 1.34*** | 1.37*** |
| United Kingdom | 0.18*** | 1.17*** | 1.33*** | 0.01 | 1.37*** | 1.38*** | -0.05*** | 1.63*** | 1.54*** |
| United States | 0.73*** | 0.64*** | 1.4*** | 0.57*** | 0.93*** | 1.51*** | 0.23*** | 1.34*** | 1.61*** |
| Panel | 0.21*** | 0.43*** | 0.63*** | 0.14*** | 0.53*** | 0.68*** | 0.05*** | 0.71*** | 0.78*** |

Significance levels: * at the .05 level, ** at the 0.01 level, and *** at the .001 level.

Looking at Table IV.2, and focusing on the first three columns showing the results on the 10-year term premium, expectations, and yield for each country, there seems to be a positive statistically significant relationship between inflation and yields or their components for most countries. Since yields compensate for maturity risk, the longer the horizon, the higher the opportunity cost, the compensation for inflation risk, and the compensation for uncertainty demanded by investors. This evidence suggests that, consistent with what we would expect, higher inflation is associated with higher yields. When considering the panel results, on average, a one percentage point increase in the inflation rate is associated with a 0.63% increase in the 10-year yield, with most of the effect of inflation being captured by the expectations component (0.43%). This aggregate evidence suggests that inflation's relationship to the long-term yield might primarily operate by changing the average expected future path of the short rate, as investors likely relate changes in inflation to monetary policy action.

The country-level evidence provides a more heterogenous perspective into this relationship. For Australia, Canada, the Euro area, Japan, the Philippines, Sweden, Switzerland, the U.K., and the U.S., the 10-year yield and inflation have a strong, positive, about one-to one relationship (0.88--1.56) with each other. For other countries (Brazil, Colombia, Czech Republic, Indonesia, and Mexico) the magnitude of this relationship is about half (0.44-0.58); while for other countries (China, Hungary, Malaysia, New Zealand, Norway, Peru, and Poland) is smaller or statistically insignificant. Chile, South Africa, and Singapore counter intuitively show a negative relationship.[2]

The major takeaway is that inflation seems to affect yields through multiple channels. For Australia, Canada, Japan, Mexico, Sweden, Switzerland, and the U.K., inflation influences long-term rates through the "inflation expectations" channel given that it is the expectations component that can be more strongly associated with movements in the 10-year yield. However, alternatively, Brazil, China, Indonesia, Peru, and the Philippines are influenced by inflation through the "compensation for inflation risk" channel, since the term premium is more likely to have a stronger response to changes in inflation relative to the expectations component (in terms of magnitude). Lastly, 10-year yields for Colombia, the Czech Republic, the Euro Area, New Zealand, and the U.S. are influenced by inflation through both expectations and the term premium at about the same magnitude, suggesting that both inflation expectations and compensation for inflation risk are channels at work.

### IV.2.1 The Role of Inflation Gap

A possible reason why specific countries show a negative relationship between inflation and yields would be very aggressive inflation targeting. South Africa adopted an inflation targeting regime in 2000 following a money growth system and a pegged currency (Jonsson, 2001). Chile also switched to a targeted regime in 1991 and was able to lower inflation from 20% to the 1--3% range over the last 3 years. Chile also did not sacrifice output growth which was 6% over the first decade that the inflation targeting regime was in place (Mishkin, 2004). Singapore does not have an inflation targeting regime and instead operates with a managed float.

To further investigate the concept of credible inflation targeting by monetary authorities, I decided to create group of different countries loosely based on the coefficients for term premium and expectations on Table IV.2. In red, I included Brazil, China, Indonesia, Peru, the Philippines, given the strong relationship between inflation and the term premium; and Colombia, the Czech Republic, the Euro Area, New Zealand, and the U.S., given that inflation was related to both, the term premium and the expectations component. In blue, I included Australia, Canada, Japan, Mexico, Sweden, Switzerland, the U.K., given that inflation is associated with the expectations component; and Colombia, the Czech Republic, the Euro Area, New Zealand, and the U.S., since inflation influenced both term premium and expectations.

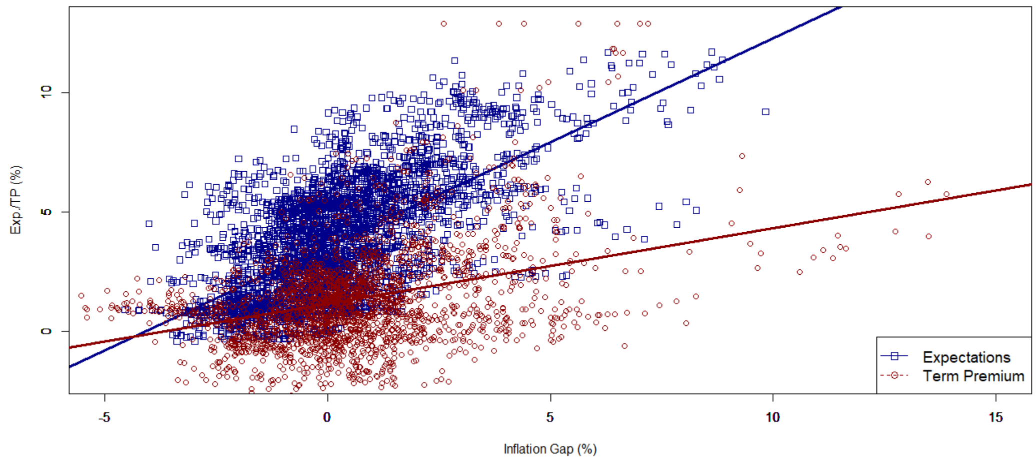
I found that there is a much greater relationship between inflation and either the term premium, the expectations component, or both. I define inflation gap as the absolute value of the difference between a country's inflation and its inflation target. Looking at Figure IV.5, when only plotting the specific countries and their respective component vs inflation gap, I find a positive relationship for both term premium and expectations relative to inflation deviations from target. The slope of the line of best fit for expectations is 1.07 and the slope of the line of best fit for the term premium is 0.27. This relationship seems to be strong, and the inflation gap, not just inflation, may be a major factor in explaining the variation of term premium and especially expectations.

### IV.2.2 Global Inflation as a Source of Risk

Is lower inflation a global phenomenon? Figure IV.6 shows that global inflation has been declining over the past 3 decades. The purpose of this thesis is to understand what factors drive term premia and expectations, and hence yields. Table IV.2 shows a strong relationship with inflation, so to expand on this finding, I form

[2]Appendix Table A.V.2 shows that when looking at the same regression in first differences, there are no negative relationships that are statistically significant.

Figure IV.5: Significant Component (TP/Exp.) vs Inflation Gap




*Sources:* Author's calculations & FRED.

two different indices to measure global inflation. The IMF calculates a global inflation measure; however, it is only available at an annual frequency and I prefer to use monthly data since it is available. Thus, I decided to create two of my own measures of global inflation rather than using the IMF's measure. The first measure is a GDP-weighted average inflation rate of all countries in my data set, where monthly inflation data are available from 1988 to 2019. This measure includes Brazil, Canada, China, Colombia, Indonesia, Japan, Malaysia, Mexico, New Zealand, Norway, Philippines, Singapore, Sweden, Switzerland, the United Kingdom and the United States. When converted to annual data, this measure had a correlation coefficient of 0.78 with the measure from the IMF. Figure IV.6 also shows similar movements compared to the IMF's measure. The GDP weights are sourced from the OECD for the year 2005.

The second measure is the first principal component of the same data as the weighted average inflation. This measure had a correlation coefficient of 0.75 with the IMF's measure. Figure IV.6 also shows the first principal component. Since the principal component is centered at zero and scaled to a standard deviation of one, the inflation rate appears lower; however, when scaled, all measures display similar patterns.

Now that I have two monthly measures of inflation, I investigate the effect of global inflation on the term premium, the expectations component, and yields with the following regression: $Z_{c,t}^{(n)} = \alpha_c^{(n)} + \beta_c^{(n)} \pi_{global,t}$, where $\pi_{global,t}$ is either the GDP-weighted average measure (Table IV.3) or the first principal component (Table IV.4).[3]

Regardless of whether global inflation is constructed with GDP weights (IV.3) or principal component analysis (IV.4), similar patterns emerge. First, the countries that were mostly affected by their respective inflation through the expectations component, are still affected by global inflation through their expectations component (Australia, Canada, Japan, Mexico, Sweden, Switzerland, and the UK). The countries that were related to local inflation through both channels, roughly by the same magnitude, are also influenced by global inflation through both channels (Colombia, Czech Republic, Euro area, and the U.S.), although if the GDP-weighted inflation measure is used, the risk compensation channel for Colombia and Czech Republic is no longer statistically significant. The countries that were mostly affected by inflation through the inflation risk compensation channel (the term premium), are also associated with global inflation through the term premium (China, Indonesia, Peru, and the Philippines). Interestingly, most countries that were not even contained in the weighted average due to lack of

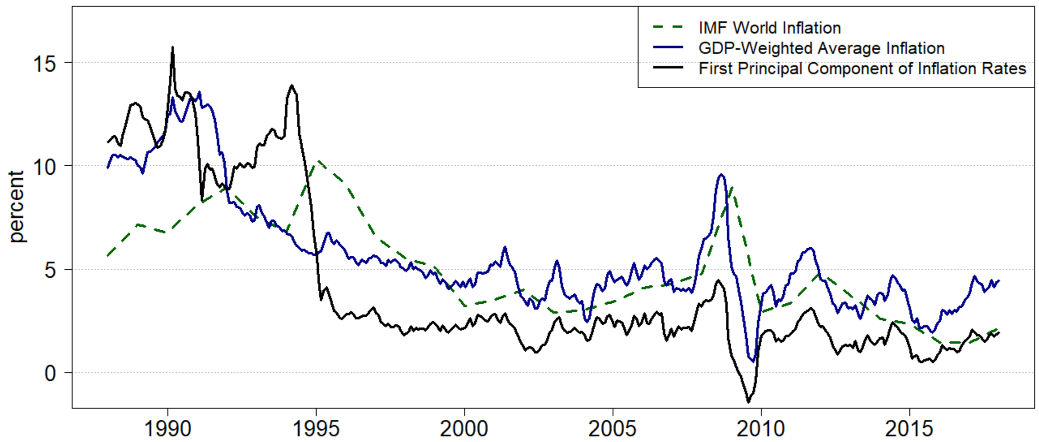
[3]Notice that the magnitude of the coefficients will have a different interpretation depending on what measure is used.

Table IV.3: Regression Coefficients on GDP-Weighted Average Inflation

| | 10y TP | 10y Exp. | 10y Yield | 5y TP | 5y Exp. | 5y Yield | 1y TP | 1y Exp. | 1y Yield |
|---|---|---|---|---|---|---|---|---|---|
| Australia | 0.05*** | 0.56*** | 0.6*** | -0.04*** | 0.67*** | 0.62*** | -0.07*** | 0.77*** | 0.66*** |
| Brazil | 0 | 0.11*** | 0.1 | -0.04 | 0.2*** | 0.18 | -0.05 | 0.4*** | 0.37 |
| Canada | 0.1*** | 0.47*** | 0.56*** | 0.04*** | 0.56*** | 0.59*** | 0*** | 0.67*** | 0.65*** |
| Chile | 0.23*** | 0.1*** | 0.35*** | 0.32*** | 0.21*** | 0.53*** | 0.15*** | 0.79*** | 1.03*** |
| China | 0.16*** | 0.05*** | 0.22*** | 0.16*** | 0.09*** | 0.25*** | 0.08*** | 0.24*** | 0.32*** |
| Columbia | 0.22 | 0.37*** | 0.58*** | 0.2 | 0.61*** | 0.79*** | 0.08*** | 0.99*** | 1.06*** |
| Czech Republic | 0.2 | 0.23*** | 0.42*** | 0.22*** | 0.37*** | 0.58*** | 0.06*** | 0.59*** | 0.66*** |
| Euro Area | 0.58*** | 0.6*** | 1.18*** | 0.41*** | 0.86*** | 1.27*** | 0.11*** | 1.21*** | 1.31*** |
| Hungary | -0.2*** | 0.48*** | 0.26 | -0.12 | 0.65*** | 0.53*** | -0.03 | 0.84*** | 0.84*** |
| Indonesia | 0.59*** | 0.1*** | 0.66*** | 0.61*** | 0.2*** | 0.81*** | 0.19*** | 0.52*** | 0.67*** |
| Japan | 0.12*** | 0.32*** | 0.43*** | 0.07*** | 0.38*** | 0.45*** | 0.01*** | 0.44*** | 0.45*** |
| Malaysia | 0.02 | 0.01*** | 0.07 | 0.06*** | 0.02*** | 0.06 | 0.07*** | 0.07*** | 0.15*** |
| Mexico | 0.02 | 0.51*** | 0.54*** | -0.11*** | 0.72*** | 0.61*** | 0.01*** | 1*** | 1.02*** |
| Norway | 0.41*** | 0.49*** | 0.88*** | 0.26*** | 0.7*** | 0.96*** | 0.05*** | 0.96*** | 1.04*** |
| New Zealand | 0.18*** | 0.63*** | 0.76*** | 0.13*** | 0.9*** | 1.03*** | 0.04*** | 1.32*** | 1.39*** |
| Peru | 0.27 | 0.04*** | 0.28*** | 0.35*** | 0.08*** | 0.42*** | 0.15*** | 0.32*** | 0.5*** |
| Philippines | 1.52*** | 0.51*** | 1.99*** | 1.11*** | 0.74*** | 1.91*** | 0.25*** | 1.07*** | 1.48*** |
| Poland | 0.2*** | 0.23*** | 0.43*** | 0.22*** | 0.4*** | 0.62*** | 0.09*** | 0.8*** | 0.88*** |
| South Africa | 0.49*** | 2.04*** | 2.52*** | 0.25*** | 2.45*** | 2.69*** | 0.02*** | 2.91*** | 2.95*** |
| Singapore | 0.2*** | 0.09*** | 0.27*** | 0.23*** | 0.15*** | 0.39*** | 0.09*** | 0.25*** | 0.35*** |
| Sweden | 0.1*** | 0.63*** | 0.74*** | 0.06*** | 0.73*** | 0.78*** | 0.04*** | 0.85*** | 0.89*** |
| Switzerland | -0.05*** | 0.4*** | 0.35*** | -0.06*** | 0.47*** | 0.4*** | -0.03*** | 0.52*** | 0.53*** |
| United Kingdom | 0.05*** | 0.52*** | 0.56*** | 0 | 0.61*** | 0.61*** | -0.03*** | 0.73*** | 0.68*** |
| United States | 0.23*** | 0.16*** | 0.4*** | 0.18*** | 0.24*** | 0.42*** | 0.07*** | 0.34*** | 0.41*** |

Significance levels: * at the .05 level, ** at the 0.01 level, and *** at the .001 level.

Figure IV.6: Measures of Global Inflation




*Source: FRED & author's calculations.*

data still hold significance on global inflation for different maturities across the term premium, expectations, and yields. The similarity between country-specific inflation results and global inflation results suggest that the effect of inflation on yields is more likely tied to global factors. However, some resultssuggest that country-specific inflation factors might differ from the effect on yields relative to global inflation. For example, there is a set of countries' inflation rates that have either a small/statistically insignificant or even negative relationship with yields or the expectations component (Chile, Hungary, New Zealand, Poland, South Africa, Singapore). This is no longer true when the global inflation rate is considered instead.

Based on the Tables IV.2, IV.3 & IV.4, it is clear that inflation is typically a major factor explaining term premium at longer maturities and expectations across all maturities, but that there are some differences across countries. The main takeaway is that inflation influences yields though multiple channels; through both inflation expectations and risk compensation, which also seems to be a global phenomenon.

Figure IV.7 shows the mean absolute difference between local and both measures of global inflation over time. Since 2000, inflation between most countries has been relatively stable and declining. It is also interesting to note that during the 2008 global financial crisis, inflation was still very connected throughout the world. This implies that global inflation is highly connected which could explain why some countries have significance with global, but not local inflation.

### IV.2.3 Explaining Term Premia and Expectations: Panel Regression Approach

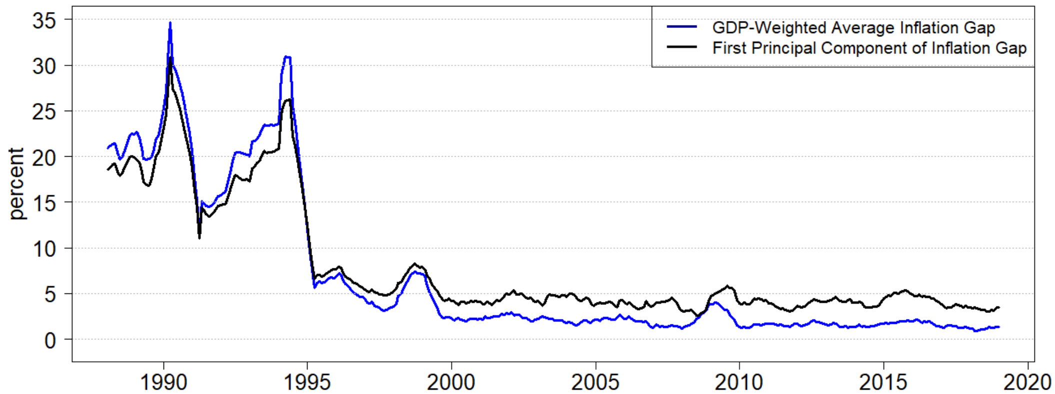
In this section, I explore the effects of inflation on term premia and expectations by following the panel regression framework proposed by Wright (2011). Wright (2011) showed that the term premium of some developed nations can be explained by a number of different factors, including inflation uncertainty and GDP growth uncertainty from survey dispersion, and whether or not the country is in a recession. I expand on this analysis, but since inflation and GDP survey dispersion are not available for the majority of the countries I consider, I use different measures to proxy for uncertainty. The data I am using include the one-year trailing standard deviation of inflation, the inflation rate, OECD recession indicators, and the Economic Policy Uncertainty Index from www.policyuncertainty.com. The regressions are panel regressions across all countries with available data:

Table IV.4: Regression Coefficients on First Principal Component of Inflation Rates

| | 10y TP | 10y Exp. | 10y Yield | 5y TP | 5y Exp. | 5y Yield | 1y TP | 1y Exp. | 1y Yield |
|---|---|---|---|---|---|---|---|---|---|
| Australia | 0.06*** | 0.88*** | 0.93*** | -0.08*** | 1.06*** | 0.97*** | -0.11*** | 1.26*** | 1.09*** |
| Brazil | 0.18 | 0.07*** | 0.23*** | 0.13 | 0.14*** | 0.29*** | 0.02 | 0.27*** | 0.3 |
| Canada | 0.12*** | 0.71*** | 0.82*** | 0.03 | 0.85*** | 0.88*** | -0.01*** | 1.04*** | 1.01*** |
| Chile | 0.18*** | 0.08*** | 0.28*** | 0.23*** | 0.16*** | 0.38*** | 0.09*** | 0.55*** | 0.71*** |
| China | 0.08*** | 0.02*** | 0.11*** | 0.07*** | 0.04*** | 0.11*** | 0.04*** | 0.12*** | 0.17*** |
| Colombia | 0.3*** | 0.28*** | 0.58*** | 0.25*** | 0.46*** | 0.7*** | 0.08*** | 0.75*** | 0.82*** |
| Czech Republic | 0.2*** | 0.19*** | 0.39*** | 0.19*** | 0.3*** | 0.48*** | 0.06*** | 0.49*** | 0.56*** |
| Euro Area | 0.41*** | 0.4*** | 0.81*** | 0.28*** | 0.58*** | 0.86*** | 0.07*** | 0.82*** | 0.89*** |
| Hungary | -0.04 | 0.39*** | 0.33*** | 0.01 | 0.54*** | 0.56*** | 0.01 | 0.7*** | 0.71*** |
| Indonesia | 0.46*** | 0.08*** | 0.52*** | 0.48*** | 0.16*** | 0.64*** | 0.16*** | 0.43*** | 0.55*** |
| Japan | 0.15*** | 0.5*** | 0.62*** | 0.08*** | 0.58*** | 0.68*** | 0.01*** | 0.68*** | 0.7*** |
| Malaysia | 0 | 0.01*** | 0.03 | 0.03 | 0.01*** | 0.02 | 0.04*** | 0.05*** | 0.1*** |
| Mexico | 0 | 0.34*** | 0.34*** | -0.09*** | 0.49*** | 0.41*** | 0.01*** | 0.68*** | 0.69*** |
| Norway | 0.3*** | 0.34*** | 0.61*** | 0.19*** | 0.48*** | 0.67*** | 0.05*** | 0.69*** | 0.78*** |
| New Zealand | 0.17*** | 0.41*** | 0.51*** | 0.13*** | 0.58*** | 0.69*** | 0.06*** | 0.86*** | 0.92*** |
| Peru | 0.31*** | 0.04*** | 0.25*** | 0.32*** | 0.07*** | 0.37*** | 0.13*** | 0.28*** | 0.43*** |
| Philippines | 0.91*** | 0.39*** | 1.27*** | 0.77*** | 0.58*** | 1.4*** | 0.22*** | 0.91*** | 1.25*** |
| Poland | 0.18*** | 0.18*** | 0.36*** | 0.19*** | 0.32*** | 0.5*** | 0.07*** | 0.63*** | 0.7*** |
| South Africa | 0.27*** | 1.27*** | 1.53*** | 0.12*** | 1.53*** | 1.64*** | 0.01 | 1.84*** | 1.87*** |
| Singapore | 0.1*** | 0.06*** | 0.15*** | 0.13*** | 0.09*** | 0.23*** | 0.05*** | 0.16*** | 0.22*** |
| Sweden | 0.14*** | 0.94*** | 1.08*** | 0.08*** | 1.09*** | 1.17*** | 0.05*** | 1.29*** | 1.35*** |
| Switzerland | -0.08*** | 0.61*** | 0.53*** | -0.1*** | 0.71*** | 0.6*** | -0.04*** | 0.79*** | 0.82*** |
| United Kingdom | 0.07*** | 0.79*** | 0.85*** | -0.02*** | 0.95*** | 0.94*** | -0.05*** | 1.18*** | 1.11*** |
| United States | 0.33*** | 0.26*** | 0.6*** | 0.25*** | 0.38*** | 0.65*** | 0.1*** | 0.55*** | 0.67*** |

Significance levels: * at the .05 level, ** at the 0.01 level, and *** at the .001 level.

Figure IV.7: Mean Absolute Difference Between Local and Global Inflation




*Source: FRED & author's calculations.*

$TP_{t,c}^{(10y)} = \alpha + \beta X_{t,c} + e_{t,c}$ and $EXP_{t,c}^{(10y)} = \alpha + \beta X_{t,c} + e_{t,c}$, where $t$ is the time, $c$ is the country, and $X_{t,c}$ is a matrix of regressors defined in Tables IV.5 and IV.6.

Table IV.5: Regression Results on 10-Year Term Premium

| Regressor | | | | | |
|---|---|---|---|---|---|
| Std. Dev. of Inflation | 0.48 | | 0.40 | 0.42 | 0.40 |
| | (0.03) | | (0.03) | (0.03) | (0.03) |
| Inflation | | 0.21 | 0.21 | 0.14 | 0.15 |
| | | (0.01) | (0.01) | (0.01) | (0.01) |
| Recession Indicator | | | | -0.09 | -0.13 |
| | | | | (0.03) | (0.03) |
| Std. Dev. of Recession Indicator | | | | | 0.50 |
| | | | | | (0.07) |

Table IV.6: Regression Results on 10-Year Expectations

| Regressor | | | | | |
|---|---|---|---|---|---|
| Std. Dev. of Inflation | 0.52 | | 0.35 | 0.45 | 0.48 |
| | (0.04) | | (0.04) | (0.05) | (0.05) |
| Inflation | | 0.43 | 0.41 | 0.48 | 0.47 |
| | | (0.01) | (0.01) | (0.01) | (0.01) |
| Recession Indicator | | | | -0.24 | -0.17 |
| | | | | (0.05) | (0.05) |
| Std. Dev. of Recession Indicator | | | | | -0.78 |
| | | | | | (0.11) |

Tables IV.5 and IV.6 show inflation and standard deviation of inflation are both significant factors in all regressions. Inflation is more significant for the expectations component, while standard deviation of inflation is equally significant for term premium and expectations. The regression also shows that expectations and term premia are pushed downwards during recessions. These results match with those of Wright (2011) and support the claim that there is a strong positive relationship between term premium and inflation uncertainty. These results also support the story that inflation is a significant and positively correlated factor in the yield curve of nearly all countries for both the expectations and the term premium components.

CHAPTER V

# Conclusion, Caveats, and Potential Extensions

In this thesis, I first decompose the interest rates of the U.S. based on the ACM model to determine how each component, the term premium and expectations, is changing long-term yields. I begin with the U.S. and conclude that it is not a single component responsible for the long-term decline, but instead both components working in conjunction that are driving yields lower. I continue the same analysis for 24 different countries to determine which other countries follow this same pattern. I found that while all but only a few countries had a decline in long-term yields over the past decade, they are not all explained by the same component. Countries like Switzerland, South Africa, Sweden, and the U.K. have had a decline in yields explained mostly by the expectations component. However, other countries like Chile, China, Columbia, the Czech Republic, and Indonesia have had a smaller decline in yields but can be explained almost entirely by the term premium. Lastly, the vast majority of countries including Canada, the Euro Area, Japan, and the U.S. have had declines explained by both components.

The major factor almost all countries had in common was inflation. Common literature suggests that inflation plays a major role in the expectations component through the expected inflation channel and inflation uncertainty should play a major role in the term premium through the risk compensation channel. In the past, inflation was more uncertain and thus it followed that volatility of policy rates was much higher and central banks did not provide clear forecasts for interest rate decisions. Now, central banks are pointing to a gradual tightening of interest rates and prolonged coordination of policy rates (Filardo and Hofmann, 2014). This lower volatility could be a major reason why the term premium has declined. I found significant evidence to support all of these claims. I also found that inflation plays a major role in both expectations and that term premium and global inflation is often more significant than local inflation for specific countries such as New Zealand, South Africa and Singapore. This is because inflation is becoming more connected as more countries are targeting price stability. Absolute deviation from target inflation increases risk premium and expectations over the long term. Individually breaking down the U.S. 10-year yield, I find that both inflation and inflation volatility have had a major role in changing yields through both expectations and the term premium components.

## V.1 Caveats

The ACM model is easy to implement and provides accurate results without the need for any data other than yields. However, there are some other factors that should be considered when estimating term premia. The first includes accounting for the zero lower bound. It is possible to impose a zero lower bound on nominal interest rates to get a more robust estimate by either incorporating a shadow rate model or allowing for a regime switching environment. Another extension to the model would be to add confidence intervals to the different countries in the sample. Malik and Meldrum (2016) suggest using 95% confidence intervals to account for the uncertainty around term premia estimates.

## V.2 Extensions

I would also like to incorporate additional unspanned factors to the ACM model to improve the fit and gain interpretation of different macroeconomic variables. Global inflation has been a major influence on both term premium and yields and, perhaps, adding it as an unspanned factor for different countries would allow me to gain a better understanding about the relationship between expectations and term premium with global inflation. I would also like to further enhance the ACM model to jointly account for both nominal and real interest rates in order to get the market expected inflation rate, the inflation risk premium and a more thorough measure of liquidity premium. Although limited, I also have data on Chile's inflation adjusted bonds. Many countries in the sample likely have liquidity issues and it may be wise to correct for potential bias in the estimates due to a lack of liquidity premium.

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Appendix Chapter A.I

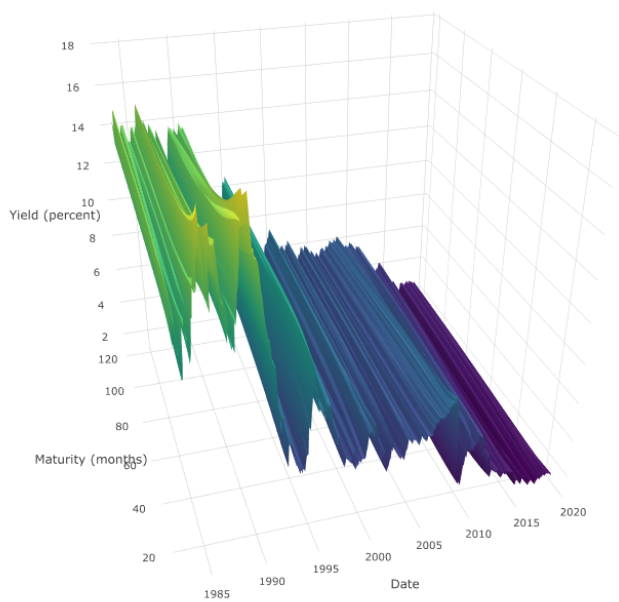
# Appendix: Interest Rate Decomposition by Country

### A.I.1 Australia

Australia is considered a developed market and bond data exist back to the seventies. However, the data are incomplete during the 1970's and into the early 80's; hence, in order to build the best model, this thesis uses only data for Australia from March 1983 to February 2019. Using this time period allows me to utilize data on 3- and 6-month bonds and 1- to 10-year bonds. This period also highlights the clear decline in long-term interest rates, as seen in Figure A.I.1. The 10-year yield decreased by more than 12 percentage points from 14.51% in March 1983 to 2.15% in February 2019. This decline is also clearly demonstrated in the downward trend of the first factor, which represents the level of the yield curve.

I compared my results with that of Alles (1995), which contained data on the 3-month term premium for Australia from 1976 to 1995. These results matched the term premium produced in this model closely, confirming the validity of my estimation approach. I also compared the one-year term premium to that of Finlay and Chambers (2009) and the two were very close. Next, looking at Shah (2018), the estimations for the Australian 10-year term premium were identical to this paper's. Shah also used the ACM method to calculate the term premium.

Figure A.I.1: Australia: Yield Curve (left) and Yield Curve Factors (right)



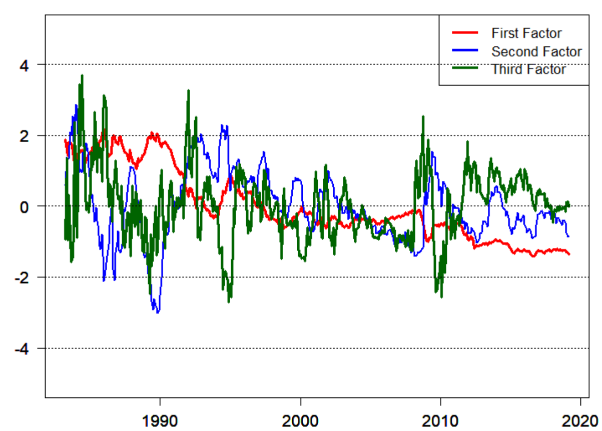




Table A.I.1: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 432 | −0.146 | 0.272 | −0.848 | −0.367 | −0.101 | 0.049 | 0.395 |
| 24-month | 432 | 0.021 | 0.086 | −0.280 | −0.019 | 0.029 | 0.068 | 0.354 |
| 36-month | 432 | 0.056 | 0.124 | −0.434 | −0.019 | 0.051 | 0.125 | 0.490 |
| 60-month | 432 | −0.005 | 0.144 | −0.645 | −0.082 | 0.013 | 0.083 | 0.420 |
| 84-month | 432 | −0.045 | 0.146 | −0.539 | −0.139 | −0.018 | 0.071 | 0.235 |
| 120-month | 432 | 0.100 | 0.123 | −0.350 | 0.014 | 0.118 | 0.183 | 0.587 |

Figure A.I.2: Australia: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

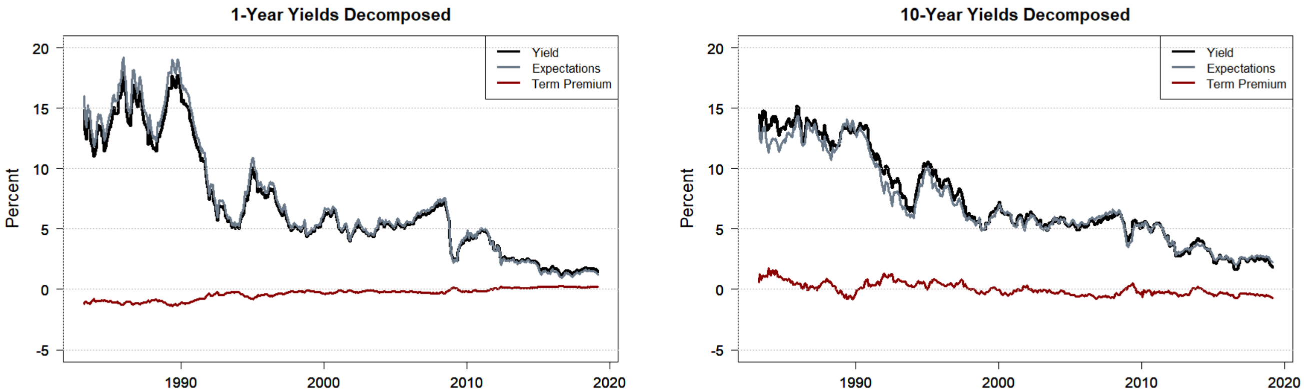



Figure A.I.3: Australia: Term Premium Curve (left) and Expectations Curve (right)

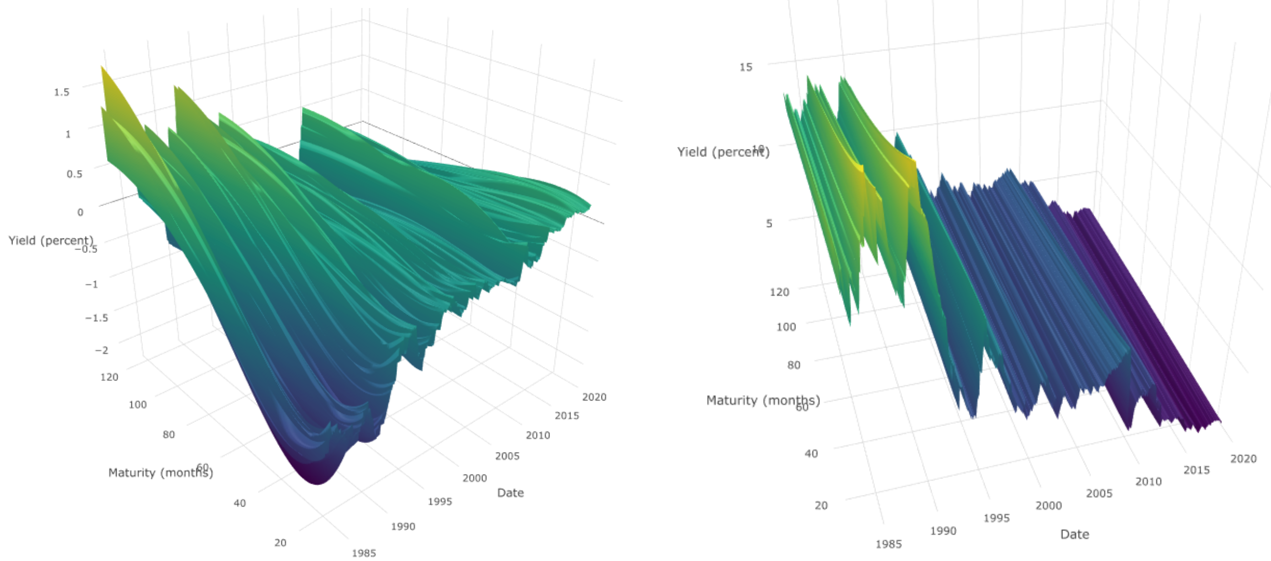


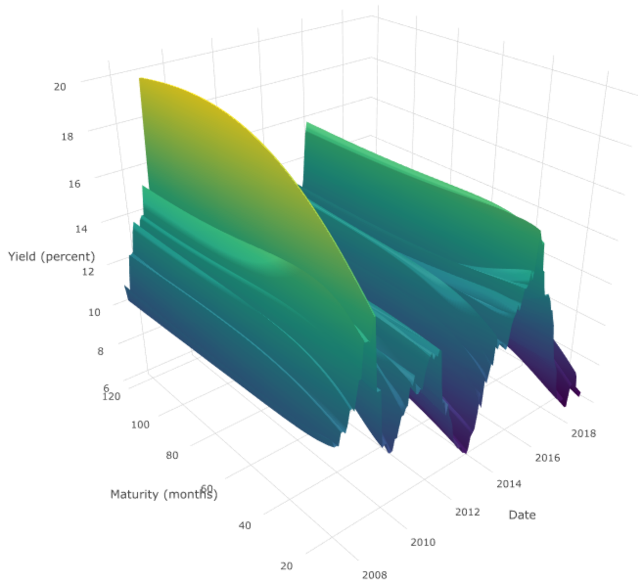

Figure A.I.2 shows that the 1-year term premium has increased slightly over time, however there appears to be a decline in the 10-year term premium. The 10-year term premium decreased by 1.29% from 0.6% in March 1983 to –0.7% in February 2019. Importantly, the more significant decrease appears in the expectations component. Figure A.I.3 shows there exists a decline in the expectations component across all maturities. The 10-year expectations component decreased by 11.34% from 13.6% in March 1983 to 2.26% in February 2019. Thus, this decomposition implies that the decline is mainly explained by the decrease in expectations, but is also amplified by the decrease in the term premium. It is interesting to note that Australia often contains an inverted yield curve and this also appears in the expectations curve in Figure A.I.3.

### A.I.2 Brazil

Brazil is a major economic global center in Latin America and the eighth largest economy by GDP (IMF 2018). Brazil is an emerging economy that has had struggled with inflationary pressures and the decline in oil prices, for these reasons Brazil has not had the same decline in interest rates as other countries. Government bond data for Brazil are not available until April of 2007, therefore the data are from April 2007 to February 2019. Using this time period allows me to utilize data on 3- and 6-month bonds and 1- to 10-year bonds. The 10-year yield decreased slightly by almost 2 percentage points from 11.04% in April 2007 to 9.14% in February 2019. The Brazilian yield curve fluctuates rapidly and has higher rates than most other countries, reflecting the riskier economic conditions in the country.

The current literature does not contain any data on the term premium of Brazil. In the article Blake et al. (2015), the authors used the ACM process to calculate term premia for multiple Latin American countries. The authors did not publish estimates of the term premium for Brazil, however they did note that the Brazilian term premium had a strong correlation with the U.S.. During the period of April 2007 to November 2018, the estimated correlation I obtain between 10-year U.S. and 10-year Brazil term premia was 0.52, thus supporting this claim. I also compared the yield curve data to an IMF paper, Alves et al. (2011), which matched closely and included the large spikes in long term yields.

Figure A.I.4: Brazil: Yield Curve (left) and Yield Curve Factors (right)



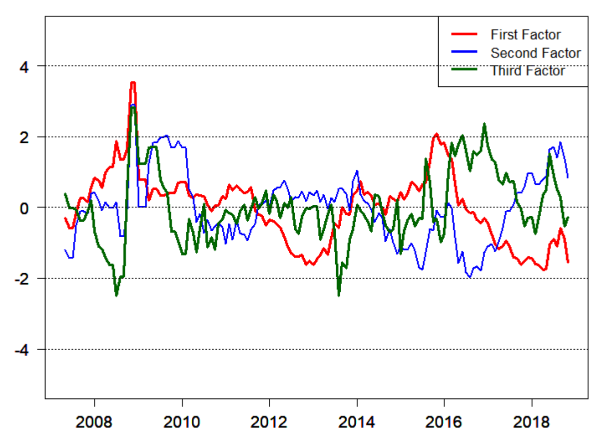



Table A.I.2: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 143 | −0.017 | 0.238 | −0.478 | −0.212 | −0.021 | 0.128 | 0.479 |
| 24-month | 143 | 0.078 | 0.186 | −0.293 | −0.049 | 0.084 | 0.196 | 0.532 |
| 36-month | 143 | 0.144 | 0.173 | −0.233 | 0.036 | 0.178 | 0.255 | 0.583 |
| 60-month | 143 | 0.300 | 0.166 | −0.044 | 0.210 | 0.291 | 0.415 | 0.943 |
| 84-month | 143 | 0.555 | 0.116 | 0.373 | 0.475 | 0.526 | 0.608 | 1.153 |
| 120-month | 143 | 1.164 | 0.159 | 0.565 | 1.052 | 1.160 | 1.279 | 1.592 |

Figure A.I.5: Brazil: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

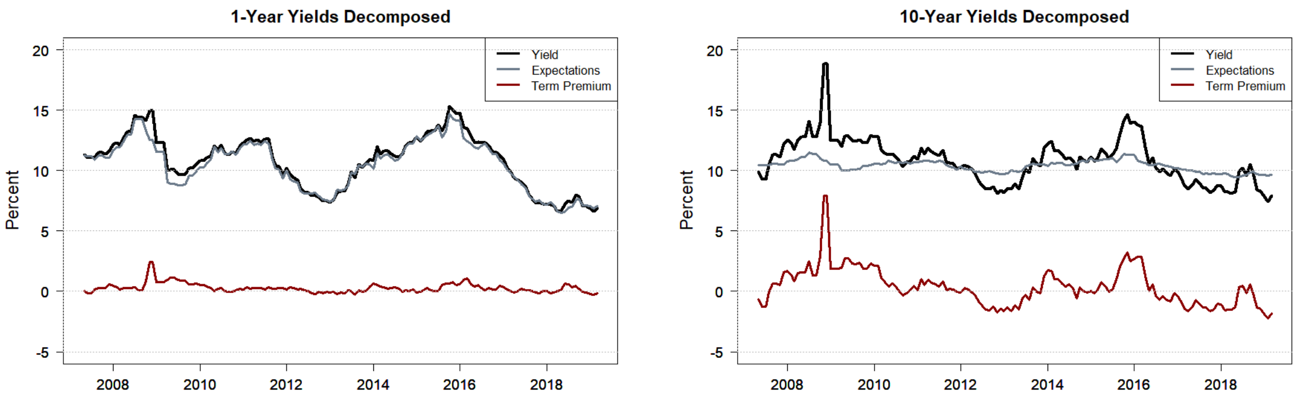



Figure A.I.6: Brazil: Term Premium Curve (left) and Expectations Curve (right)

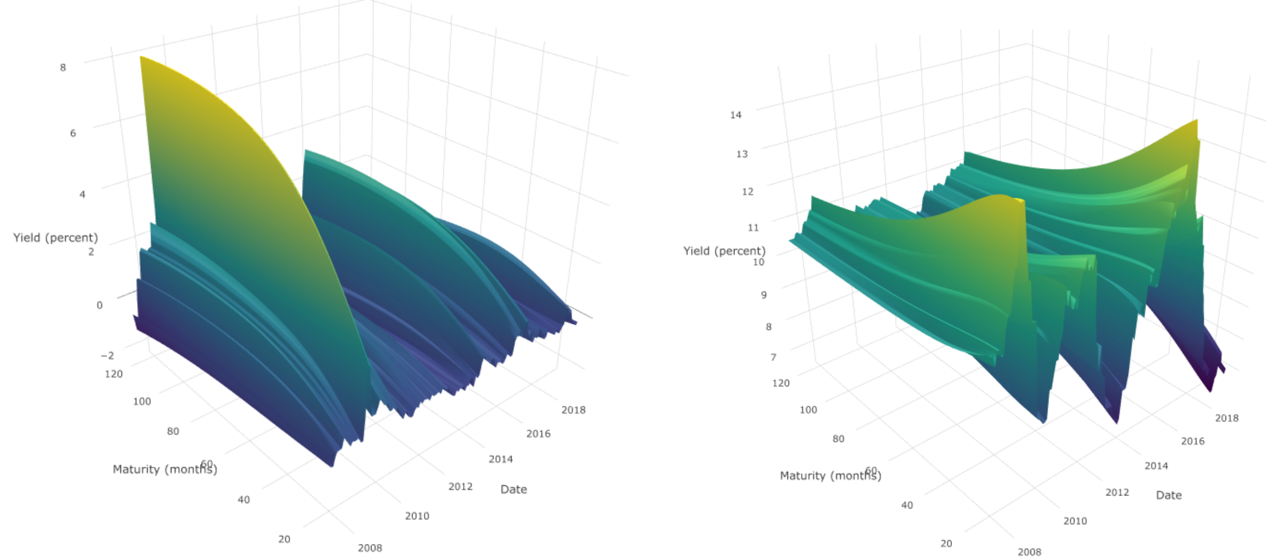



Figure A.I.5 shows that the 1-year term premium has remained near zero and the 10-year term premium has fluctuated with yields quite frequently, but declined slightly since 2007. The 10-year term premium decreased by 1.19% from --0.62% in April 2007 to --1.81% in February 2019. The 10-year expectations component has remained relatively constant and flat when compared with yields over the last decade. The 10-year expectations component decreased by 0.81% from 10.46% in April 2007 to 9.65% in February 2019. Visually, Figure A.I.5 and Figure A.I.6 show that most of the variation in long-term yields is explained by fluctuations in the term premium while most of the fluctuation of short-term yields is explained by fluctuations in the expectations component. The correlation coefficient between 10-year yields and 10-year term premium is 0.98, compared with 0.71 for 10-year yields and 10-year expectations. This changes significantly for 1-year yields. The correlation between 1-year yields and 1-year term premium is 0.40 and the correlation between 1-year yields and 1-year expectations is 0.98.

### A.I.3 Canada

Canada is a major developed economy and the tenth largest economy by GDP (IMF 2018). Government bond data for Canada are available past 1986. This time period contained data on 3- and 6-month bonds and 1- to 10-year bonds. This long sample allows for a very strong fit for the model, as seen in Table ??. This period also highlights the clear decline in long-term interest rates, as seen in Figure A.I.7. The 10-year yield decreased by more than 8 percentage points from 9.55% in February 1986 to 1% in February 2019. This pronounced decline in the yield curve is also clear in the downward trend in the first factor (level). The estimates matched closely with that of Diez de los Rios and Shamloo (2017).

Figure A.I.7: Canada: Yield Curve (left) and Yield Curve Factors (right)

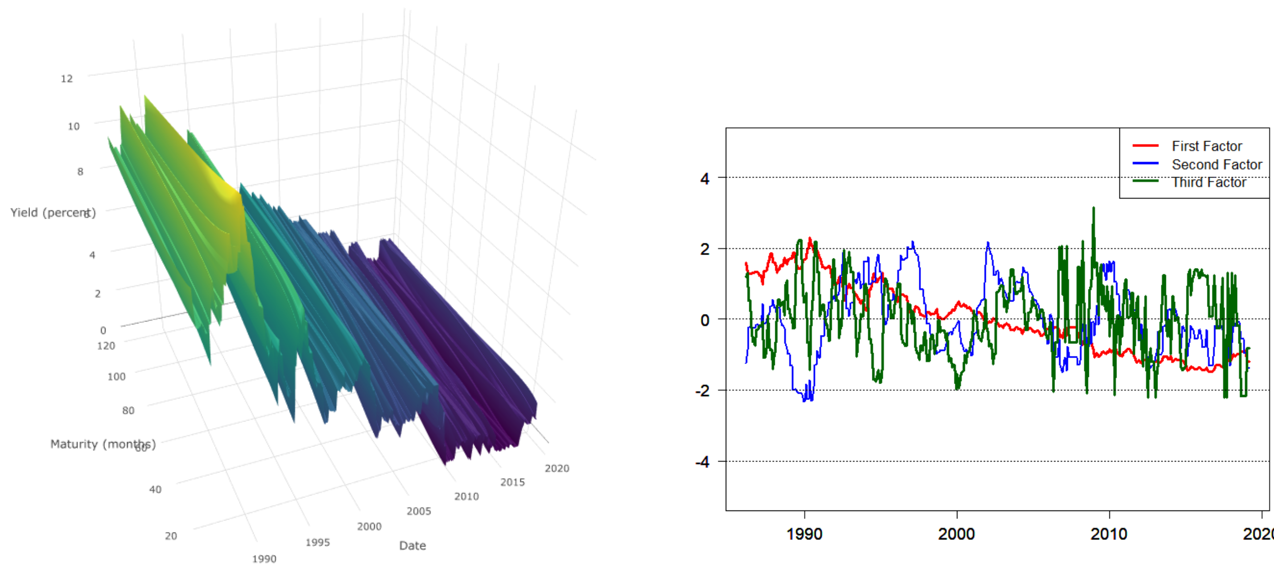



Table A.I.3: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 397 | 0.025 | 0.120 | −0.382 | −0.031 | 0.033 | 0.089 | 0.405 |
| 24-month | 397 | 0.015 | 0.125 | −0.339 | −0.073 | 0.015 | 0.112 | 0.304 |
| 36-month | 397 | 0.015 | 0.065 | −0.146 | −0.036 | 0.014 | 0.053 | 0.250 |
| 60-month | 397 | 0.040 | 0.098 | −0.165 | −0.026 | 0.032 | 0.107 | 0.377 |
| 84-month | 397 | 0.096 | 0.080 | −0.097 | 0.038 | 0.085 | 0.158 | 0.340 |
| 120-month | 397 | 0.189 | 0.183 | −0.417 | 0.090 | 0.171 | 0.293 | 0.756 |

Figure A.I.8: Canada: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

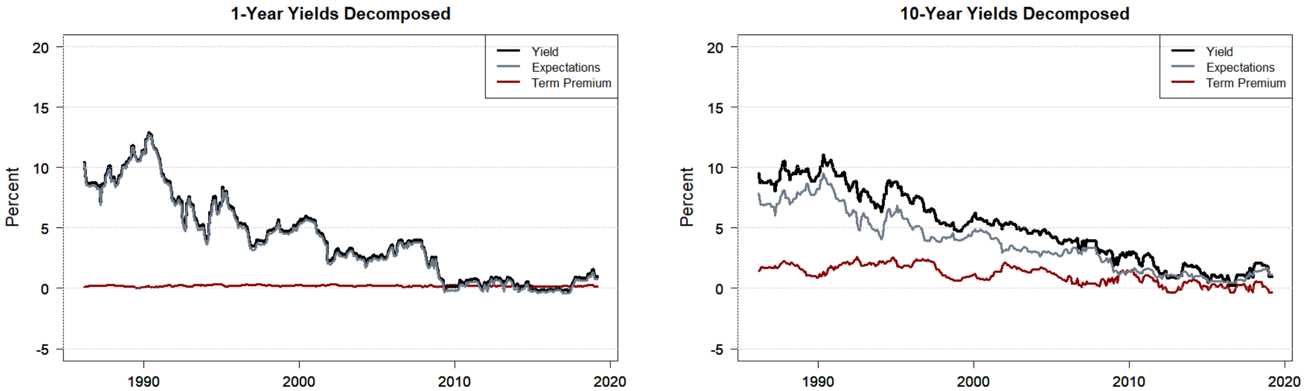



Figure A.I.9: Canada: Term Premium Curve (left) and Expectations Curve (right)

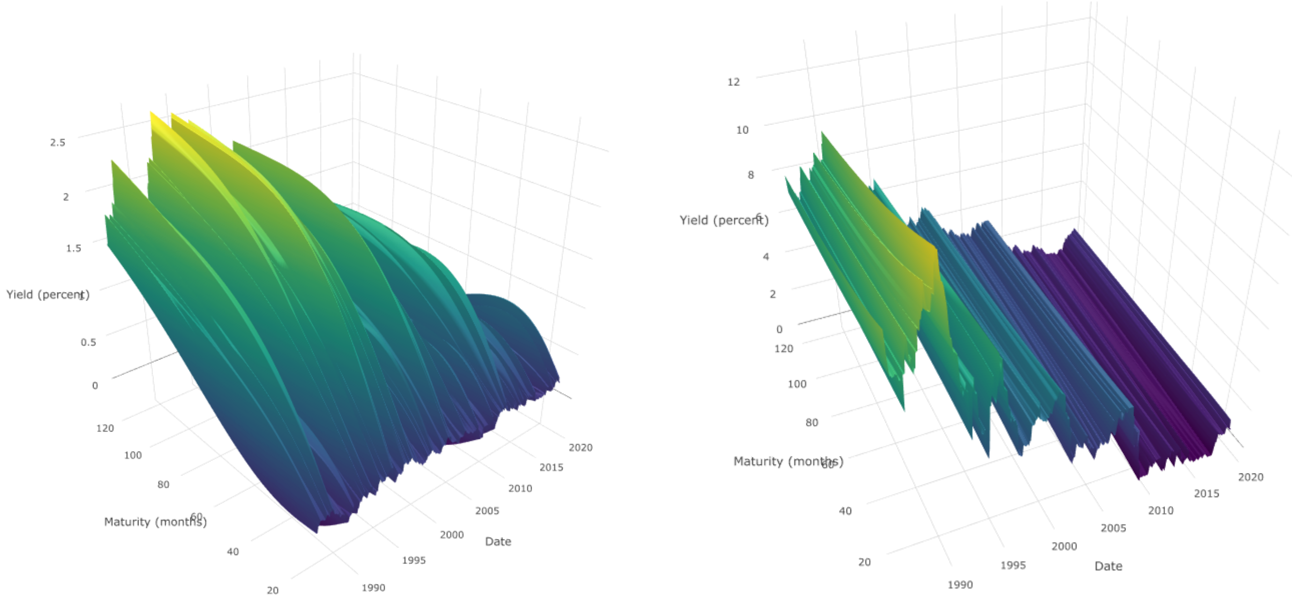


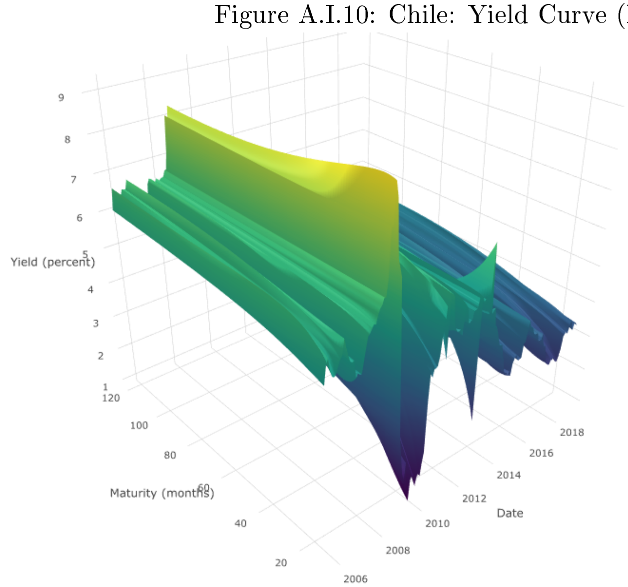

Figure A.I.8 shows that the 1-year term premium has remained near zero throughout the last 3 decades. During this time, the 10-year term premium declined significantly. The 10-year term premium decreased by 1.8% from 1.47% in February 1986 to –0.32% in February 2019. There is also a consistent decline in both the 1-year and 10-year expectations component. The 10-year expectations component decreased by 6.75% from 7.89% in February 1986 to 1.14% in February 2019. This decomposition suggests that the decline in short term interest rates is explained mostly by the change in the expectations component and the change in long-term rates is explained by a decline in both term premium and expectations.

## A.I.4 Chile

Chile is a developing South American country bordering Argentina with a GDP of $277 billion (IMF 2018). Government bond data for Chile are available from October 2005, the data in this thesis are from September 2005 to February 2019. This time period contains data on 3- and 6-month bonds and 1- to 10-year bonds. Short-term rates have fluctuated often and in February of 2014, the 1-year yield spiked to 8.65% as seen in Figure A.I.10. Chile has experienced a slow decline in long-term interest rates as seen in Figure A.I.10. The 10-year yield decreased nearly 2 percentage points from 6.05% in September 2005 to 4.14% in February 2019. There are also sharp declines in the first factor or level and it is generally trending downward.

Blake et al. (2015) published an estimate of term premium for Chile and other Latin American countries using the ACM estimation method. After comparing their estimates with the estimates from this thesis, the lower yields match precisely with any variation accounted for when adding a forth factor to the model as they did. The 10-year decomposition also matched with that of Claro and Moreno (2015), although nominal yield data was roughly 2% higher, which reflected a slightly higher term premium and expectations estimate.

Figure A.I.10: Chile: Yield Curve (left) and Yield Curve Factors (right)



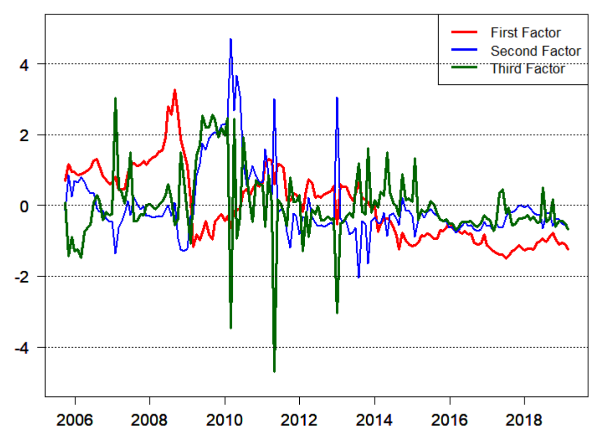




Table A.I.4: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 162 | −0.165 | 0.318 | −1.323 | −0.213 | −0.090 | −0.022 | 0.943 |
| 24-month | 162 | −0.096 | 0.124 | −0.547 | −0.152 | −0.087 | −0.005 | 0.226 |
| 36-month | 162 | −0.041 | 0.107 | −0.595 | −0.097 | −0.027 | 0.035 | 0.200 |
| 60-month | 162 | 0.035 | 0.102 | −0.448 | −0.026 | 0.042 | 0.082 | 0.504 |
| 84-month | 162 | 0.085 | 0.072 | −0.159 | 0.032 | 0.086 | 0.125 | 0.303 |
| 120-month | 162 | 0.147 | 0.148 | −0.399 | 0.089 | 0.141 | 0.198 | 0.927 |

Figure A.I.11: Chile: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

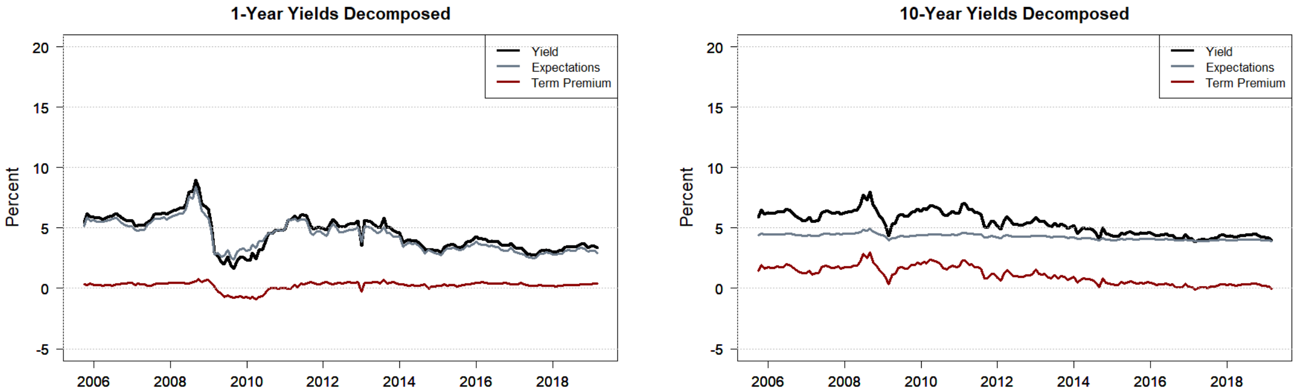



Figure A.I.12: Chile: Term Premium Curve (left) and Expectations Curve (right)

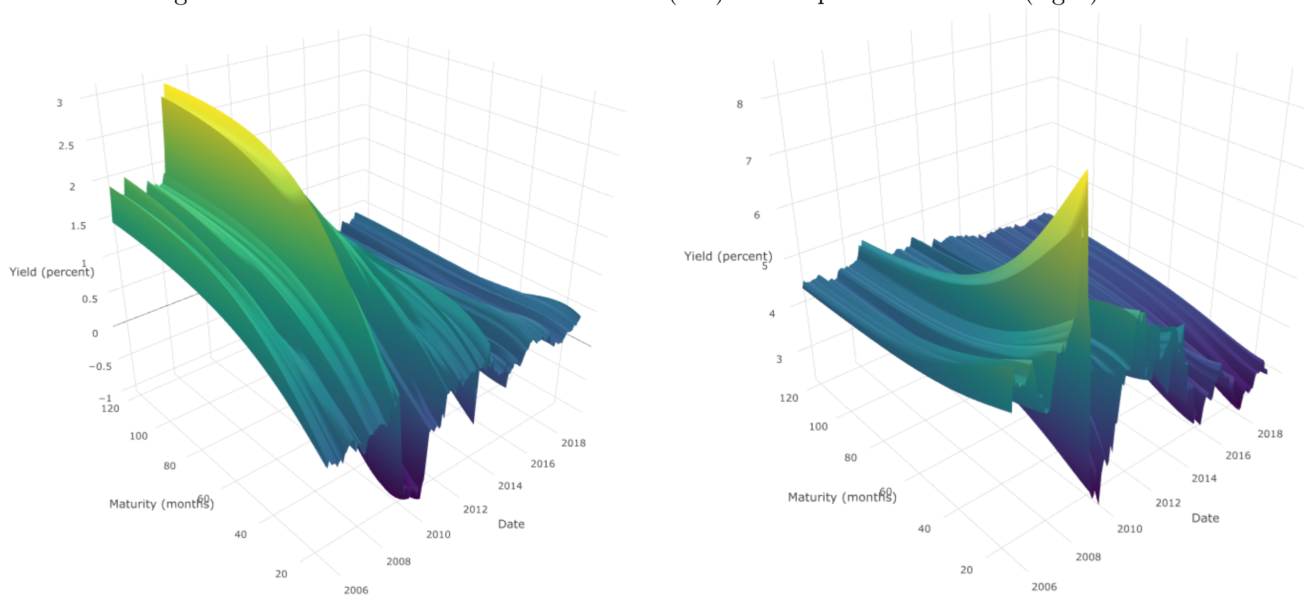



Figure A.I.11 shows that the 1-year term premium has fluctuated and declined in 2010, however it was mostly near zero for the last 12 years. Looking at the 10-year decomposition, almost all of the variation in yields appears to be explained by the term premium. The 10-year term premium decreased more than one and a half percentage point from already low levels, by 1.48%, from 1.47% in September 2005 to --0.01% in February 2019. There is also a slower and consistent decline in the 10-year expectations component by 0.46 percentage points from 4.41% in September 2005 to 3.94% in February 2019. The 10-yearexpectations component decreased by about a third of a percentage point from 4.94% in September 2005 to 4.58% in March 2017. This shows the decline in short-term interest rates is explained mostly by the change in expectations components and the change in long-term rates is mostly explained by the term premium.

### A.I.5 China

China is a massive emerging economy with a GDP second only to the U.S. (IMF 2018). Government bond data for China are available from May 2004 to February 2019. Using this time period allows me to utilize data on 3- and 6-month bonds and 1- to 10-year bonds. This period has seen mostly flat short-term yields with a slight downward trend in longer-term yields. Figure A.I.13 shows that the 10-year yield decreased by 2.02% from 5.23% in May 2004 to 3.21% in February 2019. I was unable to find any existing literature on Chinese term premia.

Although I did not find any estimates for the term premium of Chinese bonds, the bond data used in this thesis for the 2-year, 5-year, 7-year, and 10-year bonds matched with estimates found online.

Figure A.I.13: China: Yield Curve (left) and Yield Curve Factors (right)

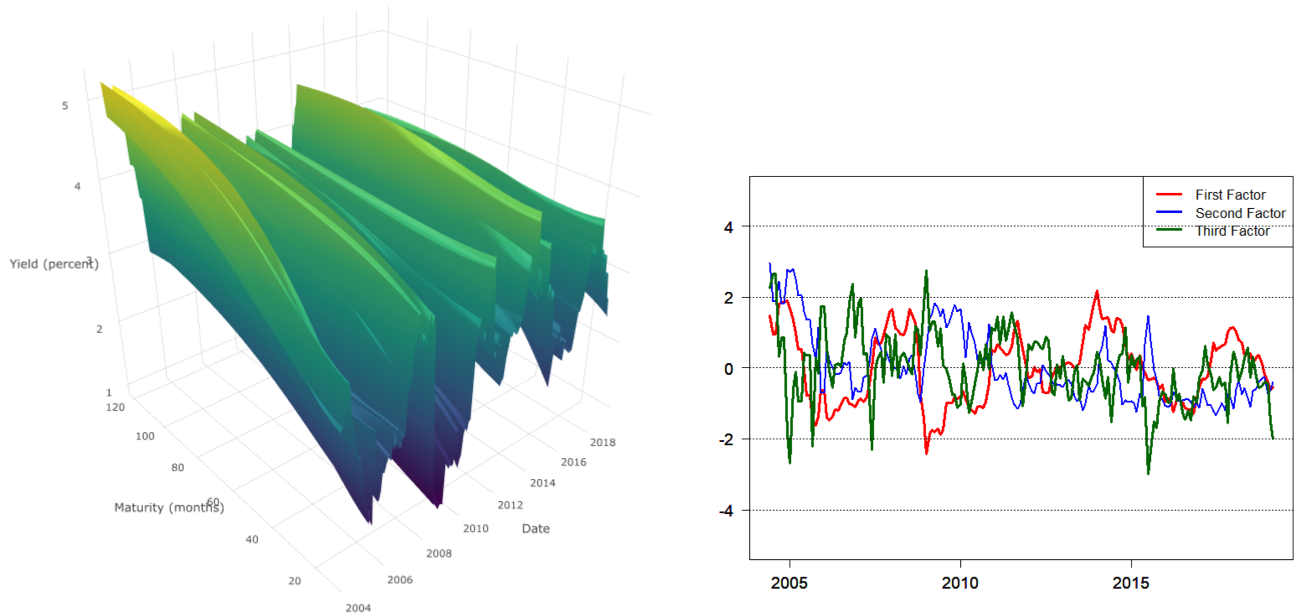



Table A.I.5: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 178 | −0.050 | 0.068 | −0.329 | −0.082 | −0.034 | −0.006 | 0.118 |
| 24-month | 178 | −0.035 | 0.058 | −0.279 | −0.058 | −0.026 | −0.003 | 0.098 |
| 36-month | 178 | −0.013 | 0.033 | −0.166 | −0.028 | −0.009 | 0.007 | 0.091 |
| 60-month | 178 | 0.014 | 0.022 | −0.038 | 0.0003 | 0.015 | 0.027 | 0.098 |
| 84-month | 178 | 0.032 | 0.030 | −0.050 | 0.010 | 0.031 | 0.052 | 0.141 |
| 120-month | 178 | 0.068 | 0.060 | −0.149 | 0.033 | 0.069 | 0.108 | 0.271 |

Figure A.I.14: China: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

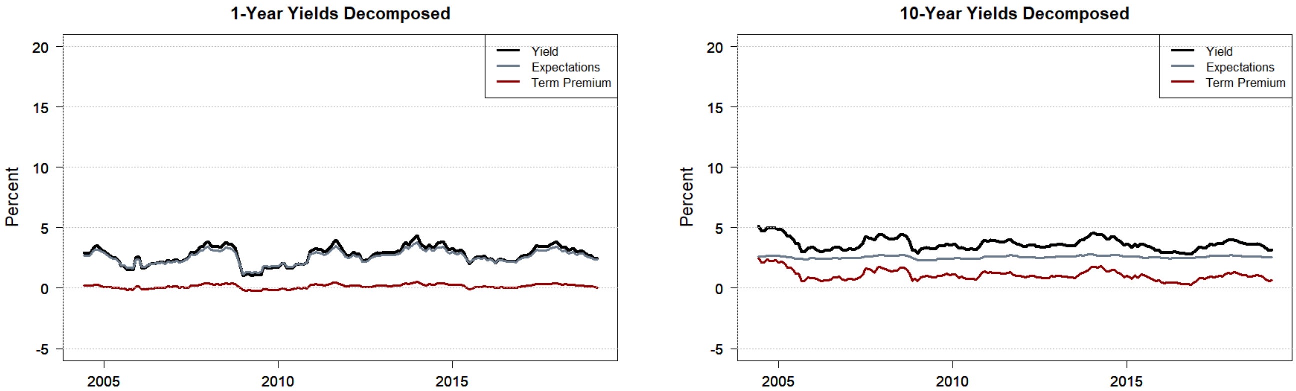
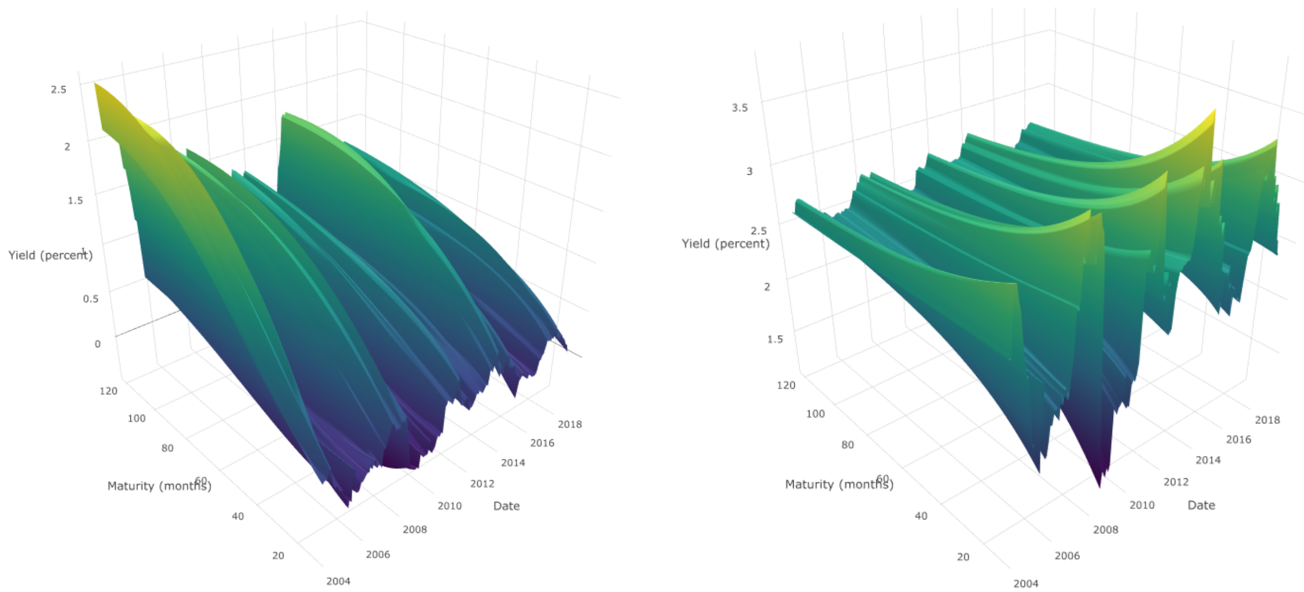



Figure A.I.15: China: Term Premium Curve (left) and Expectations Curve (right)




These results are similar to most Latin American countries like Brazil, Chile, and Peru. Figure A.I.14 shows that the 1-year term premium has remained flat since 2005. However, the 10-year decomposition shows that almost all of the decline was explained by a decline in the term premium. The 10-year expectations component decreased by 0.08% from 2.62% in May 2004 to 2.54% in February 2019. This is very flat when compared with the 10-year term premium, which decreased by 1.88% from 2.52% in May 2004 to 0.64% in February 2019.

### A.I.6 Colombia

Colombia is a developing South American country and the 40th largest economy in the world by GDP according to the IMF (IMF 2018). Government bond data for Colombia are available from June 2006 to February 2019. This time period allows me to utilize data on 3- and 6-month bonds and 1- to 10-year bonds. In order to improve the fit of the model, four factors were used instead of three as in Blake et al. (2015). Figure A.I.17 shows that since 2006, both short- and long-term interest rates have declined. The 10-year yield decreased by 3.22% from 10.07% in May 2006 to 6.85% in February 2019. This pattern is also apparent in A.I.16, which shows a sharp downward movement in the first factor (level) from 2009 to 2011.

In the paper Blake et al. (2015), the authors used the same ACM method to estimate the term premia of Colombia. The authors published term premium estimates using 2-year yields, 5-year yields, and 10-year yields. When comparing their results to the results of this thesis, the figures matched quite closely, confirming the validity of my estimates. The 10-year term premium also matched closely with that of Claro and Moreno (2015).

Figure A.I.16: Colombia: Yield Curve (left) and Yield Curve Factors (right)

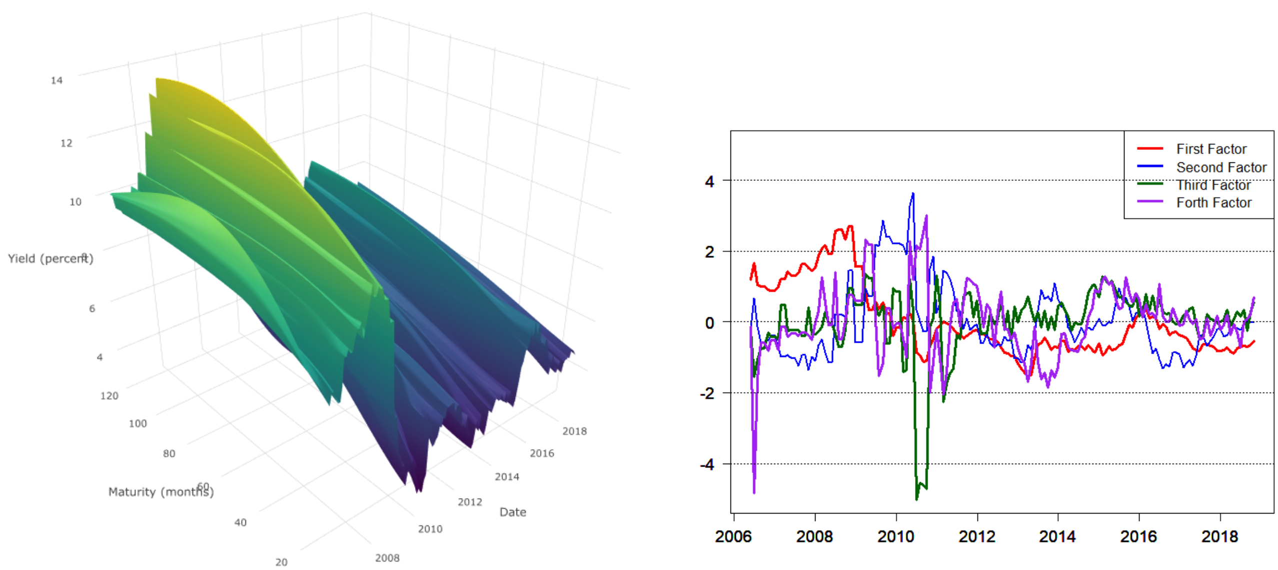



Table A.I.6: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 154 | −0.235 | 0.352 | −2.388 | −0.251 | −0.182 | −0.091 | 0.193 |
| 24-month | 154 | −0.080 | 0.121 | −0.811 | −0.097 | −0.072 | −0.032 | 0.115 |
| 36-month | 154 | 0.024 | 0.044 | −0.106 | 0.003 | 0.018 | 0.040 | 0.229 |
| 60-month | 154 | 0.075 | 0.048 | −0.086 | 0.047 | 0.076 | 0.108 | 0.200 |
| 84-month | 154 | 0.203 | 0.062 | −0.050 | 0.184 | 0.205 | 0.225 | 0.477 |
| 120-month | 154 | 0.553 | 0.056 | 0.391 | 0.526 | 0.546 | 0.575 | 0.898 |

Figure A.I.17: Colombia: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

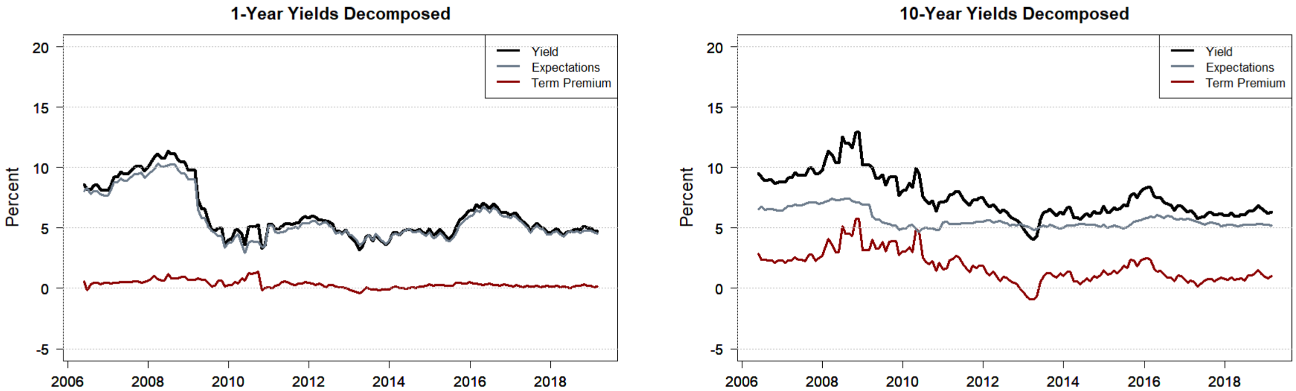



Figure A.I.18: Colombia: Term Premium Curve (left) and Expectations Curve (right)

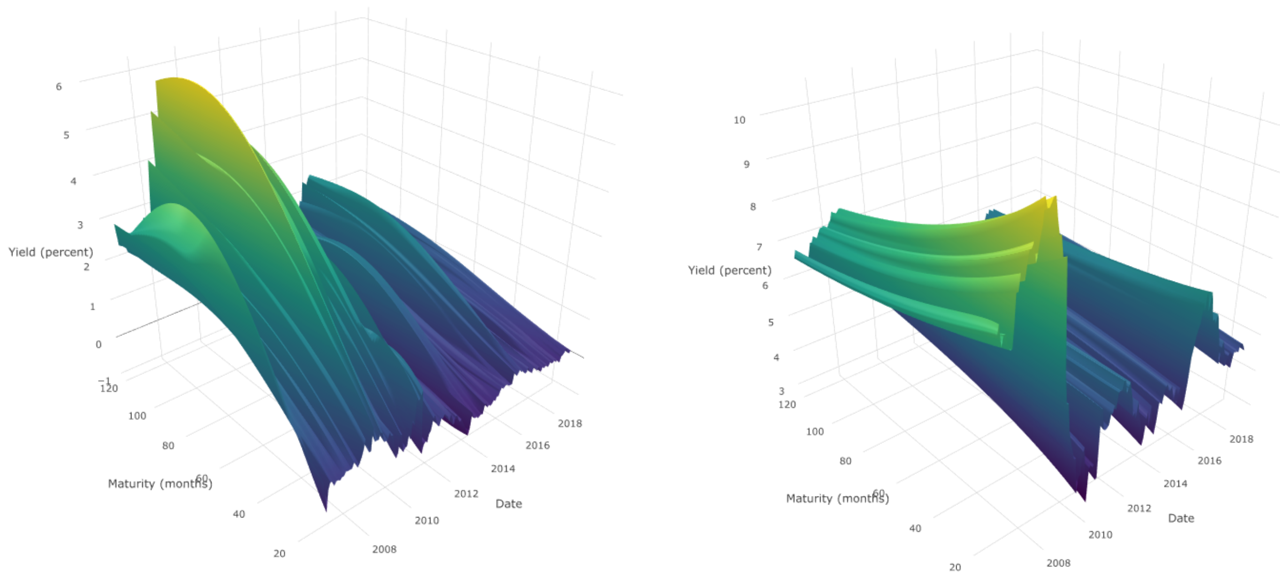



Figure A.I.17 shows that the 1-year term premium has not changed significantly over the last 12 years. However, most of the variation in 10-year yields appears to be explained by the term premium. The 10-year term premium decreased by 1.87% from 2.89% in May 2006 to 1.02% in February 2019, and the 10-year expectations component decreased by over 1 percentage point from 6.56% in May 2006 to 5.22% in February 2019. When compared with other Latin American countries, Colombia had the most fluctuation in long-term expectations, but still the majority of the fluctuation in long-term yields is explained by the term premium.

## A.I.7 Czech Republic

Czech Republic is a developed landlocked European country and the 49th largest economy by GDP (IMF 2018). Government bond data for the Czech Republic are available after 2001. This time period contains data on 3- and 6-month bonds and 1- to 10-year bonds. This period exhibits a significant decline in long-term interest rates as seen in Figure A.I.19. The 10-year yield decreased by 4.7% from 6.67% in January 2001 to 1.97% in February 2019. This decline follows most of Europe, whose rates have fallen over the last two decades.

I was unable to find any term premium data on the Czech Republic; however, the yield estimates for 1-year, 3-year, 5-year, and 10-year bonds matched closely with those of Kladıvko (2010).

Figure A.I.19: Czech Republic: Yield Curve (left) and Yield Curve Factors (right)

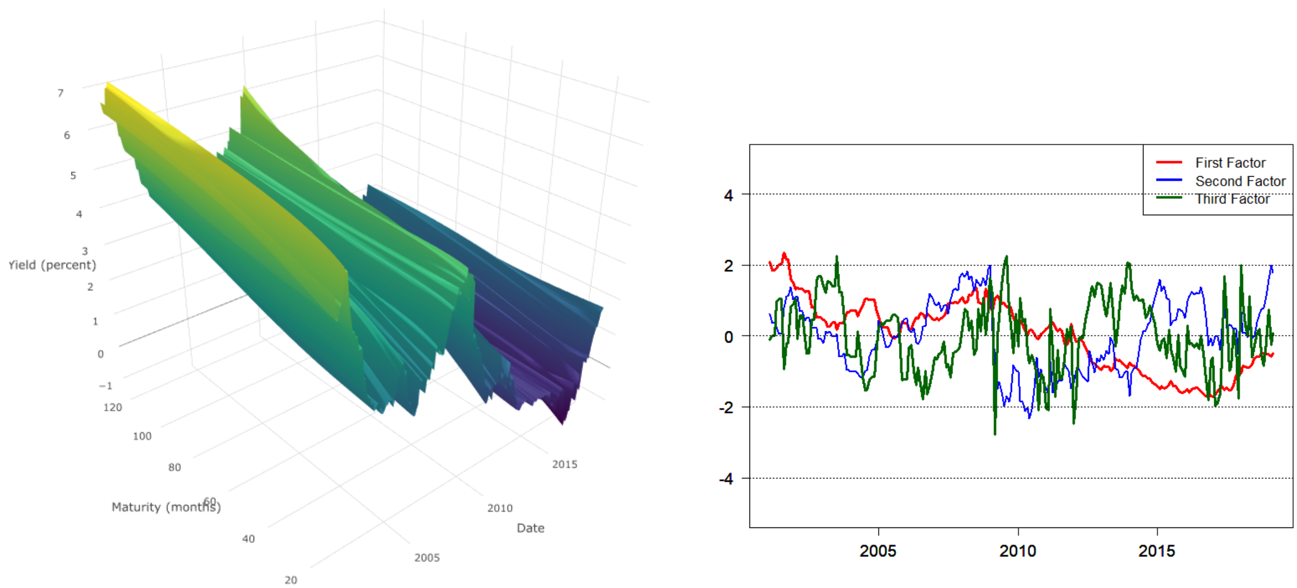



Table A.I.7: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 218 | −0.023 | 0.046 | −0.133 | −0.052 | −0.032 | 0.008 | 0.201 |
| 24-month | 218 | 0.021 | 0.057 | −0.173 | −0.020 | 0.020 | 0.057 | 0.218 |
| 36-month | 218 | 0.052 | 0.061 | −0.093 | 0.010 | 0.051 | 0.088 | 0.311 |
| 60-month | 218 | 0.085 | 0.086 | −0.082 | 0.015 | 0.072 | 0.151 | 0.329 |
| 84-month | 218 | 0.110 | 0.069 | −0.092 | 0.064 | 0.107 | 0.161 | 0.294 |
| 120-month | 218 | 0.137 | 0.108 | −0.217 | 0.065 | 0.161 | 0.212 | 0.420 |

Figure A.I.20: Czech Republic: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

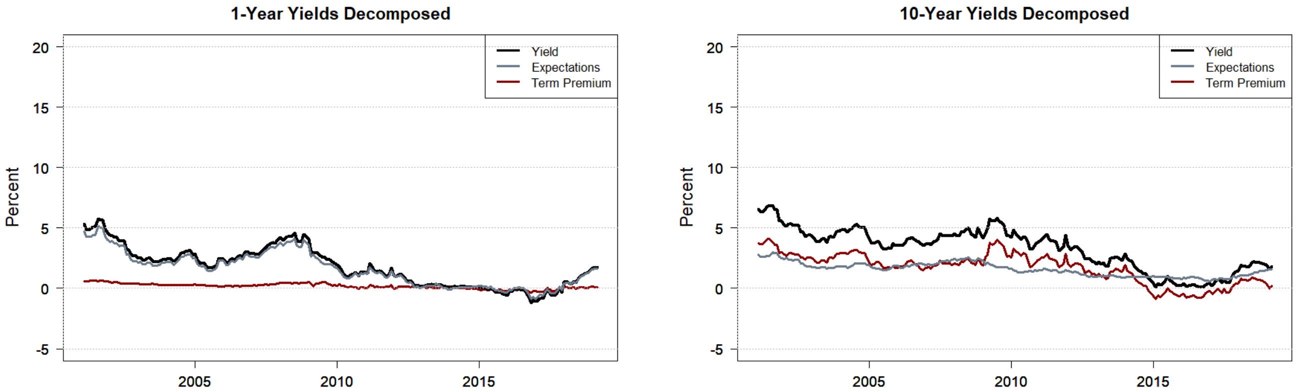



Figure A.I.21: Czech Republic: Term Premium Curve (left) and Expectations Curve (right)

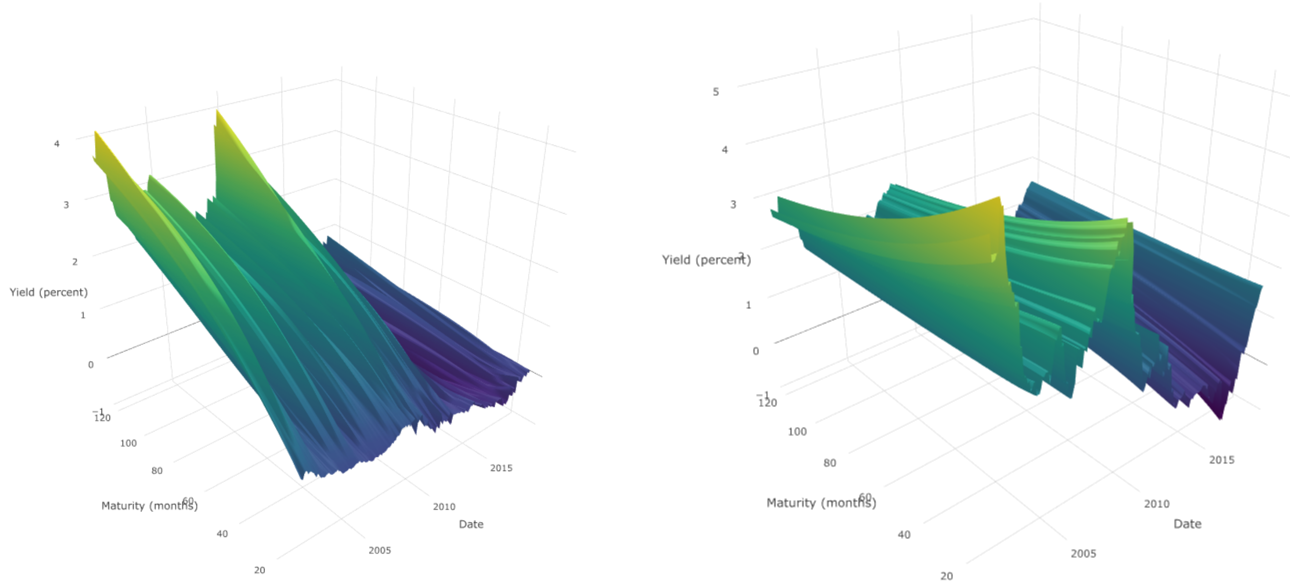


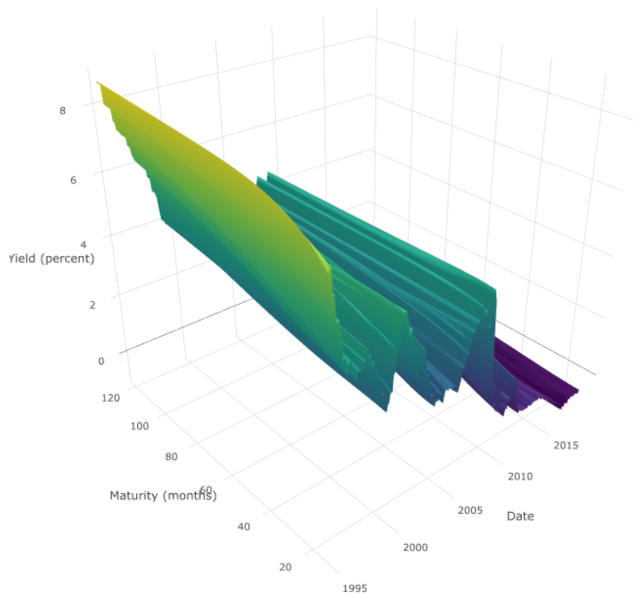

Figure A.I.20 shows that the 1-year term premium has declined slightly over the last 18 years. The 10-year yields appear to be explained by a decline in both the expectations component and the term premium. The 10-year expectations component decreased by 1.25% from 2.8% in January 2001 to 1.55% in February 2019 and the 10-year term premium decreased by 3.51% from 3.75% in January 2001 to 0.24% in February 2019. Visually, Figure A.I.20 shows that most of the variation in long-term rates is accounted for by the term premium. The expectations component had a slow consistent decline as well.

### A.I.8 Euro Area

Europe is comprised of mostly developed countries that have experienced similar struggles as the U.S. after the financial crisis. These yields are from the European Central Bank and are often used for a risk-free interest rate comprised of a weighted average of different European countries' interest rates. Government bond data for the Euro area are available past 1995 and contain data on 3- and 6-month bonds and 1- to10-year bonds. This period has a significant decline in interest rates as seen in Figure A.I.22. This is also apparent in the first factor which has trended downward during the entire period. The 10-year yield decreased by more than 8 percentage points from 8.69% in January 1995 to 0.2% in February 2019.

The estimate for the 10-year term premium for Europe matched closely with the ACM estimate seen in Cohen et al. (2018).

Figure A.I.22: Euro Area: Yield Curve (left) and Yield Curve Factors (right)



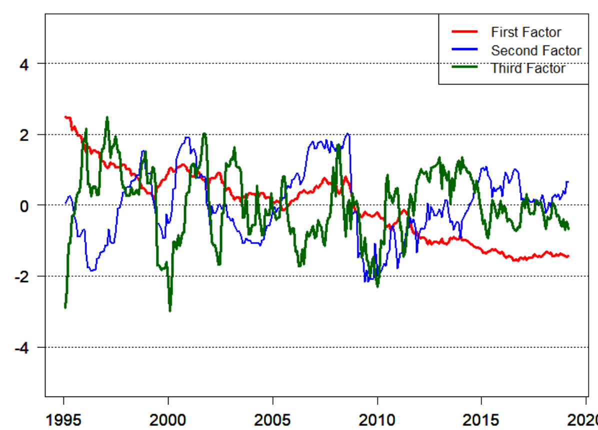




Table A.I.8: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 290 | 0.024 | 0.028 | −0.060 | 0.009 | 0.023 | 0.038 | 0.177 |
| 24-month | 290 | 0.021 | 0.040 | −0.059 | −0.009 | 0.016 | 0.045 | 0.206 |
| 36-month | 290 | 0.011 | 0.025 | −0.055 | −0.007 | 0.011 | 0.030 | 0.078 |
| 60-month | 290 | 0.010 | 0.030 | −0.134 | −0.011 | 0.015 | 0.032 | 0.067 |
| 84-month | 290 | 0.039 | 0.028 | −0.023 | 0.021 | 0.038 | 0.059 | 0.099 |
| 120-month | 290 | 0.085 | 0.055 | −0.023 | 0.042 | 0.078 | 0.120 | 0.289 |

Figure A.I.23: Euro Area: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

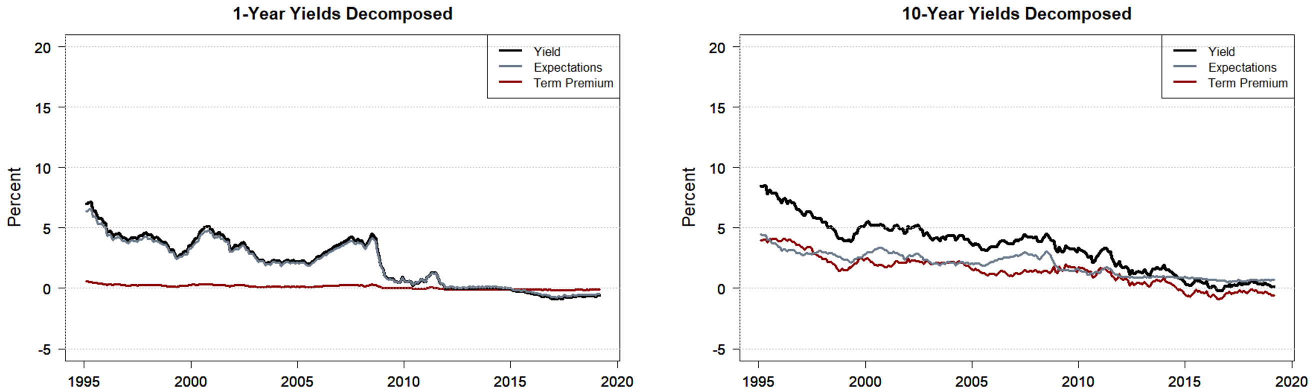



Figure A.I.24: Euro Area: Term Premium Curve (left) and Expectations Curve (right)

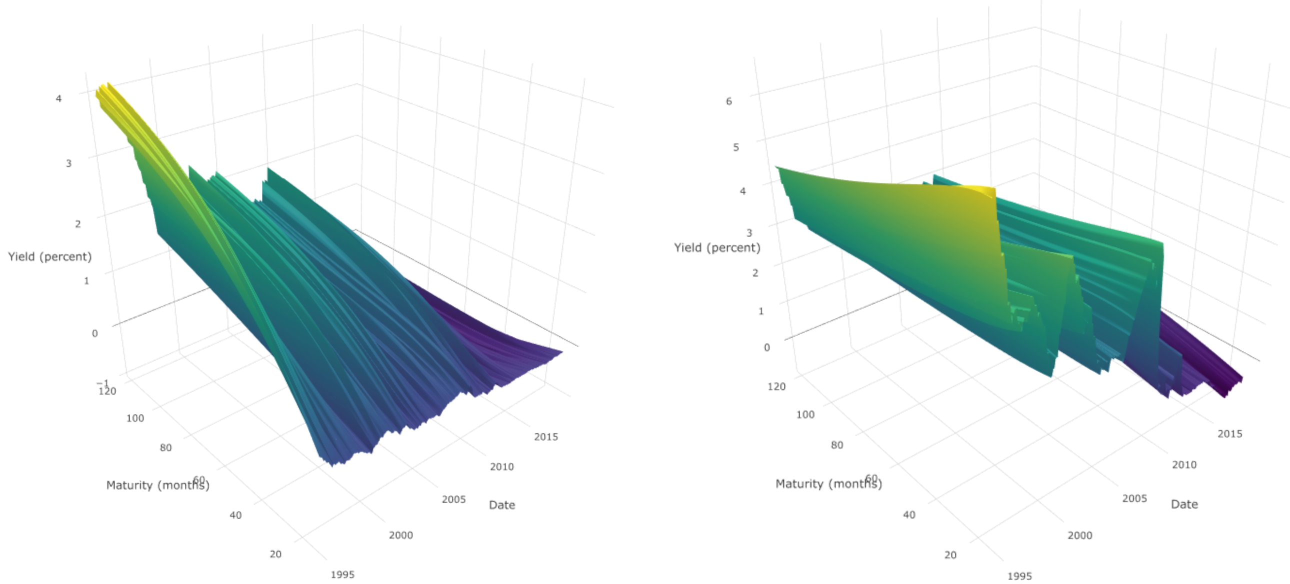



Figure A.I.23 shows that the 1-year term premium has declined slightly over the last 2 decades and has gone negative recently. The 10-year decomposition shows the steady decline of the term premium. The 10-year term premium decreased by 4.58 percentage points from 3.98% in January 1995 to –0.6% in February 2019. The 10-year expectations component decreased by 3.74 percentage points from 4.46% in January 1995 to 0.72% in February 2019. Both of these factors appear to contribute to the decline of long-term rates as seen in Figure A.I.24.

## A.I.9 Hungary

Hungary is another European country that experienced a decline in interest rates. Government bond data for Hungary are available after April of 2001 and contain data on 3- and 6-month bonds and 1- to10-year bonds. Hungary has also experienced a decline in long term interest rates as seen in Figure A.I.25. The 10-year yield decreased by 5.42 percentage points from 8.52% in April 2001 to 3.1% in February 2019.

Figure A.I.25: Hungary: Yield Curve (left) and Yield Curve Factors (right)

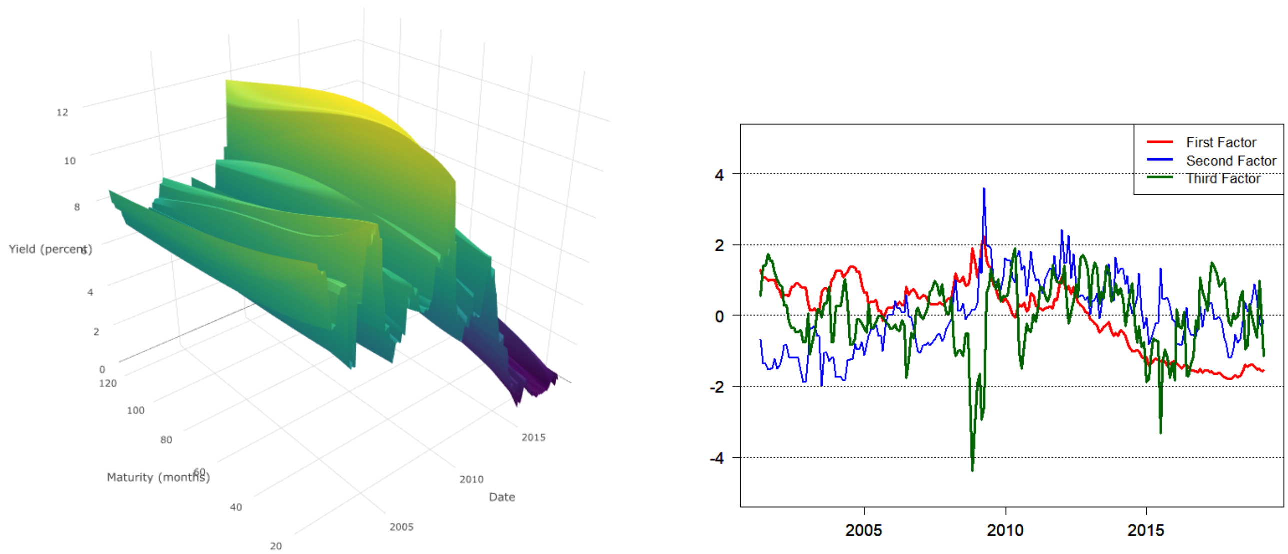



Table A.I.9: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 215 | −0.024 | 0.166 | −0.532 | −0.136 | −0.055 | 0.072 | 0.394 |
| 24-month | 215 | 0.004 | 0.096 | −0.437 | −0.060 | 0.001 | 0.066 | 0.250 |
| 36-month | 215 | 0.048 | 0.056 | −0.165 | 0.023 | 0.048 | 0.081 | 0.242 |
| 60-month | 215 | 0.140 | 0.067 | −0.028 | 0.100 | 0.143 | 0.184 | 0.473 |
| 84-month | 215 | 0.241 | 0.051 | 0.084 | 0.209 | 0.236 | 0.266 | 0.426 |
| 120-month | 215 | 0.424 | 0.118 | −0.105 | 0.368 | 0.419 | 0.500 | 0.740 |

Figure A.I.26: Hungary: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

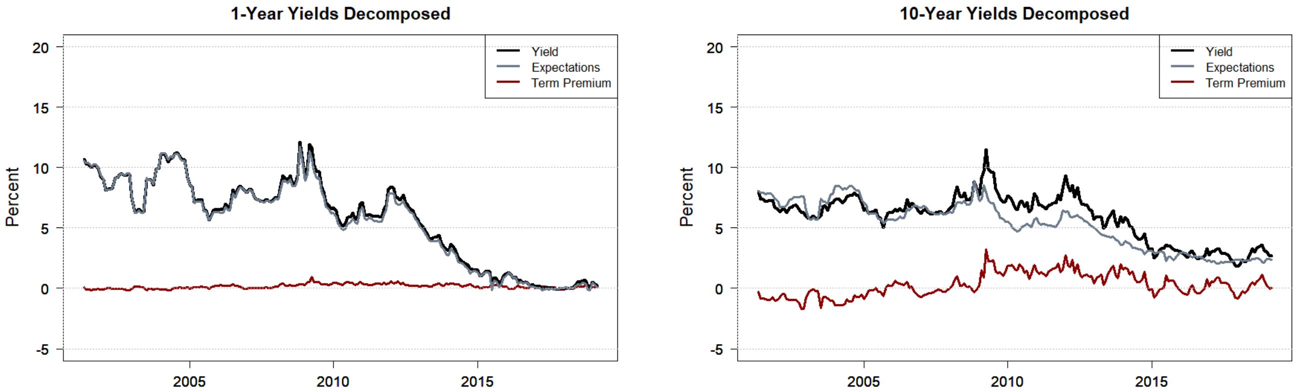



Figure A.I.27: Hungary: Term Premium Curve (left) and Expectations Curve (right)

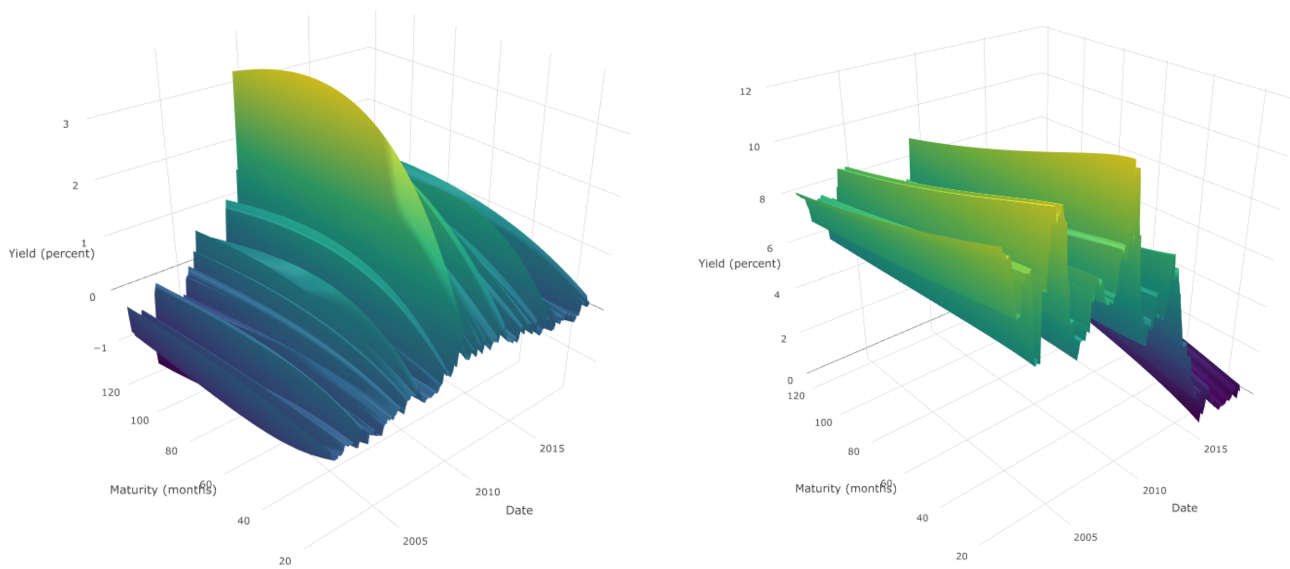
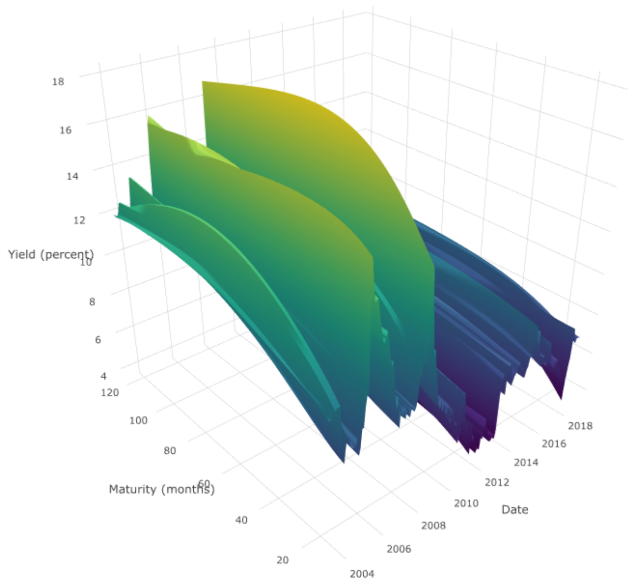



Figure A.I.26 shows that the 1-year term premium has remained flat over the last 17 years. However, inconsistent with other European countries, the 10-year decomposition shows an increase in term premium. The 10-year term premium increased by 0.34 percentage points from --0.31% in April 2001 to 0.03% in February 2019. Therefore, the decline in rates is explained by falling expectations, which follow the nominal yields closely. The 10-year expectations component decreased by 5.7 percentage points from 8.06% in April 2001 to 2.37% in February 2019.

## A.I.10 Indonesia

Indonesia is a developing Asian country consisting of a collection of islands and is the 16th largest economy by GDP (IMF 2018). Government bond data for Indonesia are available past June of 2003 and contain data on 3- and 6-month bonds and 1- to 10-year bonds. This period was volatile and also experienced a decline in long-term interest rates shown in Figure A.I.28. The 10-year yield decreased by 3.98 percentage points from 11.99% in June 2003 to 8.01% in February 2019.

Figure A.I.28: Indonesia: Yield Curve (left) and Yield Curve Factors (right)



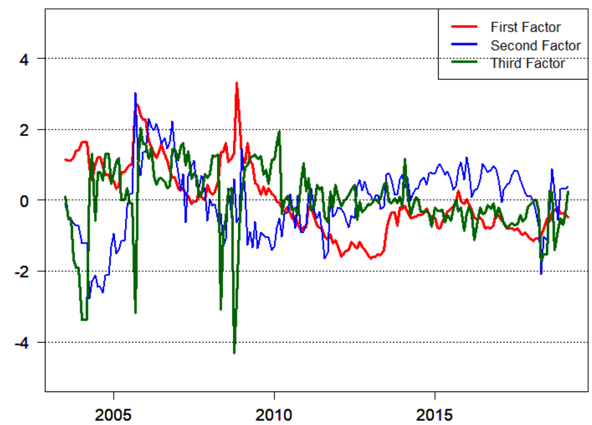




Table A.I.10: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 189 | −0.160 | 0.218 | −1.122 | −0.215 | −0.134 | −0.030 | 0.220 |
| 24-month | 189 | −0.084 | 0.281 | −1.744 | −0.163 | −0.068 | 0.051 | 0.523 |
| 36-month | 189 | 0.009 | 0.221 | −1.306 | −0.045 | 0.043 | 0.096 | 0.446 |
| 60-month | 189 | 0.277 | 0.119 | −0.057 | 0.219 | 0.296 | 0.360 | 0.763 |
| 84-month | 189 | 0.609 | 0.178 | 0.203 | 0.529 | 0.615 | 0.664 | 1.692 |
| 120-month | 189 | 0.995 | 0.229 | −0.415 | 0.884 | 0.958 | 1.073 | 1.576 |

Figure A.I.29: Indonesia: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

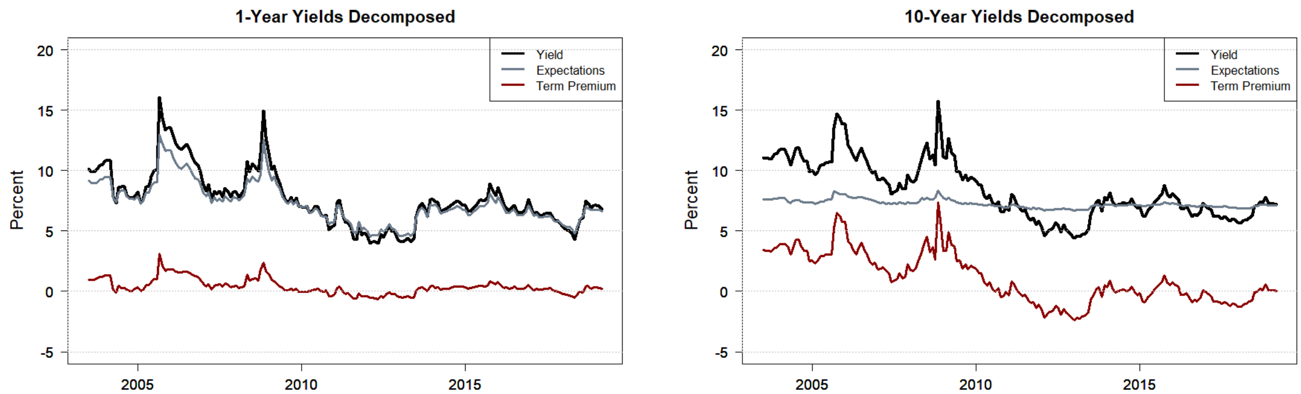



Figure A.I.30: Indonesia: Term Premium Curve (left) and Expectations Curve (right)

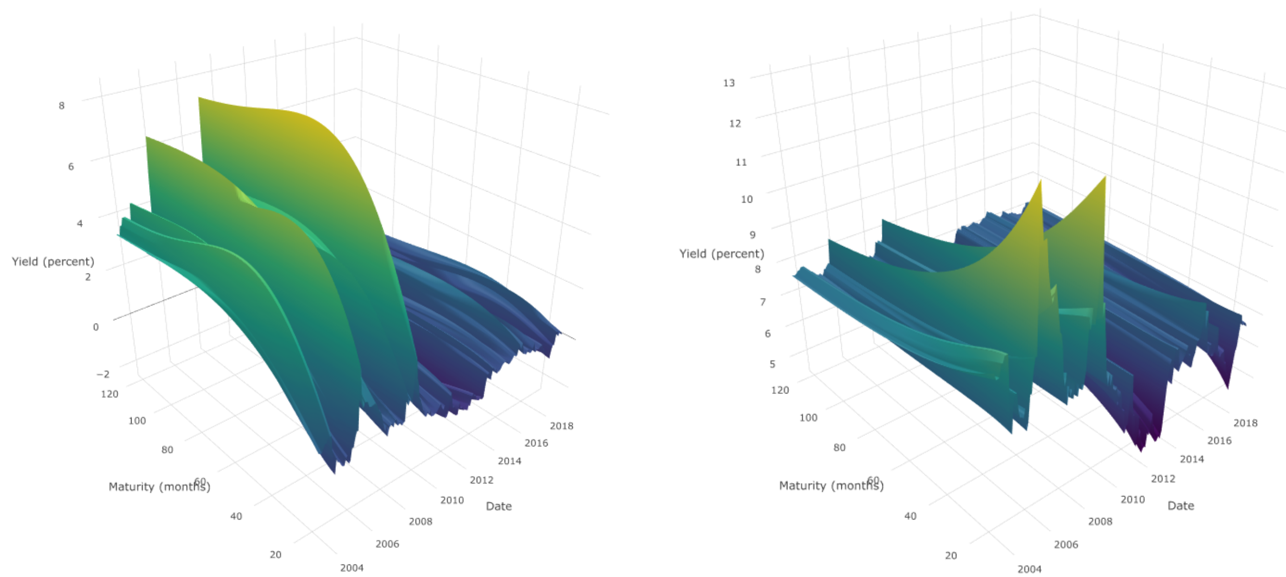


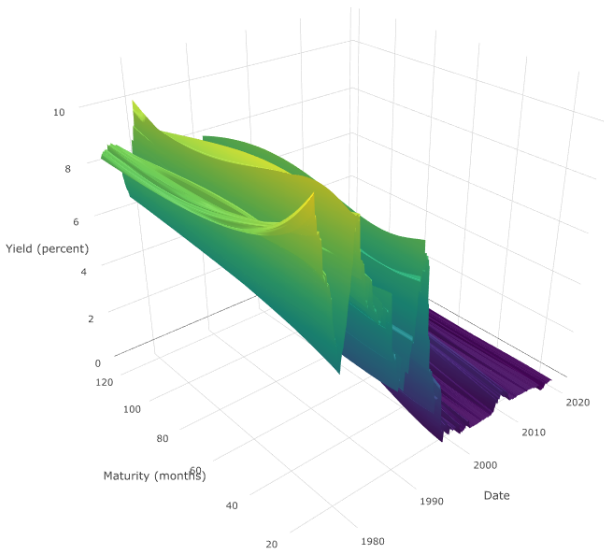

Figure A.I.29 shows that the 1-year term premium has been a contributor to the fluctuations of short-term rates. The long-term interest rate decline from 2003 to 2019 appears to be explained by falling term premium, which decreased by 3.4 percentage points from 3.42% in June 2003 to 0.02% in February 2019. The long-term expectations components have remained mostly flat. The 10-year expectations component decreased by 0.51 percentage points from 7.62% in June 2003 to 7.1% in February 2019. This is consistent with Latin American countries and China, which all contain mostly flat 10-year expectations.

## A.I.11 Japan

Japan is a developed major economic power in Asia and the third largest economy by GDP (IMF 2018). Government bond data for Japan are robust and dates back until the early seventies; the data used in this thesis are from September 1974 to February 2019. Using this time period allows me to utilize data on 3- and 6-month bonds and 1- to 10-year bonds. Figure A.I.31 shows Japan has had declining long term rates for over 4 decades. The 10-year yield decreased by 8.22 percentage points from 8.19% in September 1974 to –0.03% in February 2019.

The 10-year expectations component matched closely with the SRM estimate in Ichiue et al. (2013).

Figure A.I.31: Japan: Yield Curve (left) and Yield Curve Factors (right)



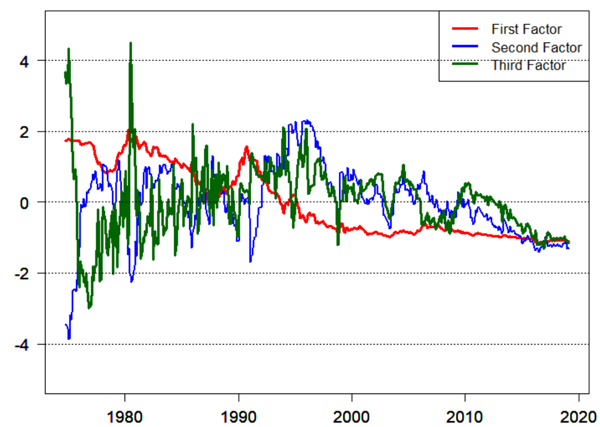




Table A.I.11: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 534 | −0.047 | 0.115 | −0.642 | −0.086 | −0.045 | −0.011 | 0.355 |
| 24-month | 534 | −0.046 | 0.112 | −0.464 | −0.093 | −0.045 | 0.007 | 0.306 |
| 36-month | 534 | −0.033 | 0.067 | −0.310 | −0.059 | −0.028 | 0.004 | 0.250 |
| 60-month | 534 | 0.020 | 0.079 | −0.293 | −0.002 | 0.023 | 0.046 | 0.317 |
| 84-month | 534 | 0.060 | 0.070 | −0.297 | 0.032 | 0.055 | 0.078 | 0.336 |
| 120-month | 534 | 0.073 | 0.182 | −0.654 | 0.023 | 0.082 | 0.153 | 0.952 |

Figure A.I.32: Japan: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

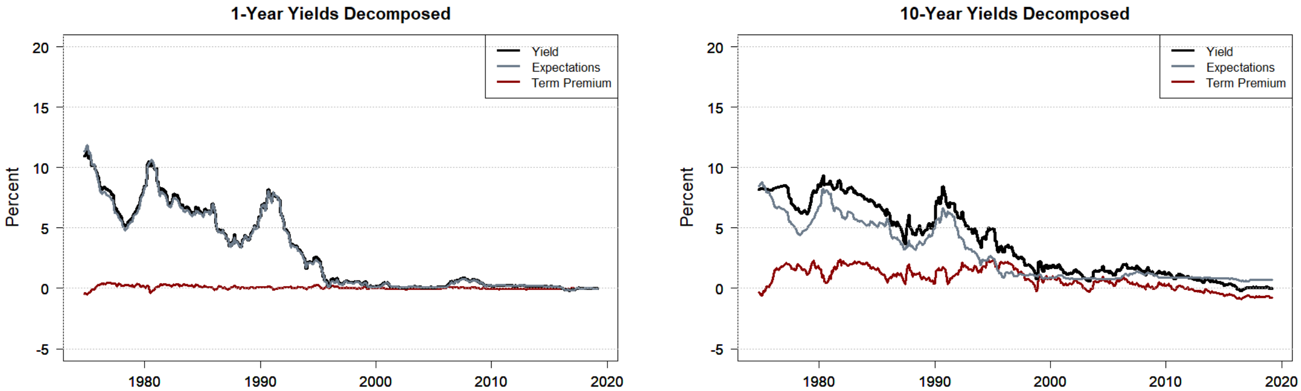



Figure A.I.33: Japan: Term Premium Curve (left) and Expectations Curve (right)

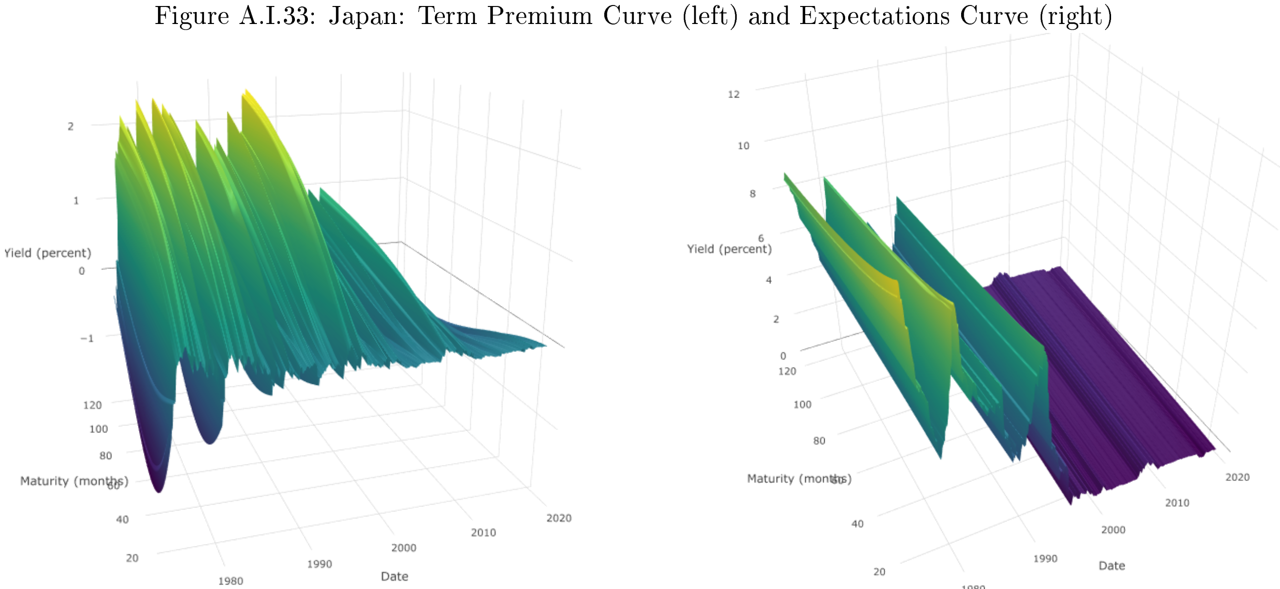
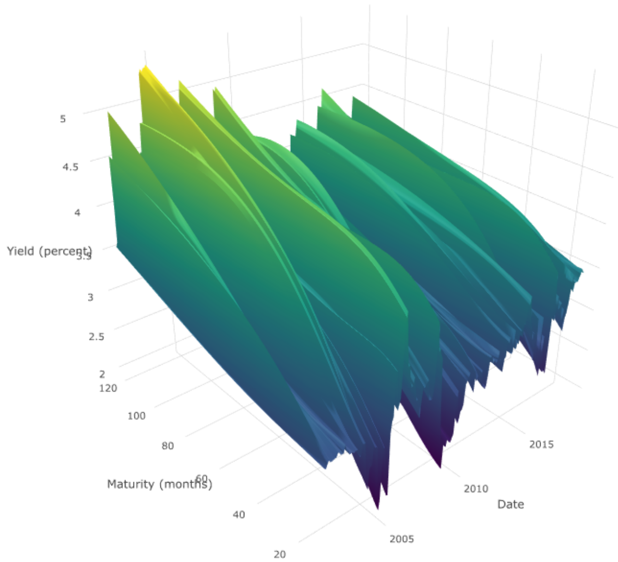



Figure A.I.32 shows the 1-year term premium has fluctuated, but remained close to zero. Prior to 1984, the expectations component and term premium moved inversely to one another, however after 1984, the two trended downward together. The 10-year term premium decreased by 0.43 percentage points from --0.36% in September 1974 to –0.79% in February 2019. The 10-year expectations component decreased by 7.81 percentage points from 8.51% in September 1974 to 0.69% in February 2019.

## A.I.12 Malaysia

Malaysia is an Asian country near Singapore and Indonesia with Government bond data available past October 2001 on 3- and 6-month bonds and 1- to 10-year bonds. This period has not seen the typical decline in interest rates that most nations experienced. The 10-year yield actually increased by over a percentage point from 3.54% in October 2001 to 4.36% in November 2018.

Figure A.I.34: Malaysia: Yield Curve (left) and Yield Curve Factors (right)



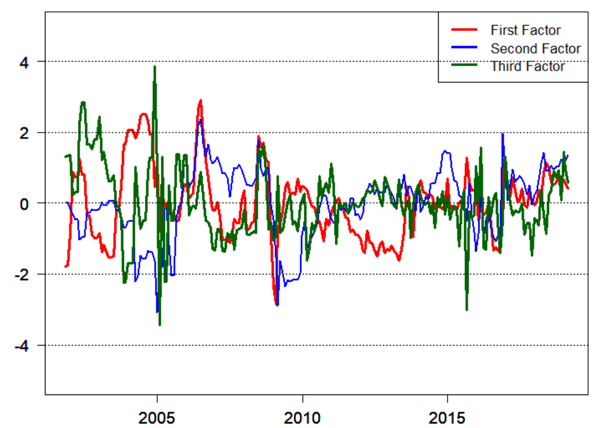
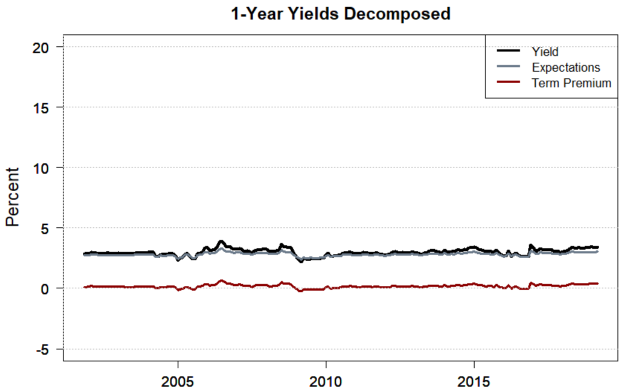




Table A.I.12: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 209 | −0.068 | 0.084 | −0.381 | −0.106 | −0.051 | −0.013 | 0.096 |
| 24-month | 209 | 0.006 | 0.081 | −0.176 | −0.047 | 0.004 | 0.049 | 0.288 |
| 36-month | 209 | 0.061 | 0.094 | −0.109 | 0.010 | 0.047 | 0.097 | 0.345 |
| 60-month | 209 | 0.089 | 0.057 | −0.024 | 0.050 | 0.078 | 0.110 | 0.246 |
| 84-month | 209 | 0.072 | 0.047 | −0.056 | 0.044 | 0.076 | 0.100 | 0.174 |
| 120-month | 209 | 0.060 | 0.079 | −0.154 | 0.003 | 0.050 | 0.112 | 0.267 |

Figure A.I.35: Malaysia: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)



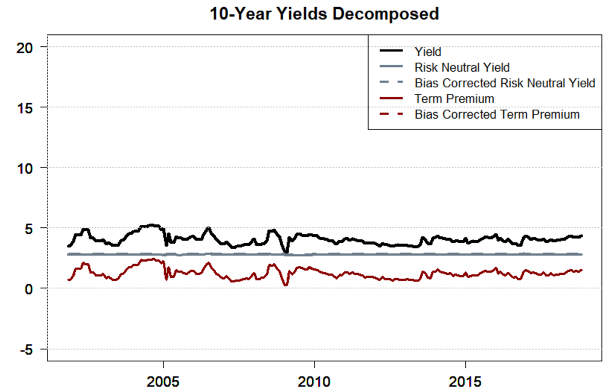
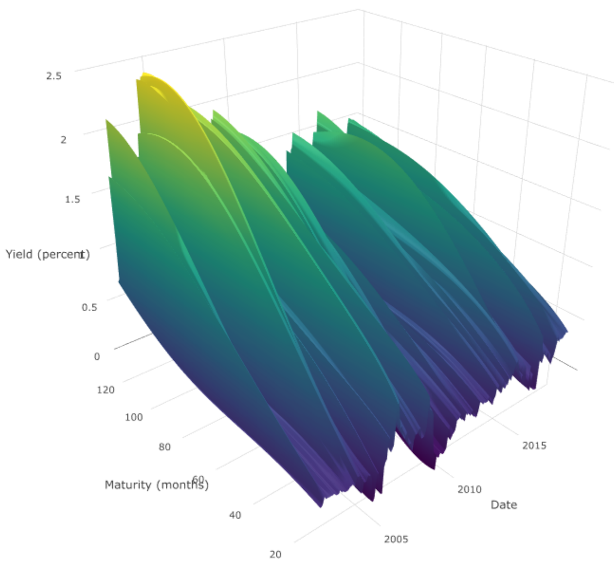




Figure A.I.36: Malaysia: Term Premium Curve (left) and Expectations Curve (right)



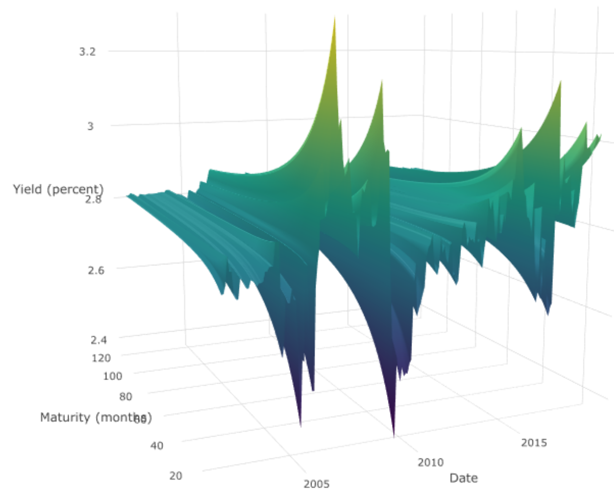




Figure A.I.35 shows that the 1-year term premium moves with the risk neutral yield. However, the fluctuation in 10-year yields appears to be explained only by the 10-year term premium, which also increased. The 10-year term premium increased by 0.57 percentage points from 0.69% in October 2001 to 1.26% in February 2019. Similar to its neighbor, Indonesia, the 10-year expectations component appears to have remained relatively flat from 2.81% in October 2001 to 2.84% in November 2018.

## A.I.13 Mexico

Mexico is a developing Latin American country bordering the U.S. and the 15th largest economy by GDP (IMF 2018). Government bond data for Mexico are available past September 2003. This time period allows me to utilize data on 3- and 6-month bonds and 1- to 10-year bonds. This period contains a decline in interest rates until 2015, then a rapid increase into 2019 as seen in Figure A.I.37. The 10-year yield decreased by 0.59 percentage points from 9.01% in September 2003 to 8.43% in February 2019.

In the paper Blake et al. (2015), the authors used the same ACM method to estimate Mexico's term premia. The authors used a four-factor model to estimate the term premium and the estimates matched closely to the estimates in this paper, confirming the validity of the model estimates. The 10-year term premium also matched with that of Claro and Moreno (2015).

Figure A.I.37: Mexico: Yield Curve (left) and Yield Curve Factors (right)

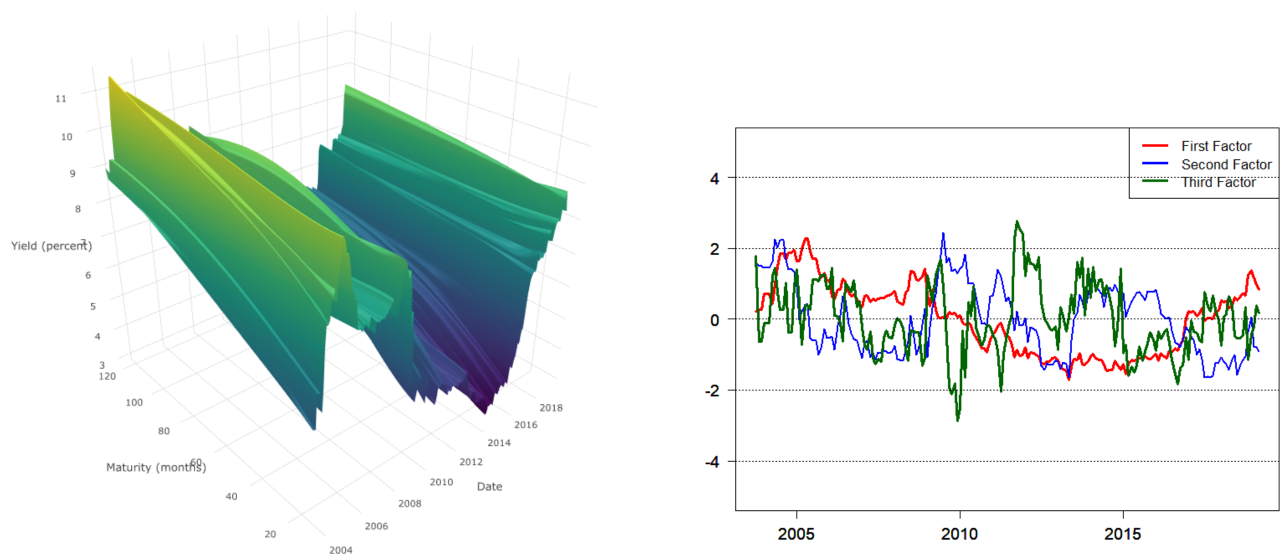



Table A.I.13: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 186 | −0.052 | 0.082 | −0.363 | −0.102 | −0.054 | −0.015 | 0.183 |
| 24-month | 186 | −0.056 | 0.105 | −0.361 | −0.119 | −0.075 | −0.008 | 0.286 |
| 36-month | 186 | −0.048 | 0.067 | −0.299 | −0.087 | −0.058 | −0.022 | 0.148 |
| 60-month | 186 | 0.015 | 0.054 | −0.127 | −0.021 | 0.014 | 0.051 | 0.182 |
| 84-month | 186 | 0.113 | 0.062 | −0.073 | 0.082 | 0.121 | 0.145 | 0.351 |
| 120-month | 186 | 0.227 | 0.123 | −0.191 | 0.167 | 0.207 | 0.282 | 0.596 |

Figure A.I.38: Mexico: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

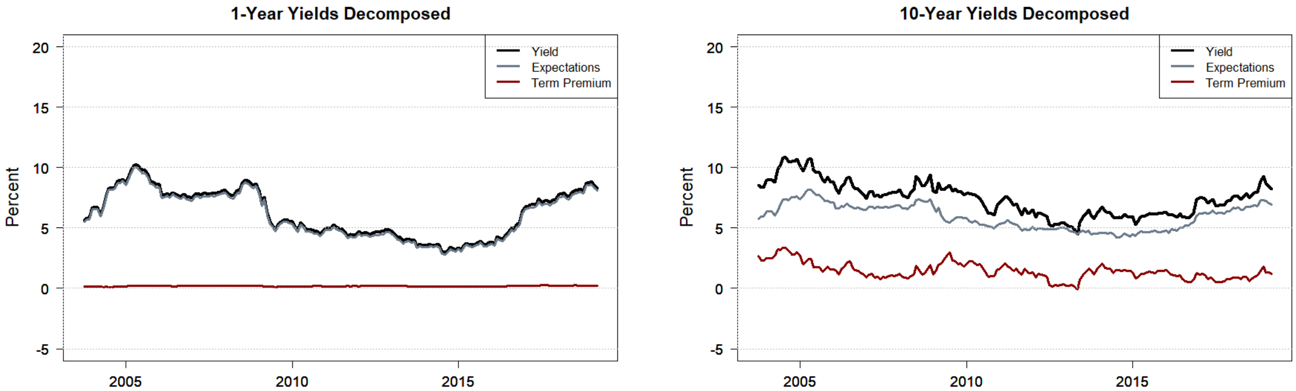



Figure A.I.39: Mexico: Term Premium Curve (left) and Expectations Curve (right)

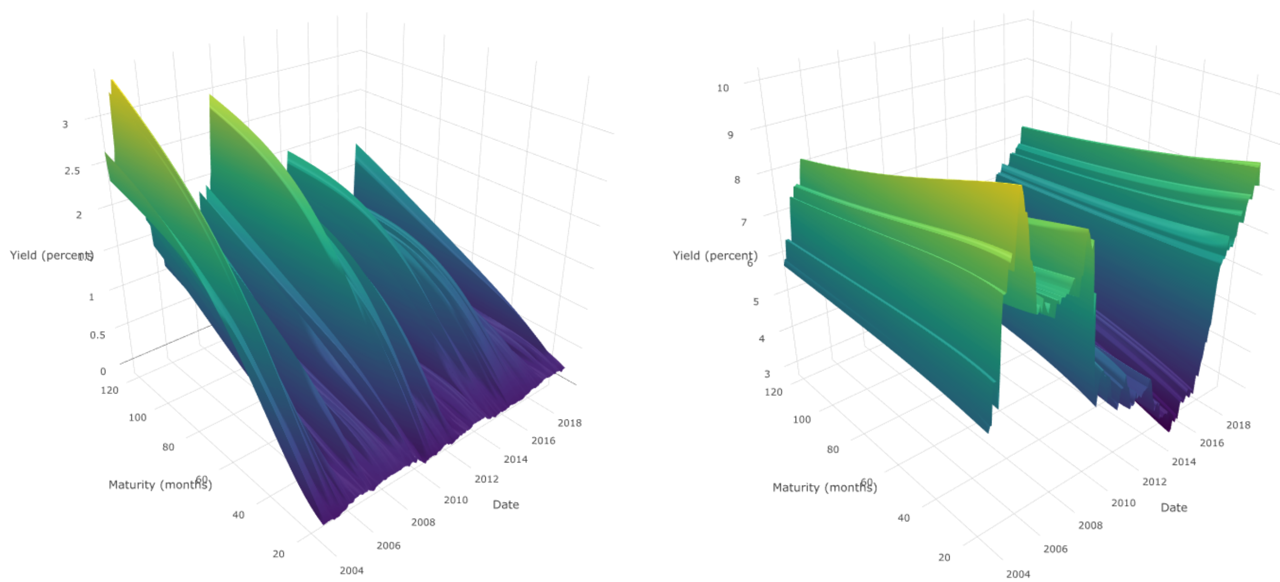



Figure A.I.38 shows that the 1-year term premium has remained relatively flat. Despite the 10-year yield remaining mostly flat over the past 15 years, the 10-year term premium decreased by 1.47 percentage points from 2.66% in September 2003 to 1.18% in February 2019. This pattern is consistent with other countries' decreasing term premium and the rise was explained by the 10-year expectations component which increased by 1.17 percentage points from 5.78% in September 2003 to 6.95% in February 2019.

## A.I.14 New Zealand

New Zealand is a developed country near Australia and is the 52nd largest economy by GDP (IMF 2018). Government bond data for New Zealand are available past 1995 and contains 3- and 6-month bonds and 1- to 10-year bonds. New Zealand experienced a decline in long-term interest rates as seen in Figure A.I.40. The 10-year yield decreased by 6.5 percentage points from 8.68% in January 1995 to 2.18% in February 2019.

Figure A.I.40: New Zealand: Yield Curve (left) and Yield Curve Factors (right)

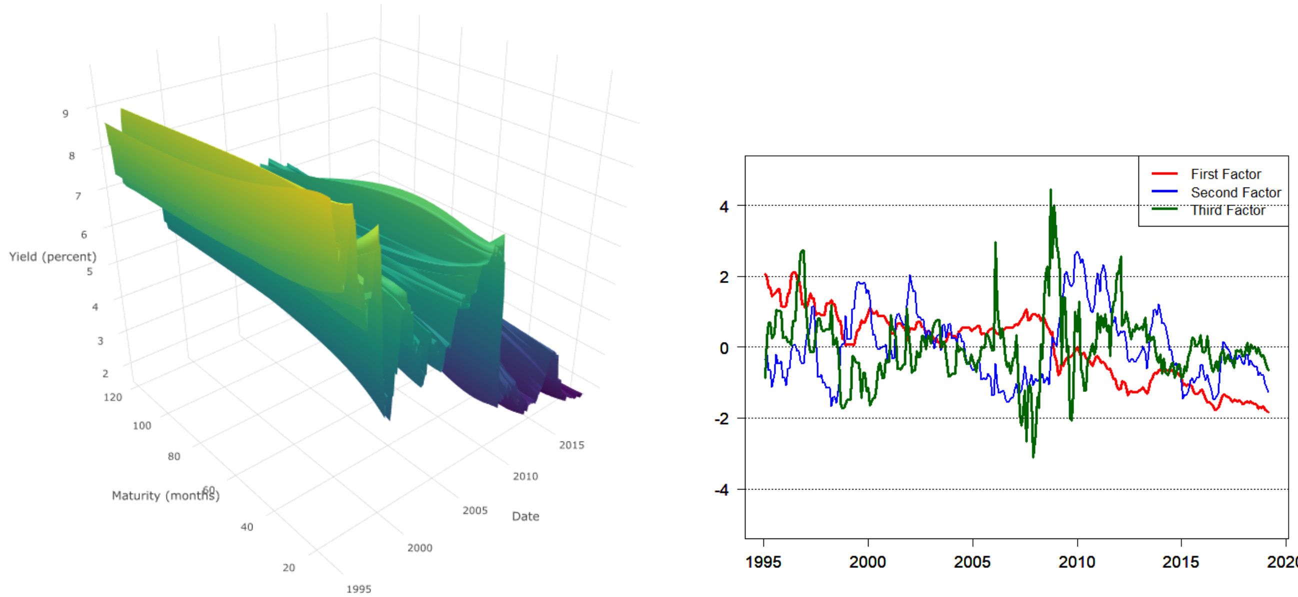



Table A.I.14: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 290 | 0.058 | 0.156 | −0.531 | −0.056 | 0.060 | 0.162 | 0.505 |
| 24-month | 290 | 0.082 | 0.285 | −1.408 | −0.041 | 0.084 | 0.235 | 0.742 |
| 36-month | 290 | 0.148 | 0.299 | −1.375 | 0.014 | 0.142 | 0.303 | 0.989 |
| 60-month | 290 | 0.280 | 0.204 | −0.398 | 0.169 | 0.257 | 0.378 | 1.074 |
| 84-month | 290 | 0.363 | 0.135 | −0.063 | 0.288 | 0.352 | 0.435 | 0.885 |
| 120-month | 290 | 0.442 | 0.262 | −1.671 | 0.380 | 0.466 | 0.557 | 1.058 |

Figure A.I.41: New Zealand: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

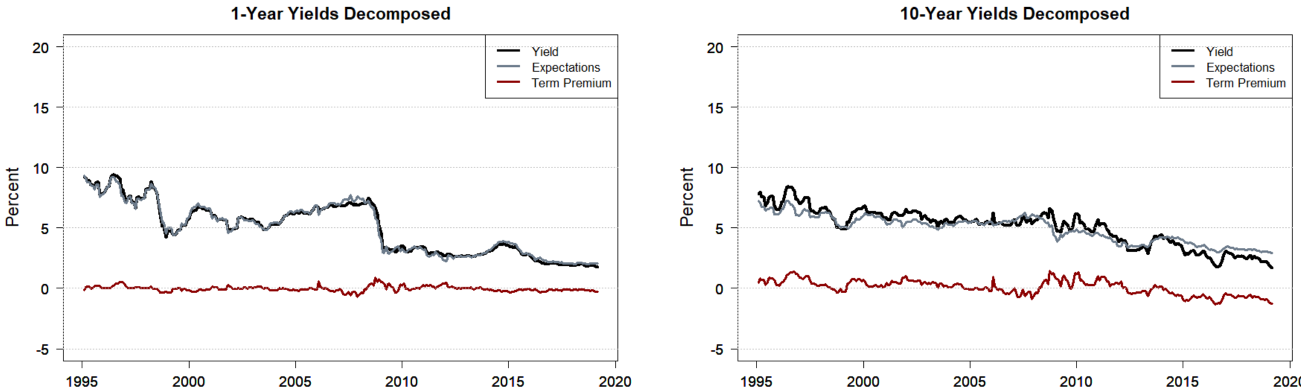



Figure A.I.42: New Zealand: Term Premium Curve (left) and Expectations Curve (right)

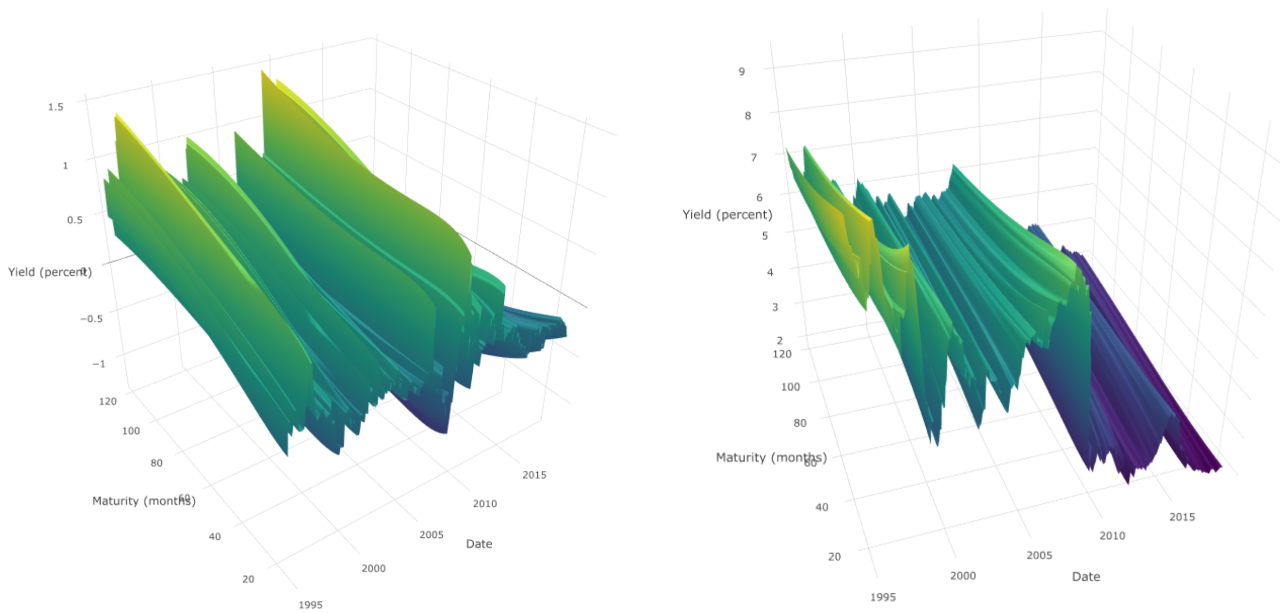



Figure A.I.41 shows that the 1-year term premium has remained near zero since 1995. Looking at the 10-year decomposition, the decline in the 10-year yield follows closely with both the 10-year term premium and the 10-year expectations component. The 10-year term premium decreased by 1.77 percentage points from 0.49% in January 1995 to --1.28% in February 2019 and the 10-year expectations component decreased by 4.32 percentage points from 7.24% to 2.93% during the same period.

## A.I.15 Norway

Norway is a developed European nation. Government bond data for Norway are available past 1995 and contain data on 3- and 6-month bonds and 1- to 10-year bonds. This period has a sharp decline in long-term interest rates as seen in Figure A.I.43. The 10-year yield decreased by more than 6 percentage points from 8.17% in January 1995 to 1.81% in February 2019.

Figure A.I.43: Norway: Yield Curve (left) and Yield Curve Factors (right)

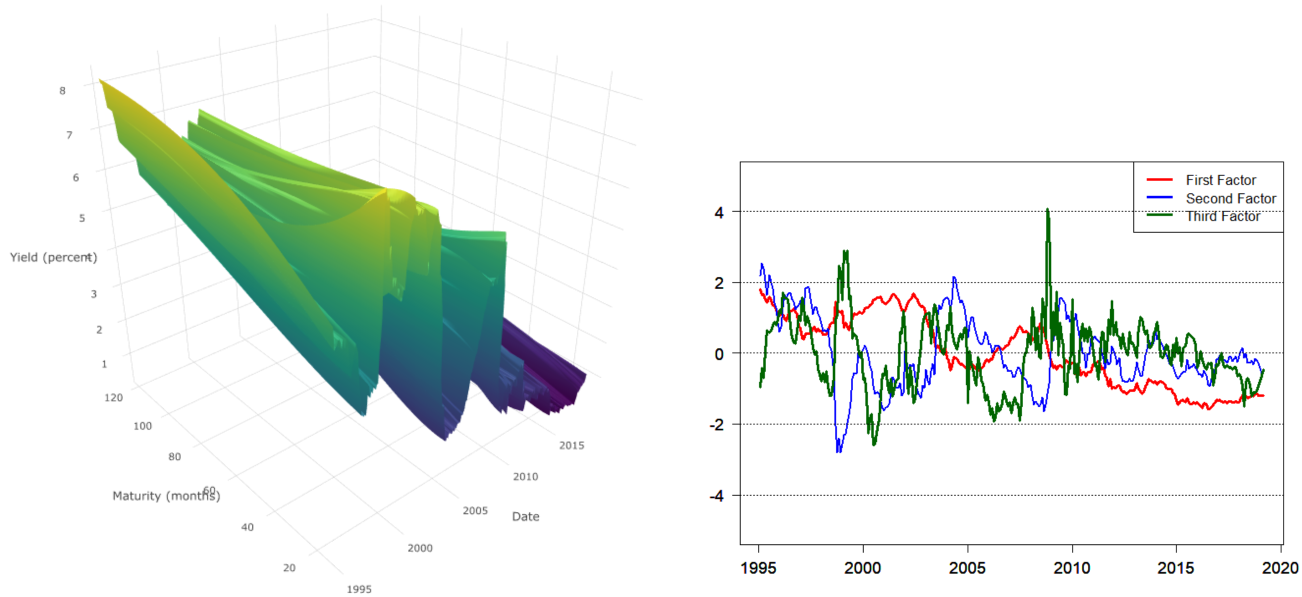



Table A.I.15: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 290 | −0.049 | 0.267 | −0.613 | −0.227 | −0.084 | 0.060 | 0.960 |
| 24-month | 290 | −0.060 | 0.125 | −0.416 | −0.131 | −0.071 | 0.012 | 0.379 |
| 36-month | 290 | −0.035 | 0.075 | −0.329 | −0.085 | −0.040 | 0.011 | 0.197 |
| 60-month | 290 | 0.040 | 0.100 | −0.334 | −0.016 | 0.046 | 0.103 | 0.290 |
| 84-month | 290 | 0.102 | 0.102 | −0.252 | 0.049 | 0.106 | 0.162 | 0.372 |
| 120-month | 290 | 0.182 | 0.186 | −0.401 | 0.092 | 0.189 | 0.296 | 0.630 |

Figure A.I.44: Norway: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

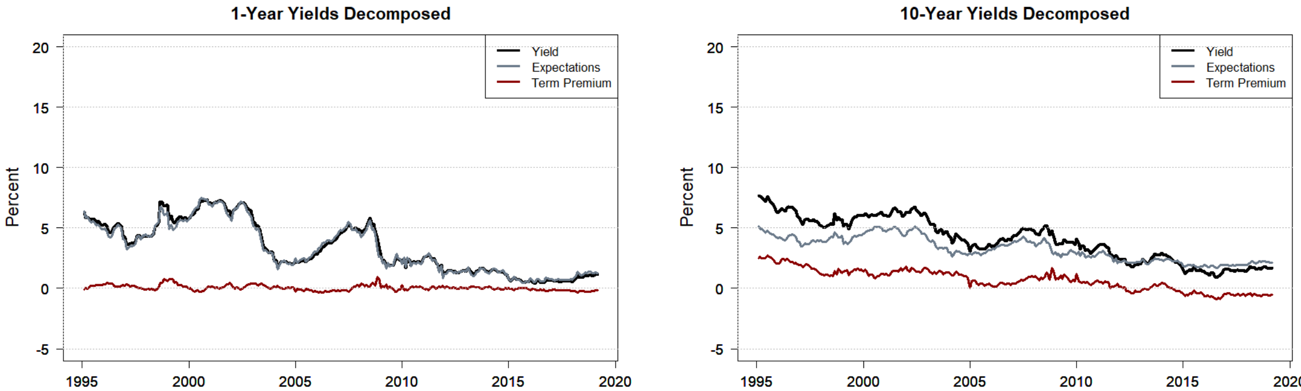



Figure A.I.45: Norway: Term Premium Curve (left) and Expectations Curve (right)

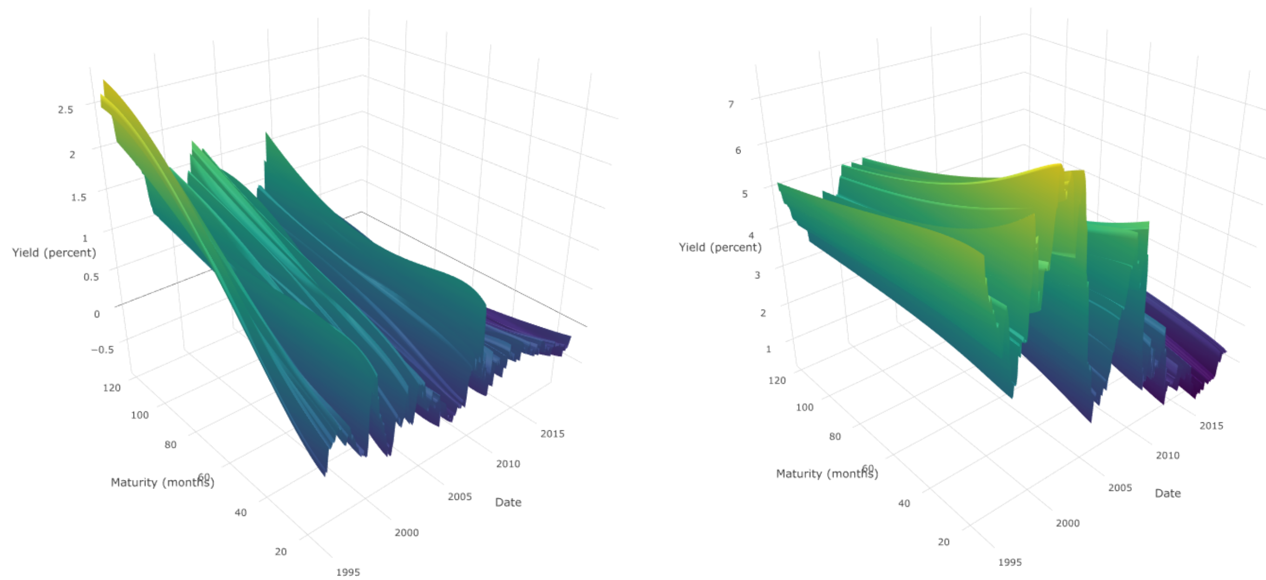



Figure A.I.44 shows that the 10-year term premium is declining along with 10-year yields. The 10-year term premium decreased by 2.99 percentage points from 2.48% in January 1995 to −0.51% in February 2019. The 10-year expectations component decreased by more than 3 percentage points from 5.15% in January 1995 to 2.13% in February 2019.

## A.I.16 Peru

Peru is a developing South American country and the 48th largest economy by GDP (IMF 2018). Government bond data for Peru are available past June 2006, from 3- and 6-month bonds and 1- to 10-year bonds. Peru has seen massive fluctuations over this period and a slight overall decline in rates. The 10-year yield decreased by 2.84 percentage points from 8.54% in June 2006 to 5.69% in February 2019.

Blake et al. (2015) also published an estimate of Peru's term premium from 2006 to 2015. This estimate used four factors and matched the results closely. The yield data used in this thesis are slightly higher than the data used in their paper and this explains any difference. The 10-year term premium also matched with that of Claro and Moreno (2015) when adjusting for the same slightly higher yield data. However, the yield data I am using matches perfectly with that of Olivares Ríos et al. (2016).

Figure A.I.46: Peru: Yield Curve (left) and Yield Curve Factors (right)

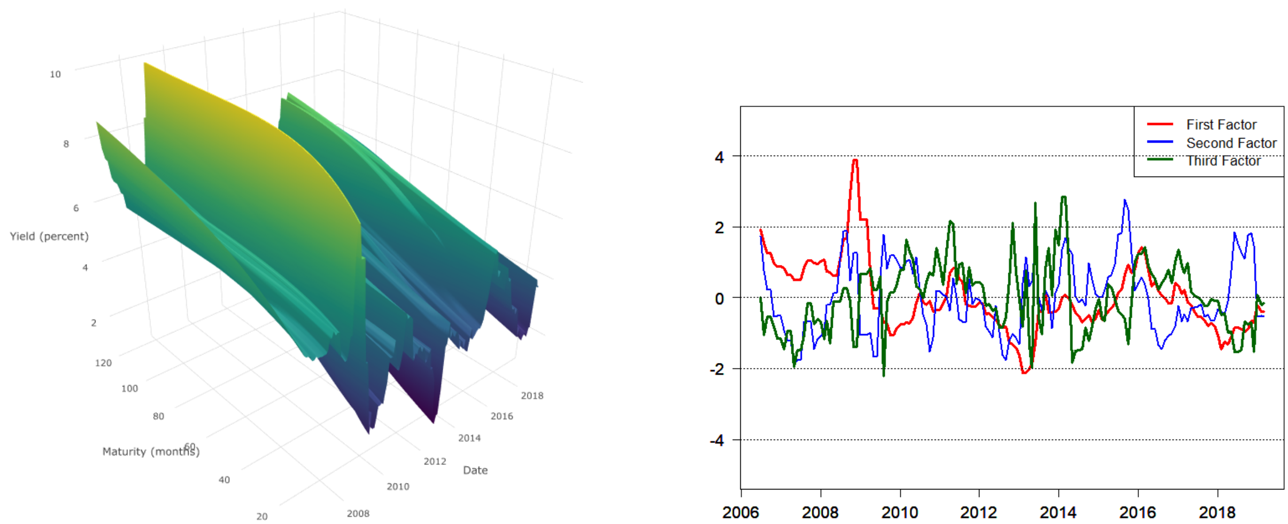



Table A.I.16: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 153 | −0.040 | 0.133 | −0.392 | −0.132 | −0.028 | 0.038 | 0.312 |
| 24-month | 153 | −0.012 | 0.200 | −0.759 | −0.142 | 0.019 | 0.104 | 0.490 |
| 36-month | 153 | 0.017 | 0.237 | −0.854 | −0.120 | 0.042 | 0.176 | 0.583 |
| 60-month | 153 | 0.051 | 0.333 | −0.874 | −0.157 | 0.062 | 0.278 | 0.829 |
| 84-month | 153 | 0.105 | 0.527 | −1.274 | −0.254 | 0.131 | 0.478 | 1.406 |
| 120-month | 153 | 0.935 | 1.459 | −3.454 | 0.037 | 0.940 | 1.968 | 4.556 |

Figure A.I.47: Peru: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

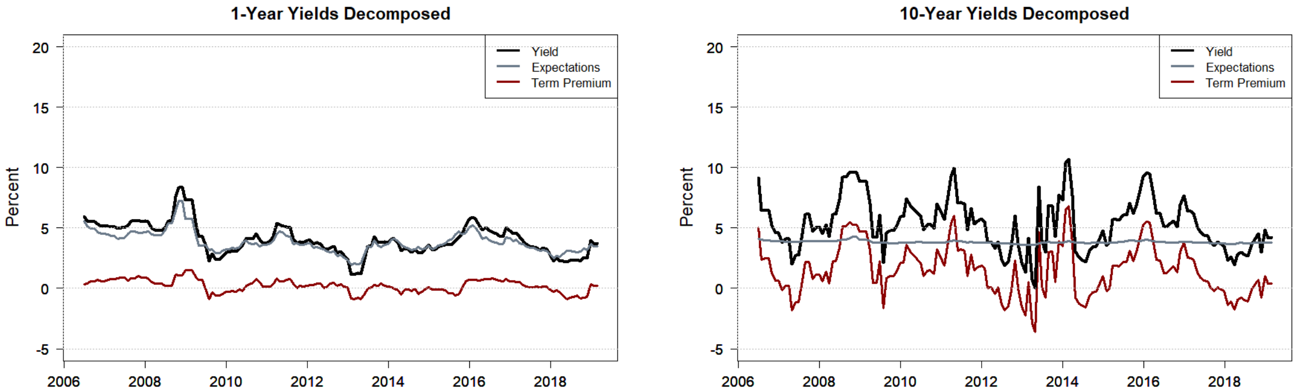



Figure A.I.48: Peru: Term Premium Curve (left) and Expectations Curve (right)

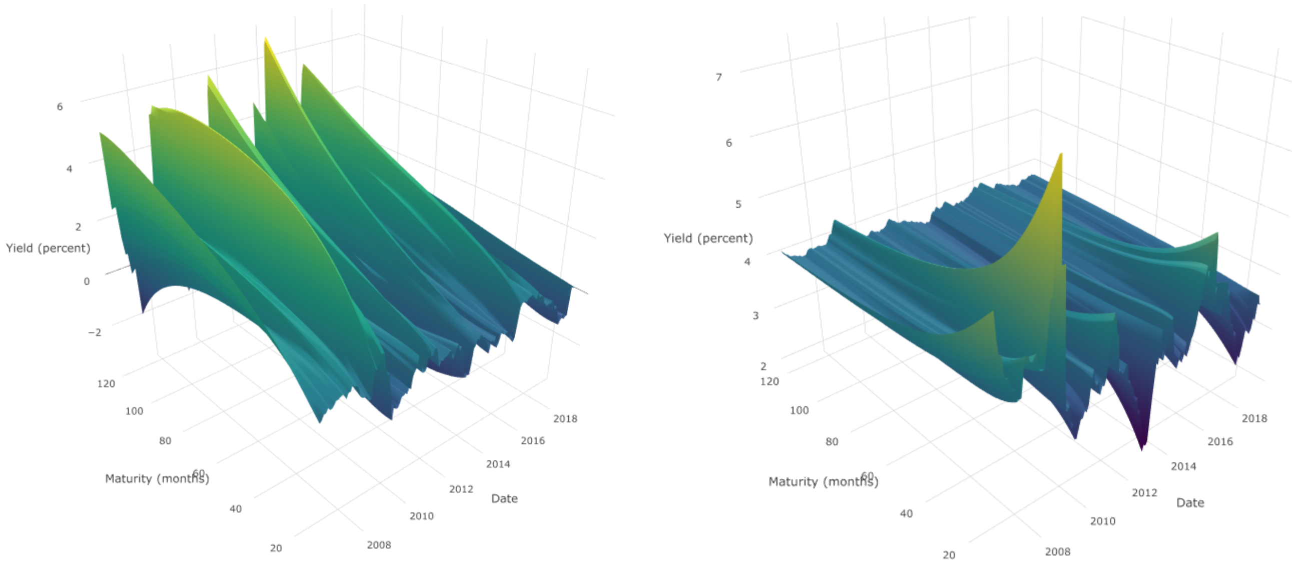



Figure A.I.47 shows that the 1-year term premium has declined slightly over the last 12 years. The 10-year expectations component is nearly flat and the decline in the term premium explains most of the decline and variation. The 10-year term premium decreased by 4.62 percentage points from 5.04% in June 2006 to 0.42% in February 2019 and the 10-year expectations component decreased by a small amount by 0.3 percentage points from 4.08% in June 2006 to 3.78% in February 2019.

### A.I.17 Philippines

The Philippines is an Asian country considered the 39th largest economy by GDP (IMF 2018). Government bond data for the Philippines are available past July 1996 and contain 3- and 6-month interest rates as well as 1- to 10-year interest rates. The Philippines has experienced a decline in long-term interest rates as seen in Figure A.I.49. The 10-year yield decreased by 9.58 percentage points from 16.03% in July 1996 to 6.45% in February 2019.

Figure A.I.49: Philippines: Yield Curve (left) and Yield Curve Factors (right)

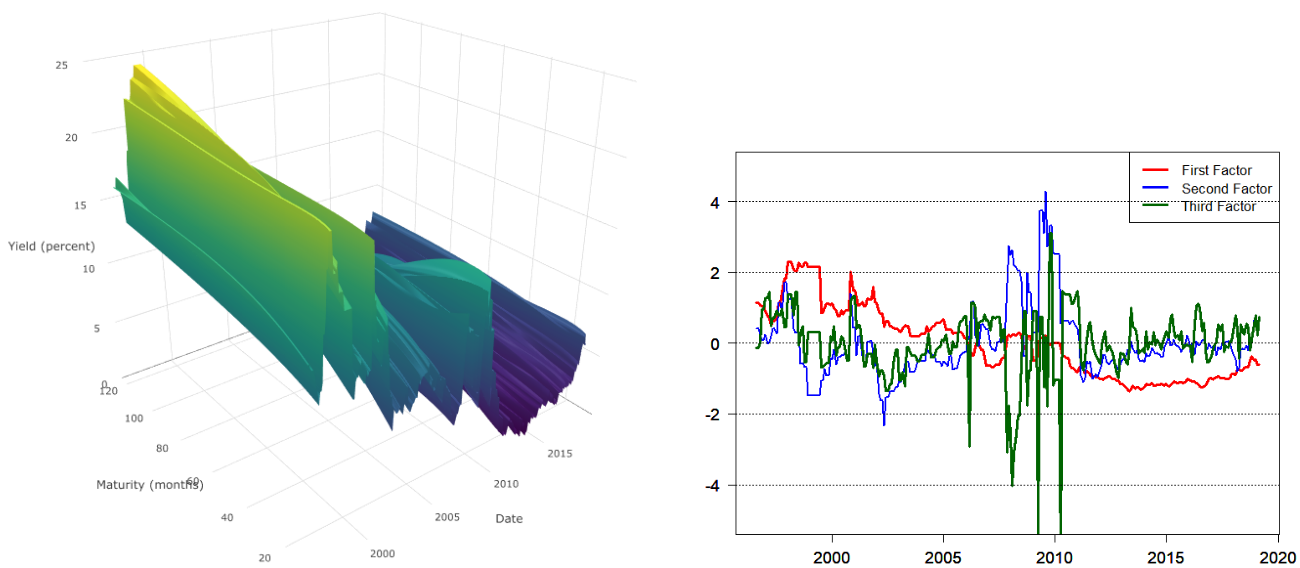
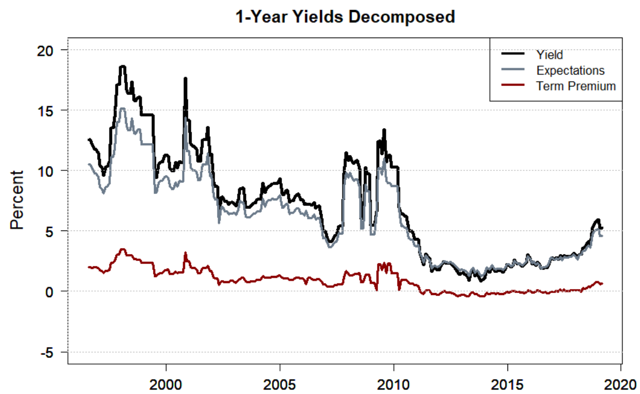



Table A.I.17: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 272 | 0.537 | 0.582 | −2.401 | 0.159 | 0.467 | 0.812 | 2.354 |
| 24-month | 272 | 0.633 | 0.517 | −1.090 | 0.261 | 0.595 | 0.943 | 2.158 |
| 36-month | 272 | 0.646 | 0.371 | −0.399 | 0.357 | 0.600 | 0.869 | 1.756 |
| 60-month | 272 | 0.747 | 0.156 | 0.510 | 0.608 | 0.718 | 0.867 | 1.092 |
| 84-month | 272 | 1.100 | 0.195 | −0.062 | 1.010 | 1.101 | 1.195 | 1.548 |
| 120-month | 272 | 1.792 | 0.323 | 0.153 | 1.662 | 1.799 | 1.960 | 2.711 |

Figure A.I.50: Philippines: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)



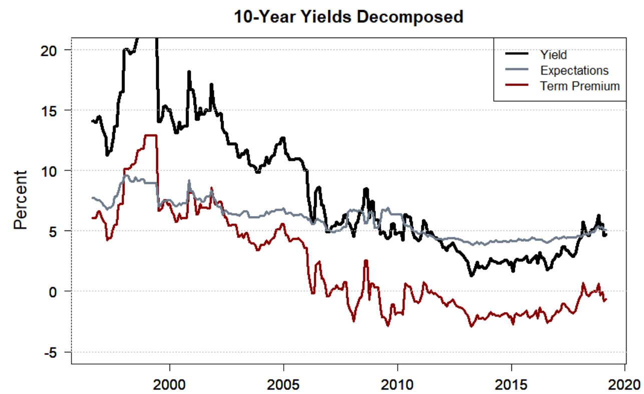
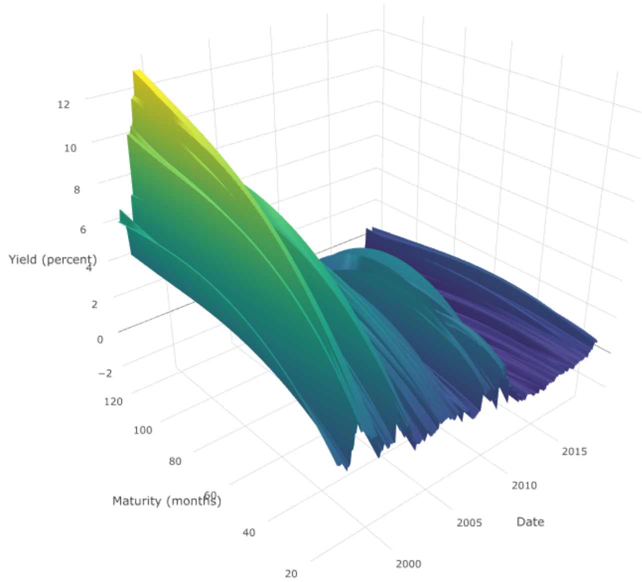




Figure A.I.51: Philippines: Term Premium Curve (left) and Expectations Curve (right)



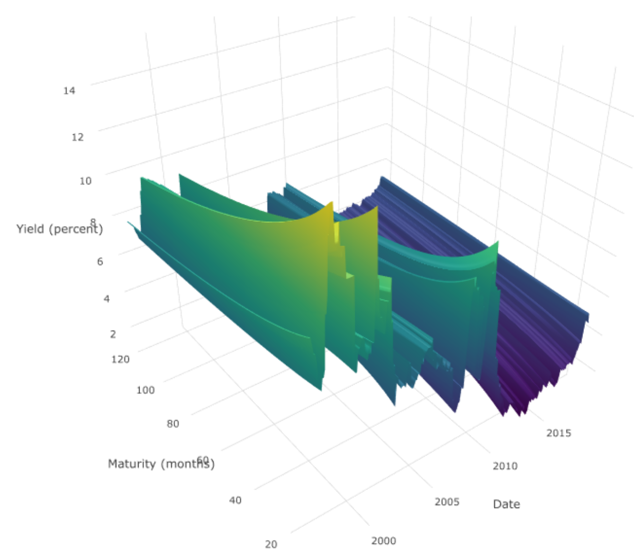




Figure A.I.50 shows that the 1-year term premium has declined slightly over the two decades. The 10-year decomposition shows that the 10-year premium explains most of the variation in 10-year yields. The term premium is also in decline over the period. The 10-year term premium decreased by 6.73 percentage points from 6.08% in July 1996 to --0.65% in February 2019. The expectations component has beenin slow decline as well. The 10-year expectations component decreased by 2.64 percentage points from 7.75% in July 1996 to 5.11% in February 2019.

## A.I.18 Poland

Poland is a developed European country and the 24th largest economy by GDP (IMF 2018). Government bond data for Poland are available past 2001, and contain data for 3- and 6-month bonds and 1- to 10-year bonds This period has a sharp decline in long-term interest rates as seen in Figure A.I.52. The 10-year yield decreased by more than 6 percentage points from 9.54% in January 2001 to 3.03% in February 2019.

Figure A.I.52: Poland: Yield Curve (left) and Yield Curve Factors (right)

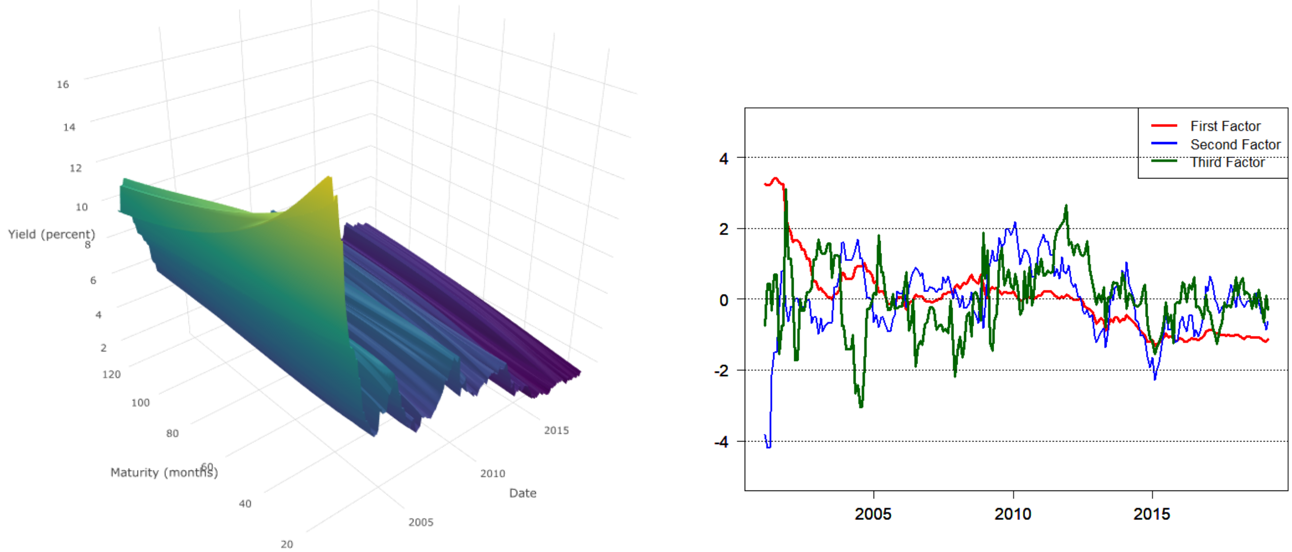



Table A.I.18: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 218 | −0.022 | 0.058 | −0.146 | −0.063 | −0.025 | 0.012 | 0.226 |
| 24-month | 218 | −0.009 | 0.073 | −0.157 | −0.055 | −0.023 | 0.032 | 0.263 |
| 36-month | 218 | 0.003 | 0.039 | −0.146 | −0.020 | −0.001 | 0.024 | 0.128 |
| 60-month | 218 | 0.023 | 0.044 | −0.168 | −0.007 | 0.032 | 0.049 | 0.126 |
| 84-month | 218 | 0.068 | 0.042 | −0.066 | 0.046 | 0.073 | 0.097 | 0.161 |
| 120-month | 218 | 0.182 | 0.083 | −0.060 | 0.127 | 0.166 | 0.224 | 0.485 |

Figure A.I.53: Poland: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

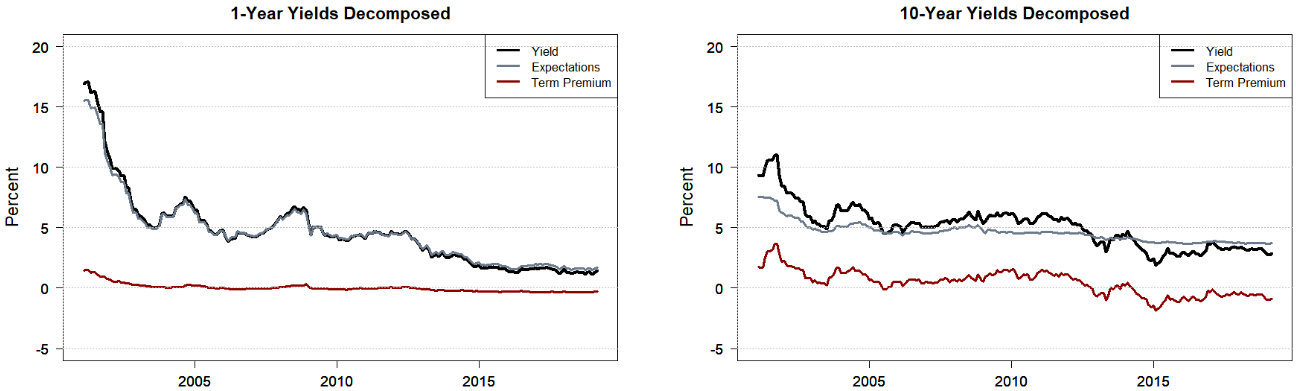



Figure A.I.54: Poland: Term Premium Curve (left) and Expectations Curve (right)

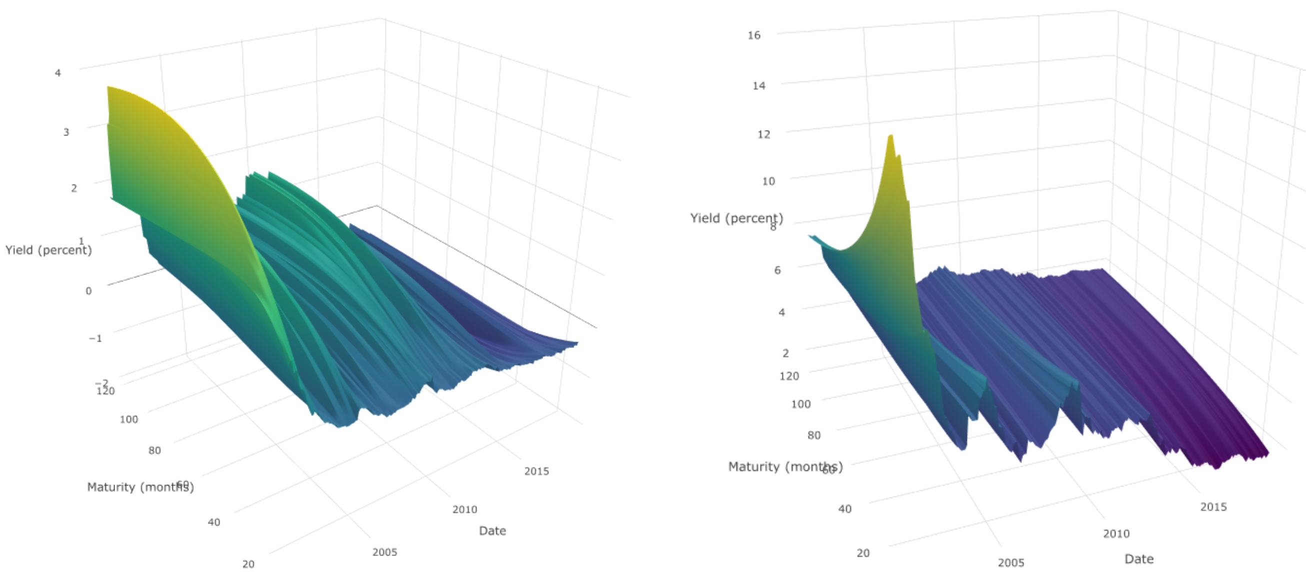
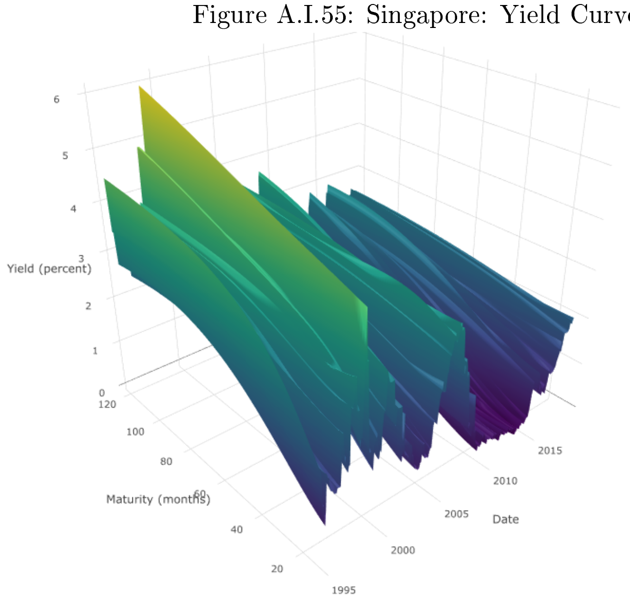



Figure A.I.53 shows that the 1-year term premium has declined over the last 17 years. The 10-year also has declined significantly. The 10-year term premium decreased to negative levels by 2.66 percentage points from 1.77% in January 2001 to --0.89% in February 2019. Most of the variation in 10-year yields also appears to be explained by the 10-year expectations component. The 10-year expectations component decreased by almost 4 percentage points from 7.57% in January 2001 to 3.74% in February 2019.

## A.I.19 Singapore

Singapore is a developed city state in Asia and Government bond data for Singapore are available past 1995 on 3- and 6-month bonds and 1- to 10-year bonds. This period has a slow decline in long-term interest rates as seen in Figure A.I.55. The 10-year yield decreased by 2.18 percentage points from 4.48% in February 1995 to 2.31% in February 2019.

Figure A.I.55: Singapore: Yield Curve (left) and Yield Curve Factors (right)



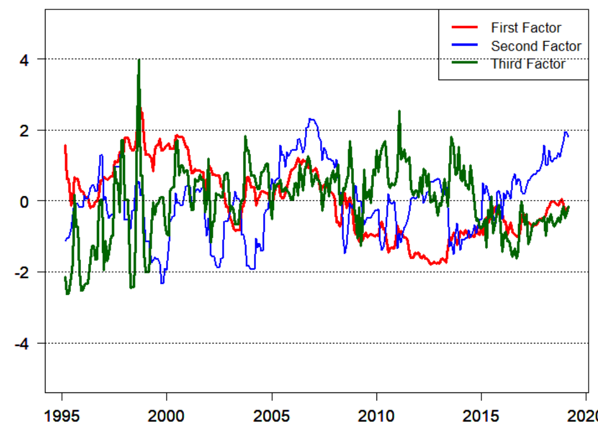




Table A.I.19: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 289 | −0.048 | 0.091 | −0.287 | −0.102 | −0.054 | 0.010 | 0.355 |
| 24-month | 289 | −0.039 | 0.098 | −0.295 | −0.097 | −0.046 | 0.019 | 0.436 |
| 36-month | 289 | −0.005 | 0.064 | −0.132 | −0.053 | −0.008 | 0.037 | 0.297 |
| 60-month | 289 | 0.049 | 0.047 | −0.067 | 0.019 | 0.041 | 0.081 | 0.169 |
| 84-month | 289 | 0.068 | 0.044 | −0.090 | 0.040 | 0.068 | 0.096 | 0.176 |
| 120-month | 289 | 0.105 | 0.087 | −0.096 | 0.054 | 0.106 | 0.143 | 0.388 |

Figure A.I.56: Singapore: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

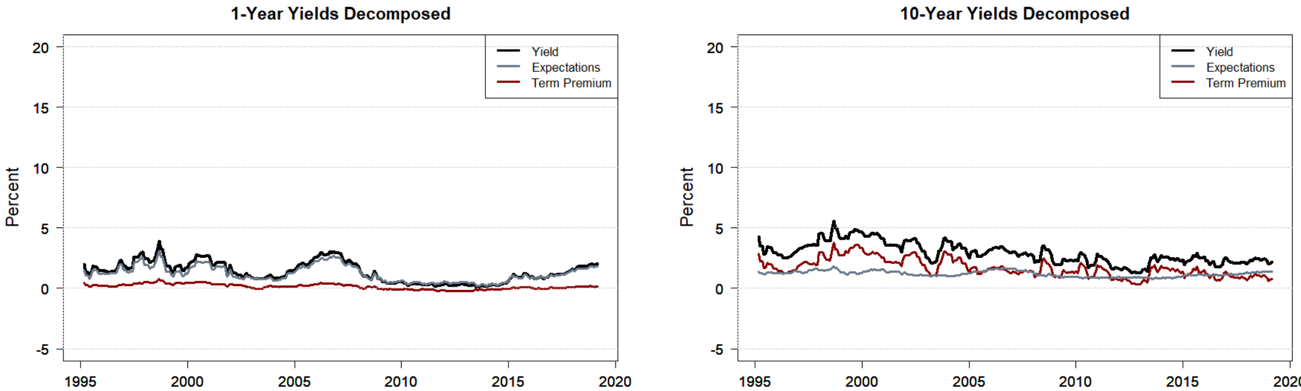



Figure A.I.57: Singapore: Term Premium Curve (left) and Expectations Curve (right)

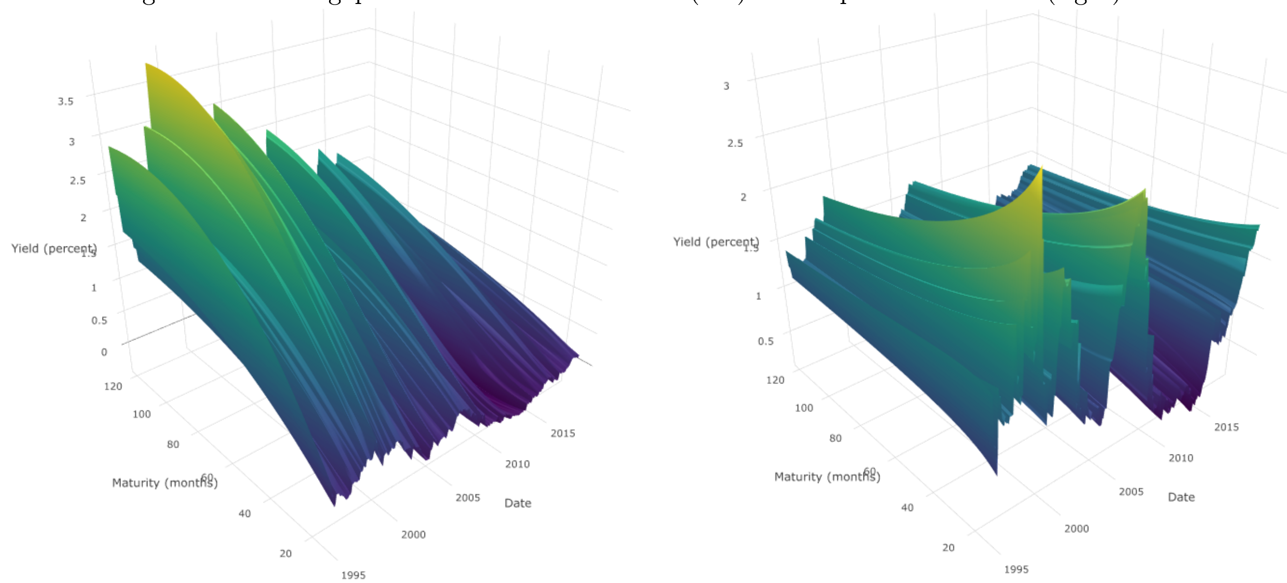


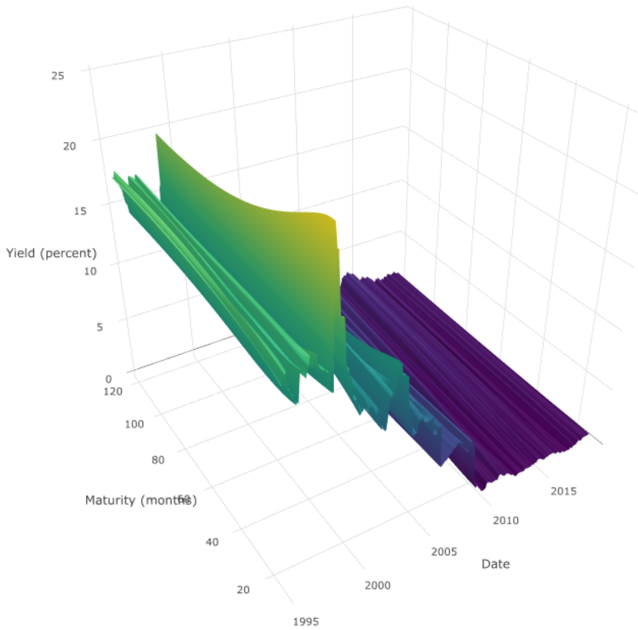

Figure A.I.56 shows that the 1-year term premium has remained mostly flat over the last 13 years. The 10-year term premium appears to account for most of the variation in 10-year yields. The 10-year term premium decreased by 2.08 percentage points from 2.88% in February 1995 to 0.8% in February 2019. The 10-year expectations component appears to be relatively flat only decreasing from 1.41% in February 1995 to 1.4% in February 2019.

## A.I.20 South Africa

South Africa is an emerging African economy and the 33rd largest economy by GDP (IMF 2018). Government bond data for South Africa are available past 1995 and contain 3- and 6-month bonds and 1- to 10-year bonds. South Africa has experienced a decline in long-term interest rates over the last 13 years, as seen in Figure A.I.58. The 10-year yield decreased by 16 percentage points from 17.36% in February 1995 to 1.35% in February 2019.

The estimates for 10-year yields and term premium matched closely with preliminary estimates found online.

Figure A.I.58: South Africa: Yield Curve (left) and Yield Curve Factors (right)



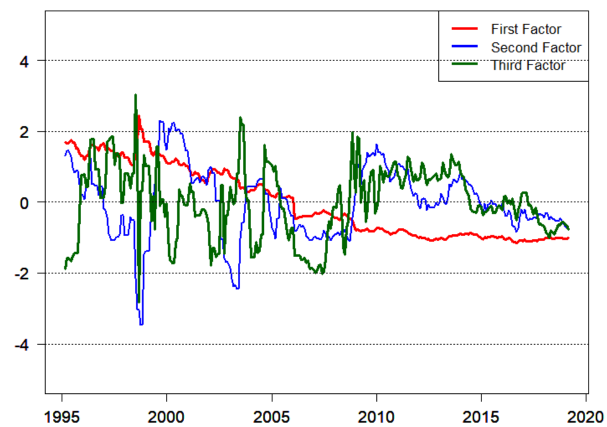




Table A.I.20: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 289 | 0.057 | 0.158 | −0.360 | −0.023 | 0.056 | 0.122 | 0.771 |
| 24-month | 289 | 0.054 | 0.098 | −0.290 | 0.014 | 0.058 | 0.092 | 0.674 |
| 36-month | 289 | 0.065 | 0.050 | −0.194 | 0.054 | 0.069 | 0.086 | 0.202 |
| 60-month | 289 | 0.113 | 0.081 | −0.377 | 0.074 | 0.117 | 0.152 | 0.447 |
| 84-month | 289 | 0.198 | 0.086 | −0.193 | 0.161 | 0.214 | 0.246 | 0.439 |
| 120-month | 289 | 0.452 | 0.144 | −0.051 | 0.407 | 0.469 | 0.523 | 1.150 |

Figure A.I.59: South Africa: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

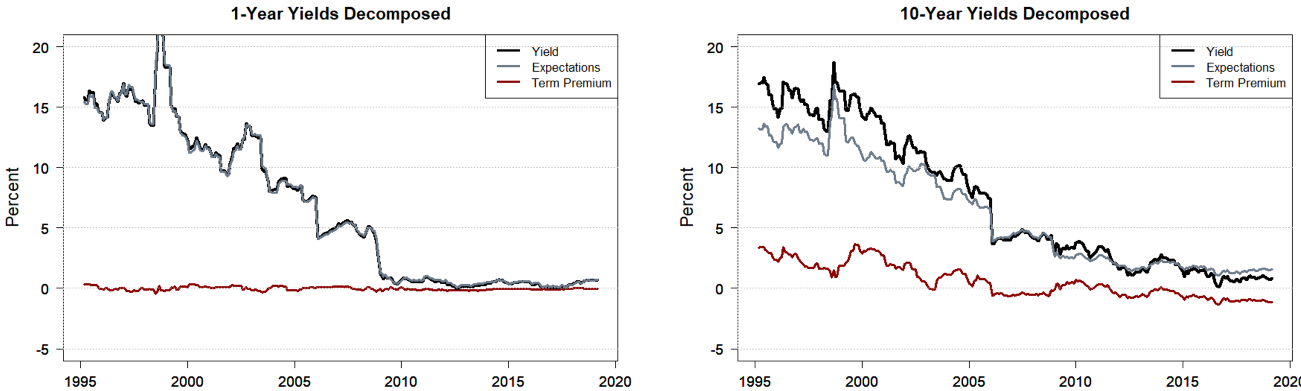



Figure A.I.60: South Africa: Term Premium Curve (left) and Expectations Curve (right)

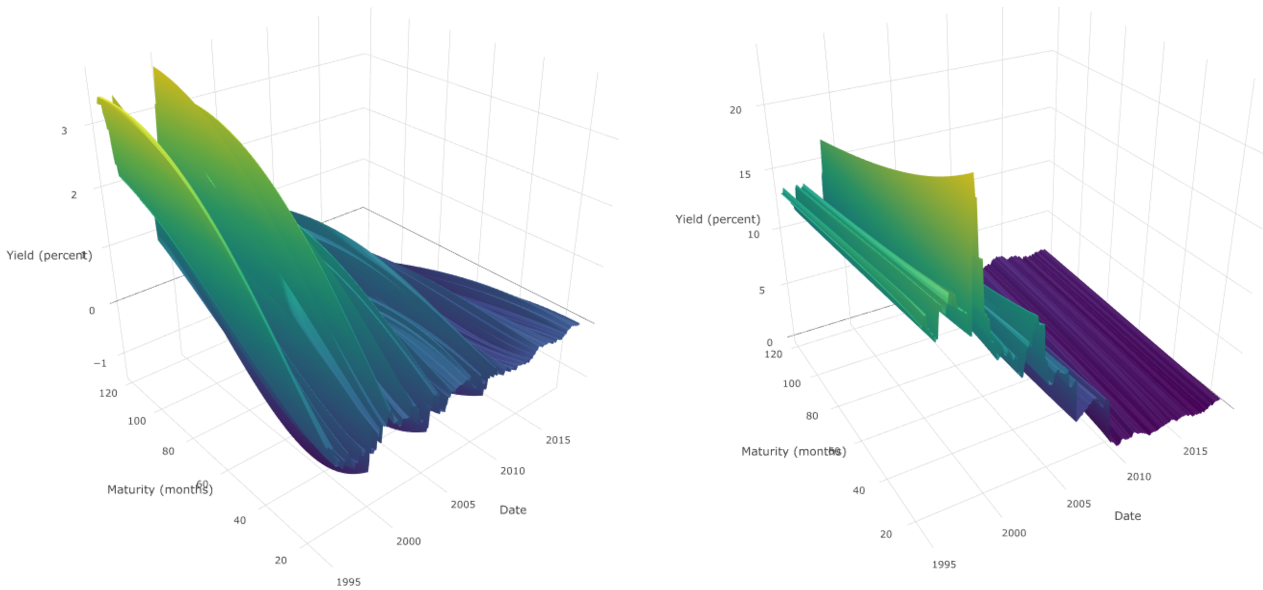


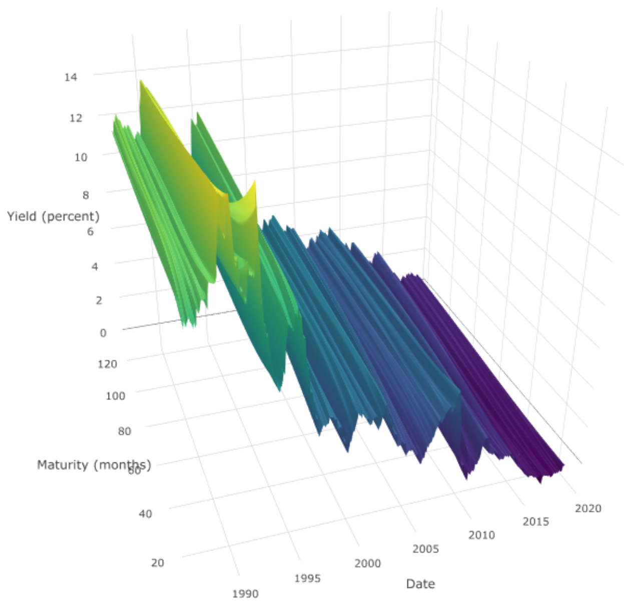

Figure A.I.59 shows that the 10-year term premium and 10-year expectations component appear to move inversely, while both trending downwards. Both variation and decline seem to be explained by thedecreasing expectations. The 10-year term premium decreased by 4.45 percentage points from 3.33% in February 1995 to –1.12% in February 2019 and the 10-year expectations component decreased by 11.68 percentage points from 13.24% to 1.56% in the same period.

## A.I.21 Sweden

Sweden is a developed European country and the 23rd largest economy by GDP (IMF 2018). Government bond data for Sweden are available past 1987, but contain only data on 3- and 6-month bonds and 1-, 2-, 5-, 7-, 9-, and 10-year yields. Like other European nations, this period has a consistent decline in long-term interest rates as seen in Figure A.I.61. The 10-year yield decreased significantly by around 11 percentage points from 11.46% in February 1987 to 0.48% in February 2019.

The estimates for yields and term premium matched closely with that of Diez de los Rios and Shamloo (2017). The estimate for the 10-year expectations component and term premium matched with the Bauer et al. (2012)method estimate from De Rezende (2017).

Figure A.I.61: Sweden: Yield Curve (left) and Yield Curve Factors (right)



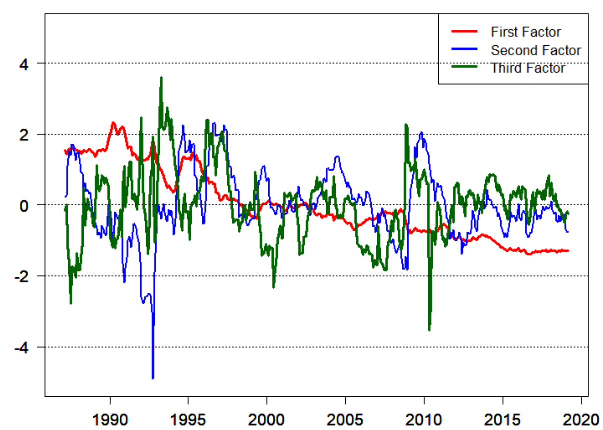




Table A.I.21: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 385 | −0.009 | 0.073 | −0.316 | −0.049 | −0.013 | 0.026 | 0.283 |
| 24-month | 385 | −0.009 | 0.056 | −0.293 | −0.030 | −0.004 | 0.019 | 0.191 |
| 36-month | 385 | −0.008 | 0.055 | −0.234 | −0.017 | 0.003 | 0.016 | 0.300 |
| 60-month | 385 | 0.025 | 0.051 | −0.167 | 0.008 | 0.029 | 0.047 | 0.231 |
| 84-month | 385 | 0.081 | 0.055 | −0.222 | 0.060 | 0.078 | 0.094 | 0.337 |
| 120-month | 385 | 0.170 | 0.114 | −0.236 | 0.125 | 0.172 | 0.213 | 0.738 |

Figure A.I.62: Sweden: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

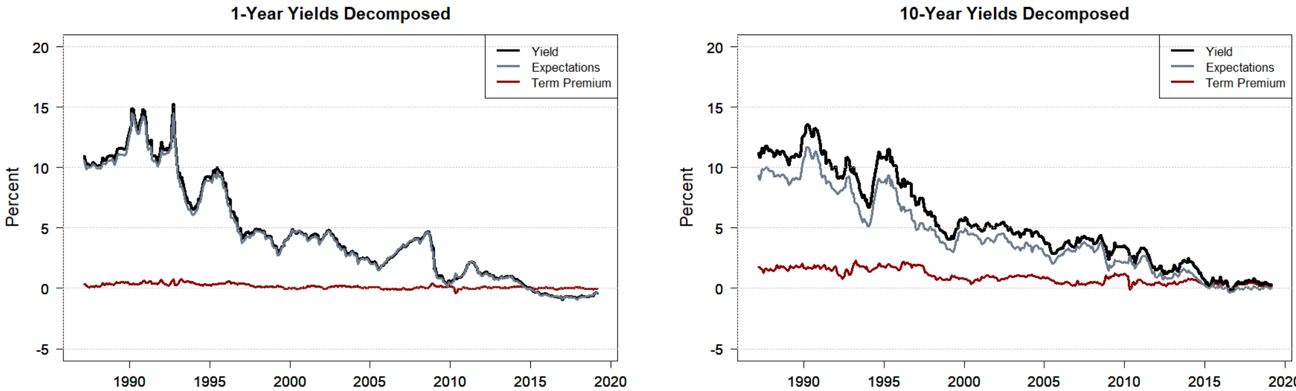
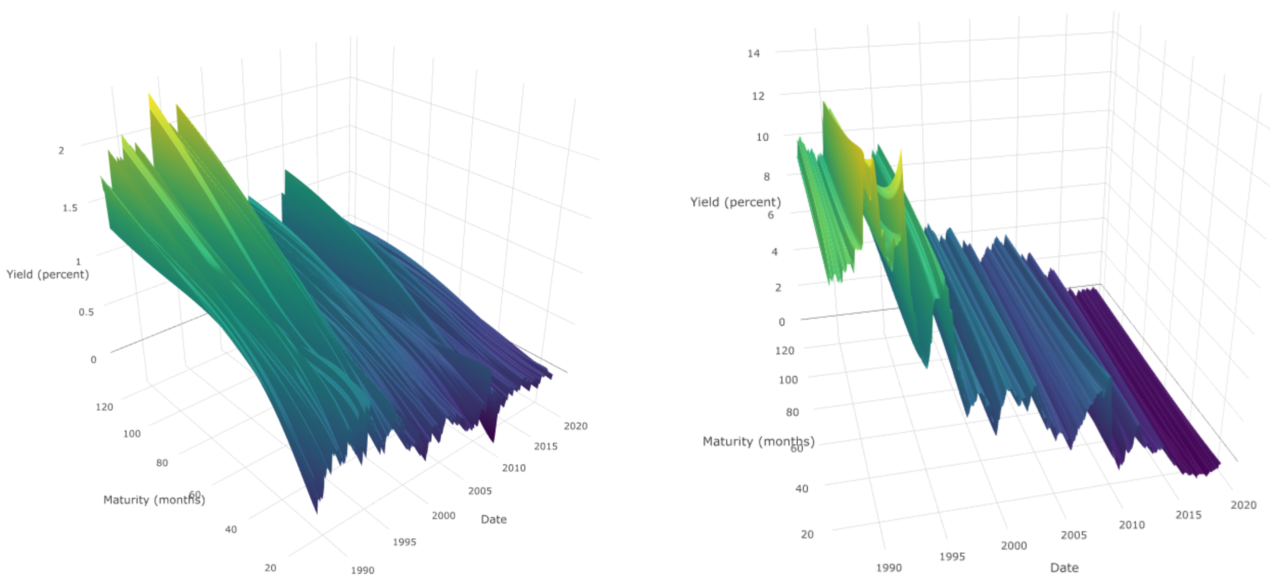



Figure A.I.63: Sweden: Term Premium Curve (left) and Expectations Curve (right)




The decline in interest rates appears to be explained by the expectations component. The 10-year expectations component decreased by more than 9 percentage points from 9.32% in February 1987 to 0.01% in February 2019. The term premium is also declining and contributing to the overall decrease. The 10-year term premium decreased by 1.61 percentage points from 1.73% in February 1987 to 0.12% in February 2019.

## A.I.22 Switzerland

Switzerland is a developed European country and the 20th largest economy by GDP (IMF 2018). Government bond data for Switzerland are available past 1998, but contain data on 1- to 10-year yields only. Like Sweden and other European nations, this period has a consistent decline in long-term interest rates as seen in Figure A.I.64. The 10-year yield decreased by 4.27 percentage points from 4% in February 1988 to --0.26% in February 2019.

Figure A.I.64: Switzerland: Yield Curve (left) and Yield Curve Factors (right)

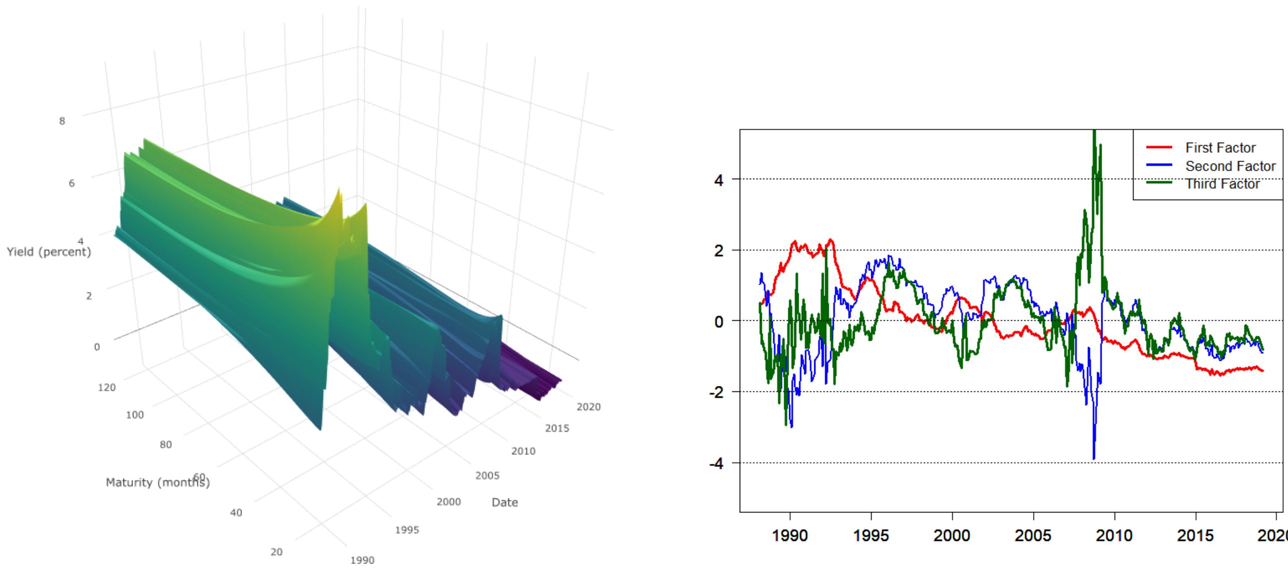
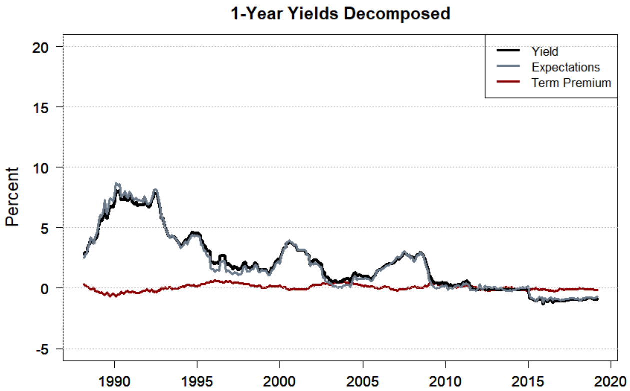



Table A.I.22: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 373 | 0.102 | 0.241 | −0.347 | −0.027 | 0.055 | 0.139 | 1.117 |
| 24-month | 373 | 0.005 | 0.126 | −0.564 | −0.067 | 0.031 | 0.093 | 0.424 |
| 36-month | 373 | 0.007 | 0.098 | −0.410 | −0.047 | 0.028 | 0.078 | 0.207 |
| 60-month | 373 | 0.050 | 0.057 | −0.088 | 0.013 | 0.053 | 0.091 | 0.164 |
| 84-month | 373 | 0.077 | 0.037 | 0.016 | 0.054 | 0.069 | 0.092 | 0.307 |
| 120-month | 373 | 0.057 | 0.100 | −0.148 | −0.017 | 0.052 | 0.125 | 0.317 |

Figure A.I.65: Switzerland: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)



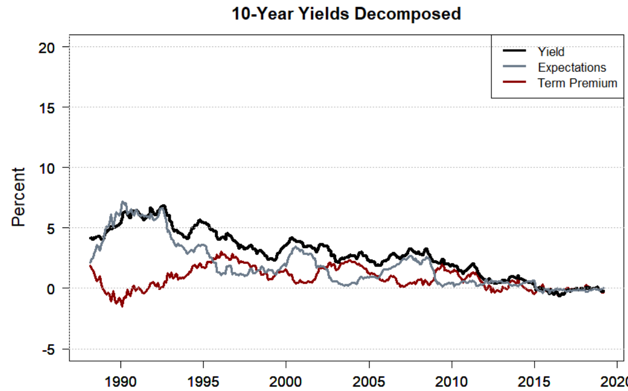
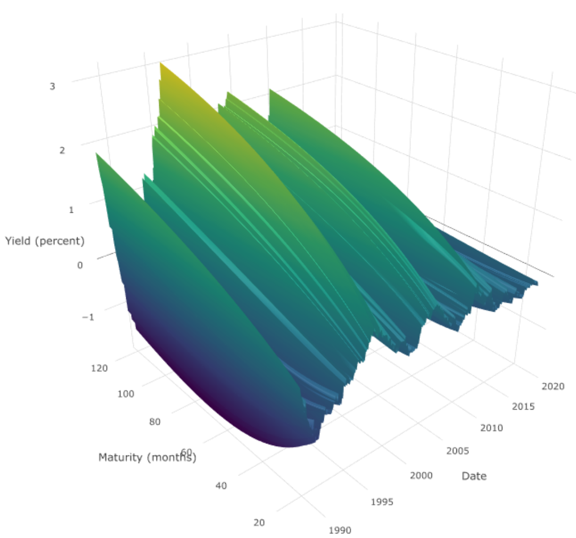




Figure A.I.66: Switzerland: Term Premium Curve (left) and Expectations Curve (right)



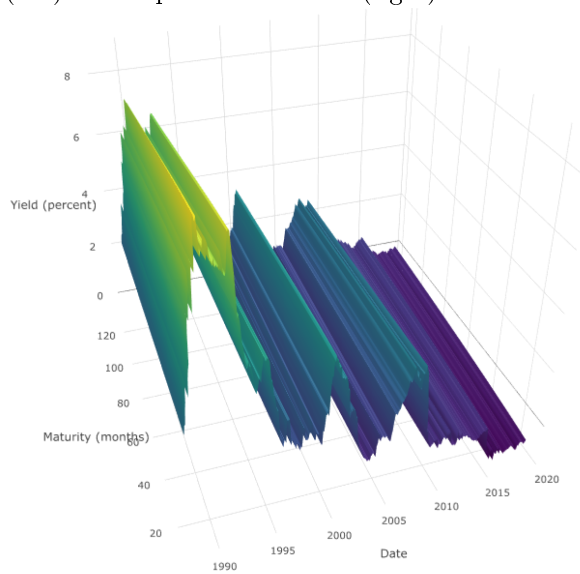




Figure A.I.65 shows that the 1-year term premium has fluctuated significantly during the past two decades. The short-term term premium moves inversely to theexpectations component and often dips below zero. The 10-year decomposition also exhibits this trend. The 10-year term premium decreased by 2.25 percentage points from 1.89% in February 1988 to –0.36% in February 2019. The 10-year expectations component decreased by 2.14 percentage points from 2.14% in February 1988 to 0% in February 2019.

## A.I.23 United Kingdom

The U.K. is a developed European country and the fifth largest economy by GDP (IMF 2018). Government bond data for the U.K. are available past February 1975 and this time period contain data on 3- and 6-month bonds and 1- to 10-year bonds. The U.K. has a slow consistent decline in long-term interest rates as seen in Figure A.I.67. The 10-year yield decreased by about 12 percentage points from 13.06% in February 1975 to 1.35% in February 2019. The estimates for yields and term premium matched closely with that of Diez de los Rios and Shamloo (2017). The 10-year expectations component matched closely with the SRM estimate in Ichiue et al. (2013). Both the term premium and expectations also matched closely with that of Malik and Meldrum (2016).

Figure A.I.67: United Kingdom: Yield Curve (left) and Yield Curve Factors (right)

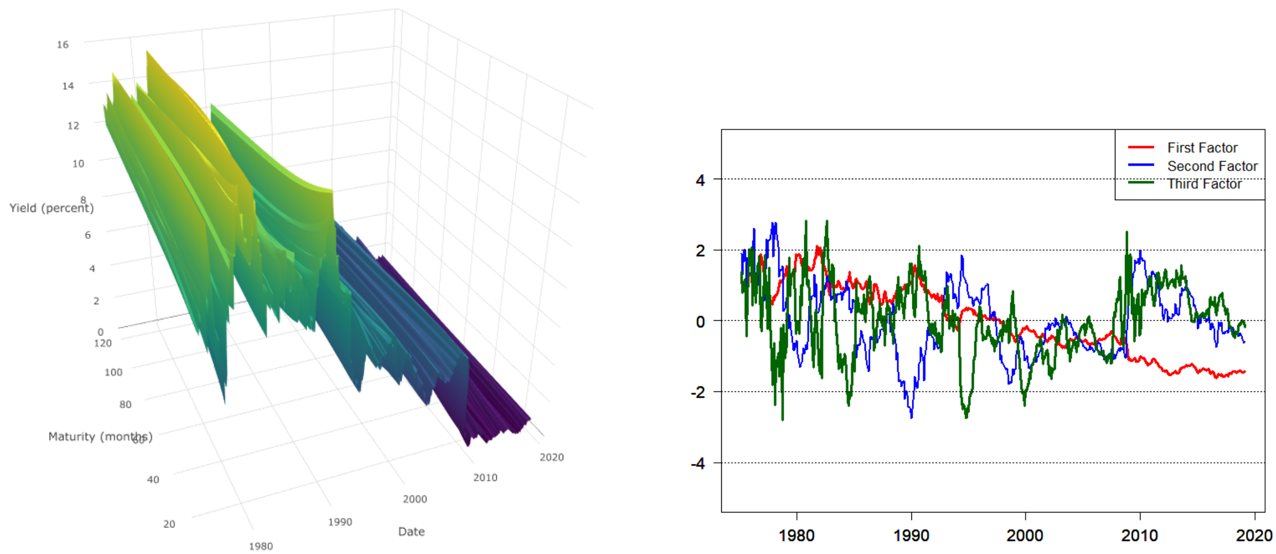



Table A.I.23: Fit Diagnostics: Yield Pricing Errors

| Statistic | N | Mean | St. Dev. | Min | Pctl(25) | Median | Pctl(75) | Max |
|---|---|---|---|---|---|---|---|---|
| 12-month | 529 | −0.101 | 0.168 | −0.847 | −0.208 | −0.068 | 0.034 | 0.209 |
| 24-month | 529 | −0.015 | 0.095 | −0.396 | −0.080 | 0.003 | 0.053 | 0.227 |
| 36-month | 529 | 0.045 | 0.036 | −0.067 | 0.031 | 0.048 | 0.061 | 0.261 |
| 60-month | 529 | 0.099 | 0.055 | −0.085 | 0.063 | 0.093 | 0.135 | 0.298 |
| 84-month | 529 | 0.139 | 0.046 | −0.072 | 0.109 | 0.138 | 0.168 | 0.334 |
| 120-month | 529 | 0.253 | 0.088 | −0.073 | 0.205 | 0.260 | 0.304 | 0.587 |

Figure A.I.68: United Kingdom: 1-Year Yields Decomposed (left) and 10-Year Yields Decomposed (right)

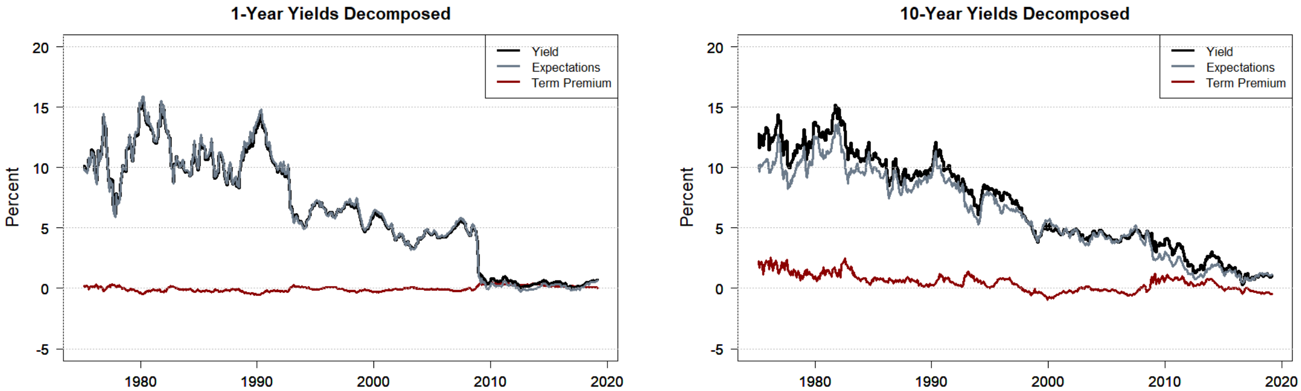



Figure A.I.69: United Kingdom: Term Premium Curve (left) and Expectations Curve (right)

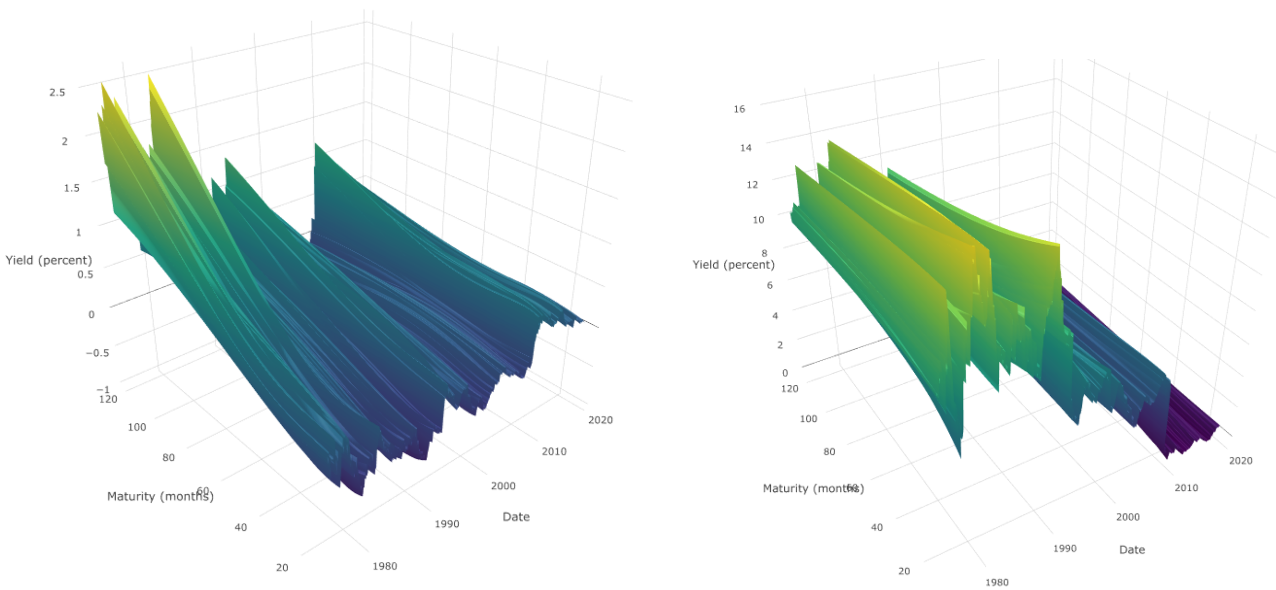



Figure A.I.68 shows a 10-year yield decomposition which contains both a declining 10-year expectations component and 10-year term premium. The 10-year term premium decreased by 2.7 percentage points from 2.26% in February 1975 to -0.44% in February 2019 and the 10-year expectations component decreased by 9.06 percentage points from 10.22% to 1.16% during the same period. Most of the fluctuation in long-term yields appears to be explained by the expectations component. The decline in long-term rates is explained mostly by the expectations component and amplified by a decline in term premia.

## Appendix Chapter A.II

# Appendix: Illiquidity (Noise) Measures by Country

Figure A.II.1: Noise Measures

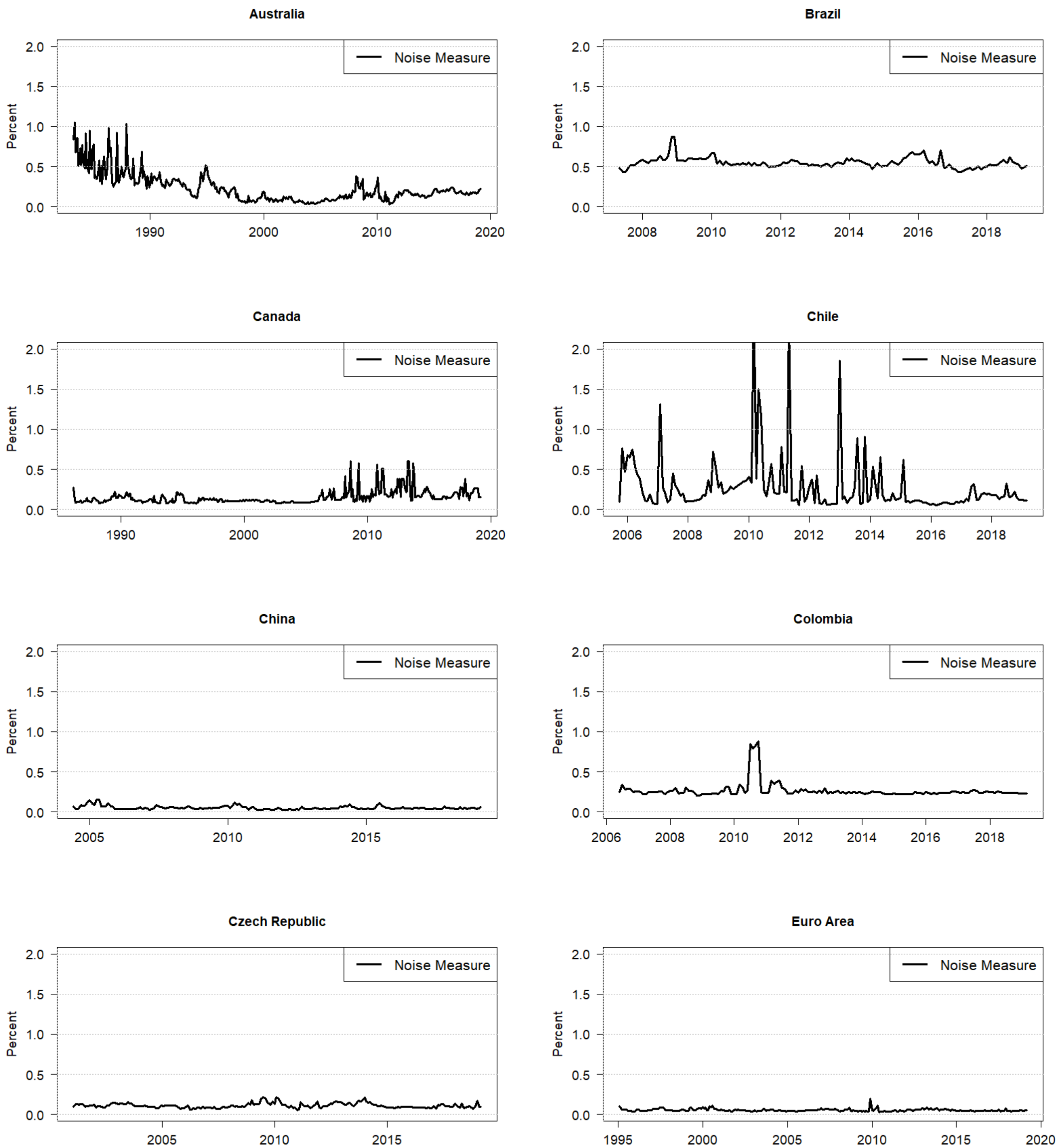


Figure A.II.2: Noise Measures Continued

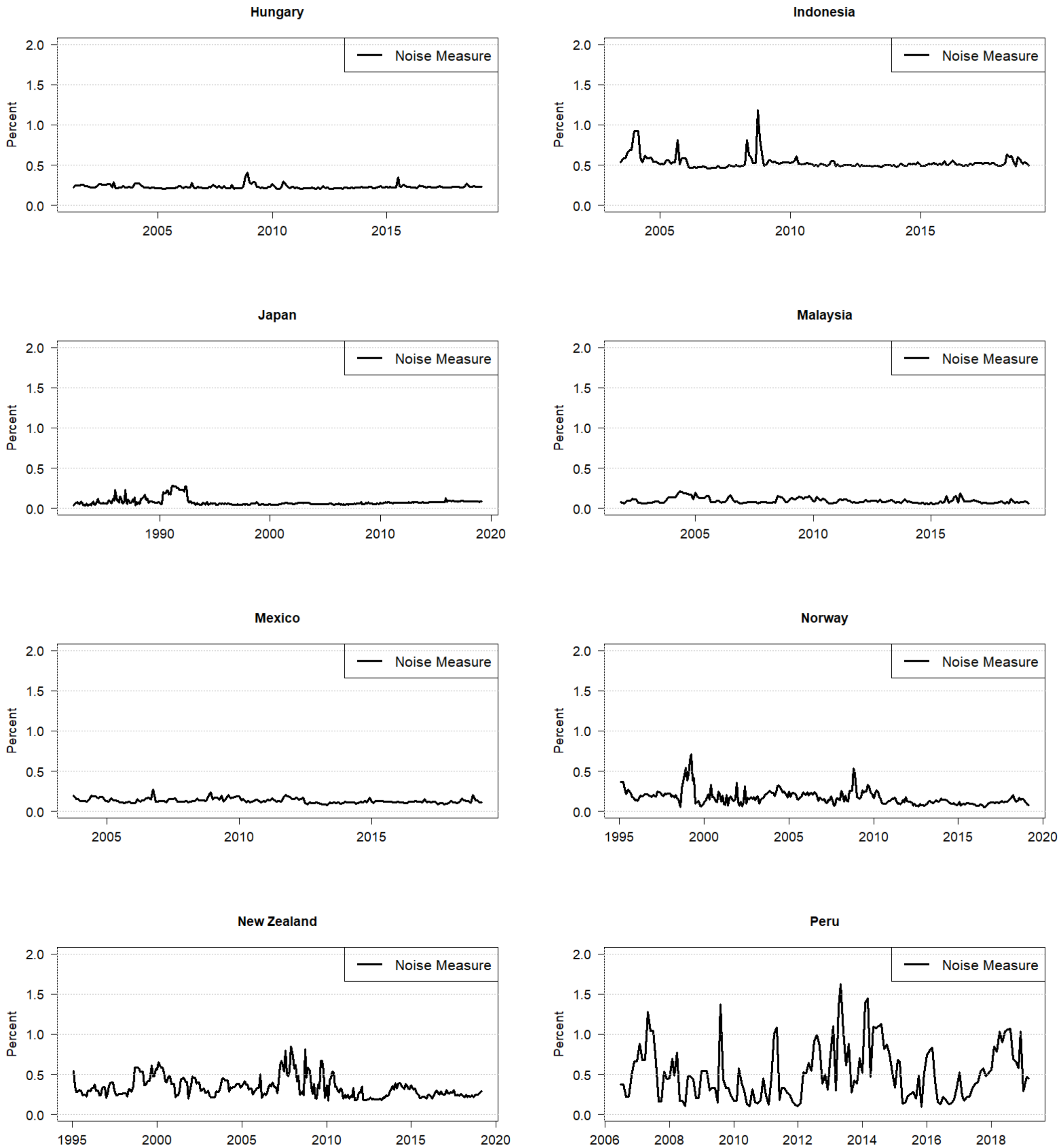
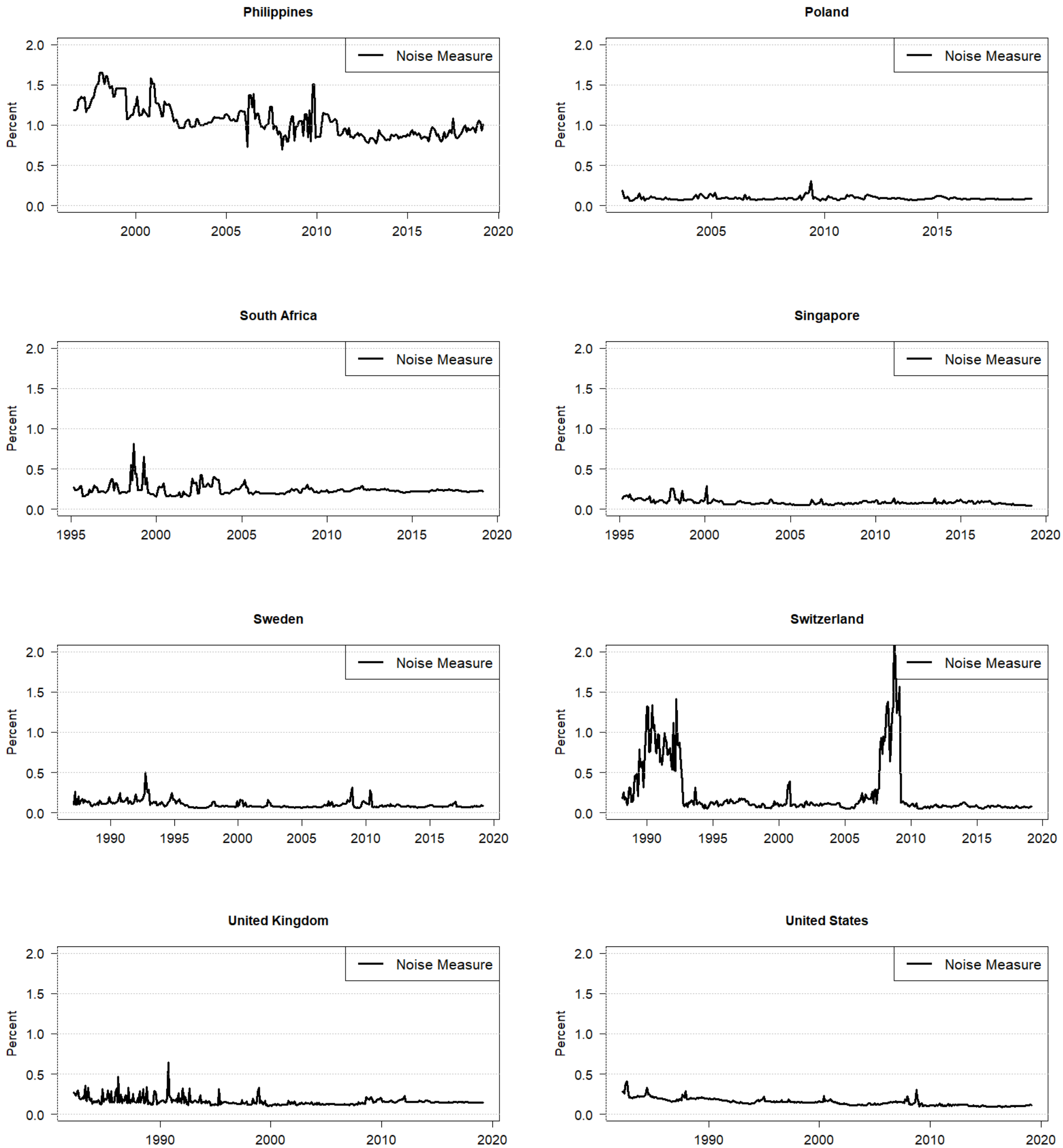


Figure A.II.3: Noise Measures Continued



Appendix Chapter A.III

# Appendix: Inflation by Country

Figure A.III.1: Inflation

Figure A.III.2: Inflation Continued

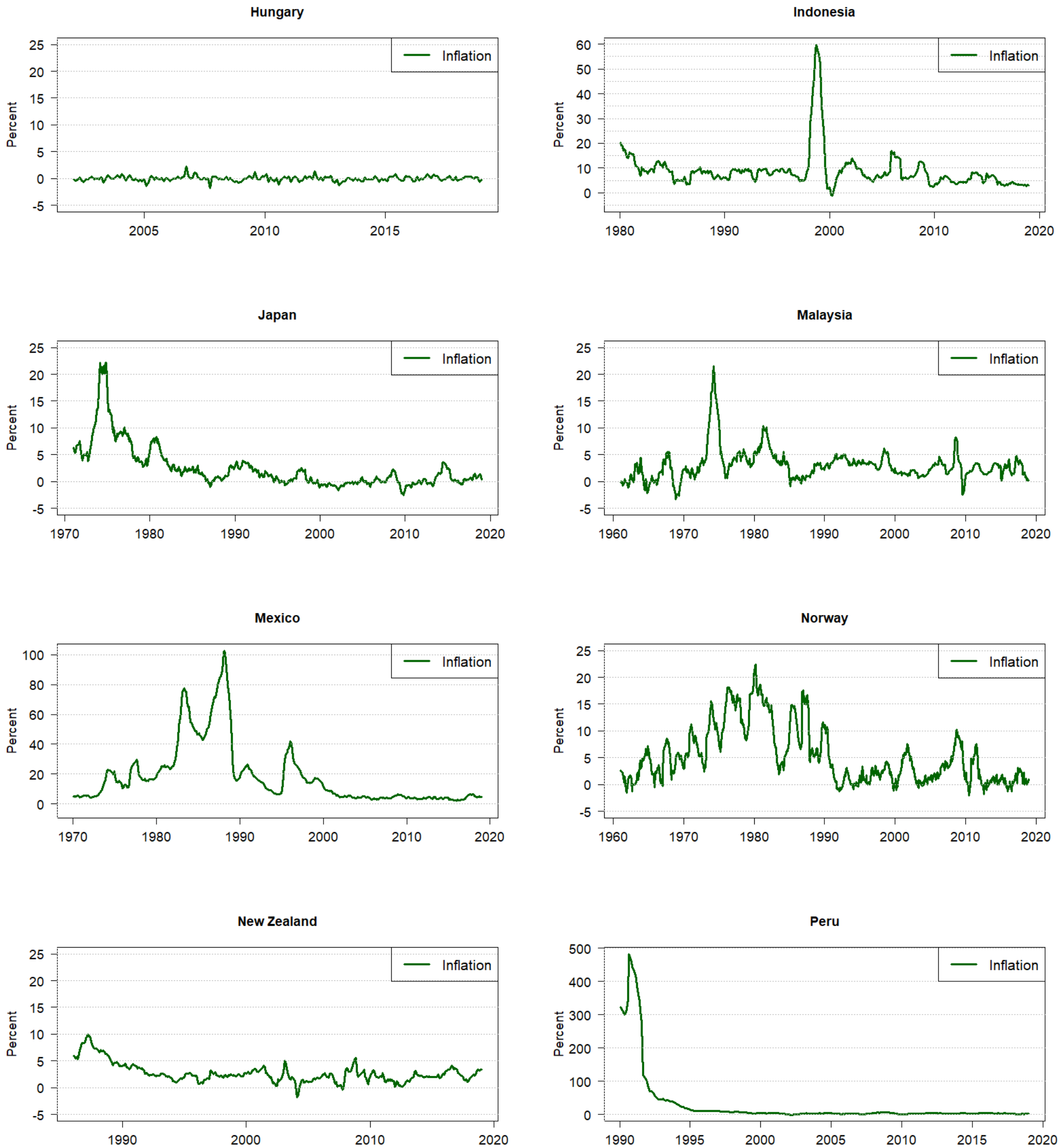


Figure A.III.3: Inflation Continued

## Appendix Chapter A.IV

# Appendix: Connectedness Analysis

An important part of explaining the global interest rate decline is determining the connection between each country. Now that I have a large database of yields and their components across 24 countries, I implement the Diebold and Yilmaz (2009) method to analyze how yields,term premia, and expectations are connected across countries. I have experience with DY (2009) since in my final paper for Macroeconomic Finance, I looked at the change in connectedness of the volatility of interest rates, equity returns, currencies, and commodities. My analysis included estimating the principal components of the data and constructing a network of asset connectedness.

This global network method involves running a VAR of all term premia, for example, and using the impulse response functions from one onto another in orderto estimate how term premia of different countries change, conditional on observing a shock to a specific country's term premium. The Diebold and Yilmaz (2009) method has been applied, for example, to study how policy uncertainty co-moves across countries (e.g., Klößner and Sekkel, 2014). The results can show if an underlying global factor exists for term premia. This can also show how much each country drives global term premia. Lastly, this can show what factors closely connect term premia globally.

## A.IV.1 Term Premium Connectedness

First, using term premium data for each country during the period of April 2007 to February 2019, I ran a monthly VAR(4) to estimate coefficients on the different countries. The sample was limited to data availability for all countries and the order of the VAR was determined using the Bayesian information criteria. Next, from the VAR, I calculate impulse response functions (IRFs)for each pair of countries. Table A.IV.1 shows the results of the IRF after 2 months. Each number in Table A.IV.1 can be interpreted as the impact of a one standard deviation shock of the term premium of the country on the column to the term premium of the country on the row after 2 months. For example, given a one standard deviation shock of the ten-year term premium in Colombia, I would expect a change of 0.05% for the ten-year term premium of Mexico. Notice that this effect need not be symmetric; that is, the same response from Mexico to Colombia, for example, is 0.06%. The reportedvalues are taken in absolute value since the takeaway of this exercise is to estimate the magnitude by which a conditional shock impacts all other countries, regardless of whether the effect is positive or negative. It is important to note that the DY method has been implemented with both IRFs and variance decompositions. One caveat of this exercise is the ordering of the variables, since the identification of the IRFs is done via Cholesky decomposition. One potential solution would be to instead consider generalized IRFs, but that is beyond the scope of my current econometric capabilities, so I leave this extension for future research. Table A.IV.1 contains a row and column with total and net influence. The row totals are the sum of the influence that everycountry has on other countries and the column totals are the sum of the influence other countries have on that country. The net row is the difference between the two and a positive value indicates a country has more influence on other countries than other countries have on it.

Table A.IV.1: Connectedness Amplitudes of 10y Term Premium

| | AUS | BRA | CAN | CHI | CHN | COL | CZR | EUR | HUN | INDO | JAP | MAL | MEX | NOR | NZ | PER | PHI | PO | SA | SNG | SWE | SWI | U.K. | U.S. | **From** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUS | 0.04 | 0.00 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.02 | 0.02 | 0.00 | 0.01 | 0.01 | 0.00 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.25 |
| BRA | 0.14 | 0.50 | 0.10 | 0.03 | 0.05 | 0.05 | 0.03 | 0.04 | 0.01 | 0.01 | 0.17 | 0.16 | 0.04 | 0.05 | 0.11 | 0.02 | 0.21 | 0.03 | 0.02 | 0.12 | 0.01 | 0.04 | 0.03 | 0.00 | 1.99 |
| CAN | 0.05 | 0.03 | 0.08 | 0.03 | 0.03 | 0.01 | 0.02 | 0.00 | 0.03 | 0.01 | 0.02 | 0.02 | 0.01 | 0.01 | 0.04 | 0.01 | 0.00 | 0.01 | 0.00 | 0.03 | 0.03 | 0.01 | 0.02 | 0.00 | 0.49 |
| CHI | 0.01 | 0.01 | 0.09 | 0.08 | 0.01 | 0.03 | 0.01 | 0.00 | 0.01 | 0.02 | 0.04 | 0.03 | 0.02 | 0.02 | 0.03 | 0.03 | 0.02 | 0.01 | 0.01 | 0.04 | 0.01 | 0.01 | 0.01 | 0.01 | 0.53 |
| CHN | 0.00 | 0.01 | 0.01 | 0.03 | 0.08 | 0.00 | 0.02 | 0.00 | 0.01 | 0.03 | 0.01 | 0.02 | 0.00 | 0.02 | 0.01 | 0.02 | 0.00 | 0.02 | 0.02 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 | 0.39 |
| COL | 0.03 | 0.08 | 0.03 | 0.04 | 0.01 | 0.18 | 0.00 | 0.02 | 0.09 | 0.02 | 0.12 | 0.06 | 0.06 | 0.01 | 0.04 | 0.04 | 0.09 | 0.02 | 0.01 | 0.06 | 0.02 | 0.02 | 0.00 | 0.01 | 1.05 |
| CZR | 0.08 | 0.04 | 0.06 | 0.02 | 0.00 | 0.06 | 0.09 | 0.00 | 0.02 | 0.00 | 0.05 | 0.02 | 0.08 | 0.00 | 0.01 | 0.03 | 0.03 | 0.01 | 0.00 | 0.02 | 0.06 | 0.02 | 0.01 | 0.02 | 0.75 |
| EUR | 0.05 | 0.03 | 0.05 | 0.04 | 0.01 | 0.03 | 0.04 | 0.05 | 0.01 | 0.00 | 0.03 | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.03 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.51 |
| HUN | 0.15 | 0.06 | 0.01 | 0.07 | 0.04 | 0.03 | 0.08 | 0.02 | 0.07 | 0.02 | 0.03 | 0.00 | 0.04 | 0.00 | 0.05 | 0.00 | 0.03 | 0.01 | 0.04 | 0.03 | 0.02 | 0.01 | 0.02 | 0.02 | 0.87 |
| INDO | 0.17 | 0.18 | 0.11 | 0.06 | 0.02 | 0.02 | 0.12 | 0.04 | 0.00 | 0.12 | 0.14 | 0.05 | 0.02 | 0.05 | 0.10 | 0.01 | 0.07 | 0.04 | 0.02 | 0.13 | 0.01 | 0.03 | 0.03 | 0.11 | 1.66 |
| JAP | 0.01 | 0.03 | 0.02 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.04 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.22 |
| MAL | 0.05 | 0.04 | 0.06 | 0.00 | 0.03 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.07 | 0.01 | 0.02 | 0.01 | 0.00 | 0.04 | 0.01 | 0.01 | 0.03 | 0.02 | 0.01 | 0.03 | 0.01 | 0.49 |
| MEX | 0.11 | 0.08 | 0.06 | 0.00 | 0.02 | 0.05 | 0.04 | 0.06 | 0.01 | 0.04 | 0.08 | 0.05 | 0.08 | 0.01 | 0.03 | 0.01 | 0.01 | 0.04 | 0.02 | 0.05 | 0.00 | 0.03 | 0.01 | 0.02 | 0.90 |
| NOR | 0.05 | 0.05 | 0.02 | 0.01 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.01 | 0.02 | 0.00 | 0.03 | 0.00 | 0.05 | 0.02 | 0.05 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.39 |
| NZ | 0.12 | 0.06 | 0.09 | 0.04 | 0.02 | 0.03 | 0.04 | 0.02 | 0.03 | 0.01 | 0.04 | 0.01 | 0.01 | 0.02 | 0.08 | 0.01 | 0.04 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.75 |
| PER | 0.21 | 0.46 | 0.08 | 0.23 | 0.12 | 0.19 | 0.09 | 0.30 | 0.12 | 0.07 | 0.06 | 0.15 | 0.01 | 0.01 | 0.05 | 0.50 | 0.07 | 0.29 | 0.17 | 0.03 | 0.07 | 0.09 | 0.11 | 0.14 | 3.61 |
| PHI | 0.03 | 0.02 | 0.00 | 0.08 | 0.02 | 0.10 | 0.00 | 0.01 | 0.07 | 0.01 | 0.05 | 0.03 | 0.08 | 0.03 | 0.05 | 0.02 | 0.27 | 0.02 | 0.02 | 0.06 | 0.00 | 0.03 | 0.03 | 0.03 | 1.08 |
| PO | 0.08 | 0.05 | 0.06 | 0.00 | 0.03 | 0.05 | 0.04 | 0.07 | 0.01 | 0.02 | 0.03 | 0.00 | 0.03 | 0.00 | 0.05 | 0.03 | 0.02 | 0.08 | 0.02 | 0.02 | 0.02 | 0.02 | 0.01 | 0.02 | 0.75 |
| SA | 0.05 | 0.02 | 0.04 | 0.03 | 0.00 | 0.00 | 0.03 | 0.05 | 0.02 | 0.01 | 0.04 | 0.02 | 0.02 | 0.01 | 0.03 | 0.02 | 0.03 | 0.03 | 0.04 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.51 |
| SNG | 0.09 | 0.04 | 0.08 | 0.05 | 0.01 | 0.02 | 0.01 | 0.00 | 0.00 | 0.02 | 0.09 | 0.02 | 0.00 | 0.01 | 0.03 | 0.06 | 0.03 | 0.02 | 0.02 | 0.06 | 0.00 | 0.01 | 0.00 | 0.02 | 0.70 |
| SWE | 0.04 | 0.02 | 0.02 | 0.02 | 0.01 | 0.00 | 0.02 | 0.03 | 0.00 | 0.01 | 0.00 | 0.02 | 0.01 | 0.01 | 0.03 | 0.00 | 0.04 | 0.01 | 0.02 | 0.01 | 0.04 | 0.00 | 0.01 | 0.01 | 0.36 |
| SWI | 0.06 | 0.04 | 0.06 | 0.03 | 0.02 | 0.00 | 0.03 | 0.04 | 0.01 | 0.00 | 0.06 | 0.02 | 0.03 | 0.01 | 0.02 | 0.03 | 0.02 | 0.01 | 0.03 | 0.02 | 0.02 | 0.06 | 0.01 | 0.02 | 0.65 |
| U.K. | 0.03 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 | 0.02 | 0.04 | 0.03 | 0.01 | 0.01 | 0.02 | 0.00 | 0.02 | 0.02 | 0.01 | 0.06 | 0.01 | 0.03 | 0.00 | 0.00 | 0.01 | 0.03 | 0.01 | 0.43 |
| U.S. | 0.10 | 0.03 | 0.09 | 0.04 | 0.01 | 0.02 | 0.03 | 0.04 | 0.03 | 0.01 | 0.07 | 0.00 | 0.05 | 0.00 | 0.06 | 0.03 | 0.07 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.00 | 0.01 | 0.83 |
| **To** | 1.74 | 1.88 | 1.28 | 0.94 | 0.56 | 0.92 | 0.82 | 0.89 | 0.60 | 0.46 | 1.19 | 0.81 | 0.64 | 0.37 | 0.93 | 0.94 | 1.25 | 0.75 | 0.54 | 0.80 | 0.39 | 0.46 | 0.46 | 0.52 | 20.14 |
| **Net** | 1.48 | -0.1 | 0.78 | 0.4 | 0.18 | -0.1 | 0.07 | 0.39 | -0.3 | -1.2 | 0.98 | 0.31 | -0.3 | -0 | 0.18 | -2.7 | 0.18 | -0 | 0.03 | 0.09 | 0.03 | -0.2 | 0.03 | -0.3 | |

Looking at Table A.IV.1, I find some interesting results. The U.S. and U.K. have little influence on the term premium of other countries, but the Euro has a larger influence. This could be due to the many European countries in the system and the fact that the sample is restricted to the 2007-2019 period.

Next, Japan has a major influence on the term premium of other nations. Japan has used quantitative easing in the past to target the term premium and may be a good indicator of default risk.

Peru has the lowest net influence and is influenced the most. This fits intuition because Peru does not have a large economy compared to most countries and there are many other Latin American countries in the system that influence Peru. The countries that influence Peru the most are Brazil and Colombia, both Latin American countries.

Brazil has the highest total influence on other countries. This also follows intuition because Brazil has a large economy and its government bonds are widely not considered risk-free, hence it would make a strong measure of risk thus affecting the term premium of other countries. This result might be in part due to Brazil's term premia moving a lot during this period, while the U.S. term premium has experienced less variability.

Next, I utilize network graphs to easily visualize the entire system of the 10-year term premium. In this graphs, every country is a "node," denoted with a circle, and connected to other nodes through "edges" or "links" showing the direction of the connection, in this case the IRFs between countries. The location of nodes depends on the betweeness of the country and the influence it has on other countries. The thickness of the arrows indicates the strength of the influence and connections with a strength below the mean network removed for a cleaner network.

The network plot uses the Girvan-Newman algorithm as in Girvan and Newman (2002) to find hidden communities within the grouping identified by node color and shaded regions. The Girvan-Newman algorithm works by progressively removing edges and using what remains to construct communities. The algorithm can identify key relationships between countries that may not immediately be seen visually.

Looking at the locations of the nodes in Figure A.IV.1, the centrality of Peru, for example, stems from its vulnerability given that Peru is influenced by many countries (notice the thickness of the arrows going into Peru). Looking at the groupings of different nodes,the U.S. and the U.K. were grouped together, this implies the term premium between the two is highly connected through the number of indirect connections they share. This fits our intuition of two economies that have engaged in quantitative easing for the first time during the period of the network and have similar risk profiles. The next interesting group is Colombia and Peru, which both are smaller economies in South America that are influenced highly by other economies.

## A.IV.2 Expectations Connectedness

Table A.IV.2 shows the equivalent table as Table A.IV.1 except for expectations components instead of term premia. High values would imply the expectations components of interest rates are connected through high IRFs coefficients in absolute value.

Figure A.IV.1: 10-Year Term Premium Connectedness

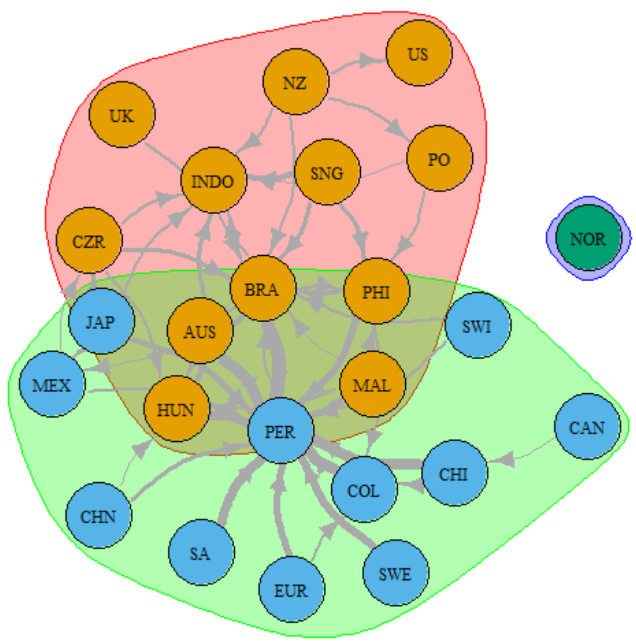


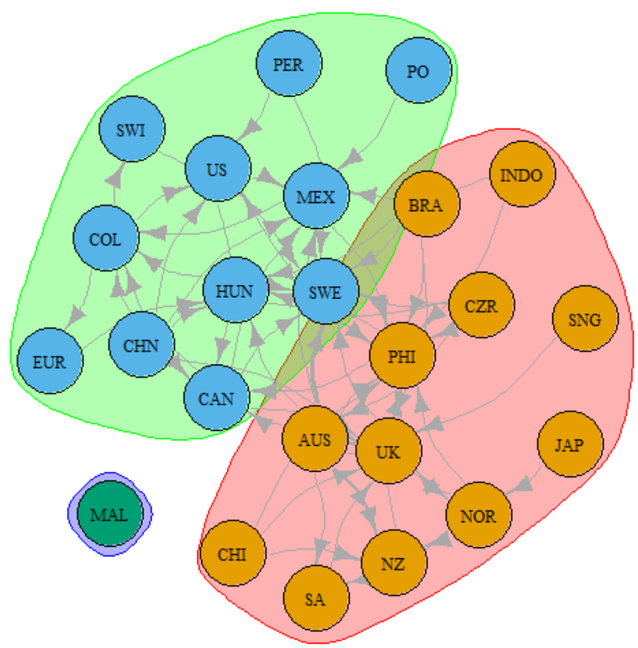
Table A.IV.2: Connectedness Amplitudes of 10y Expectations

| | AUS | BRA | CAN | CHI | CHN | COL | CZR | EUR | HUN | INDO | JAP | MAL | MEX | NOR | NZ | PER | PHI | PO | SA | SNG | SWE | SWI | U.K. | U.S. | From |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| AUS | 0.16 | 0.01 | 0.02 | 0.02 | 0.02 | 0.01 | 0.05 | 0.02 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 | 0.01 | 0.02 | 0.02 | 0.48 |
| BRA | 0.03 | 0.08 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.02 | 0.00 | 0.01 | 0.02 | 0.00 | 0.00 | 0.01 | 0.01 | 0.29 |
| CAN | 0.07 | 0.00 | 0.05 | 0.03 | 0.03 | 0.01 | 0.00 | 0.00 | 0.00 | 0.02 | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.03 | 0.34 |
| CHI | 0.03 | 0.01 | 0.00 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.14 |
| CHN | 0.01 | 0.00 | 0.00 | 0.00 | 0.03 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.09 |
| COL | 0.01 | 0.01 | 0.03 | 0.00 | 0.05 | 0.08 | 0.00 | 0.01 | 0.03 | 0.02 | 0.01 | 0.01 | 0.03 | 0.01 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.37 |
| CZR | 0.02 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.05 | 0.00 | 0.02 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.18 |
| EUR | 0.02 | 0.02 | 0.00 | 0.01 | 0.01 | 0.03 | 0.01 | 0.04 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.26 |
| HUN | 0.00 | 0.07 | 0.02 | 0.03 | 0.03 | 0.03 | 0.07 | 0.06 | 0.15 | 0.02 | 0.02 | 0.01 | 0.01 | 0.01 | 0.01 | 0.03 | 0.01 | 0.02 | 0.01 | 0.04 | 0.02 | 0.03 | 0.04 | 0.01 | 0.73 |
| INDO | 0.03 | 0.01 | 0.02 | 0.00 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 | 0.05 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.28 |
| JAP | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.08 |
| MAL | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 |
| MEX | 0.05 | 0.01 | 0.04 | 0.01 | 0.06 | 0.01 | 0.02 | 0.02 | 0.01 | 0.06 | 0.02 | 0.00 | 0.03 | 0.01 | 0.02 | 0.01 | 0.01 | 0.01 | 0.00 | 0.02 | 0.01 | 0.00 | 0.03 | 0.03 | 0.47 |
| NOR | 0.05 | 0.02 | 0.02 | 0.01 | 0.02 | 0.04 | 0.00 | 0.01 | 0.00 | 0.02 | 0.03 | 0.00 | 0.01 | 0.01 | 0.01 | 0.03 | 0.00 | 0.00 | 0.02 | 0.01 | 0.00 | 0.01 | 0.00 | 0.02 | 0.35 |
| NZ | 0.08 | 0.01 | 0.00 | 0.05 | 0.00 | 0.00 | 0.03 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.02 | 0.02 | 0.01 | 0.03 | 0.00 | 0.02 | 0.01 | 0.01 | 0.00 | 0.01 | 0.02 | 0.36 |
| PER | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.02 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.12 |
| PHI | 0.05 | 0.01 | 0.01 | 0.00 | 0.00 | 0.00 | 0.06 | 0.00 | 0.03 | 0.08 | 0.07 | 0.01 | 0.03 | 0.01 | 0.06 | 0.03 | 0.11 | 0.01 | 0.00 | 0.05 | 0.01 | 0.00 | 0.01 | 0.03 | 0.68 |
| PO | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 | 0.01 | 0.01 | 0.00 | 0.01 | 0.00 | 0.19 |
| SA | 0.09 | 0.02 | 0.01 | 0.02 | 0.02 | 0.03 | 0.00 | 0.00 | 0.01 | 0.03 | 0.02 | 0.01 | 0.01 | 0.03 | 0.01 | 0.00 | 0.01 | 0.01 | 0.04 | 0.03 | 0.01 | 0.00 | 0.01 | 0.02 | 0.43 |
| SNG | 0.01 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 0.01 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.01 | 0.01 | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 | 0.01 | 0.10 |
| SWE | 0.12 | 0.03 | 0.02 | 0.00 | 0.01 | 0.02 | 0.04 | 0.03 | 0.01 | 0.01 | 0.03 | 0.01 | 0.01 | 0.00 | 0.02 | 0.02 | 0.01 | 0.00 | 0.02 | 0.01 | 0.04 | 0.01 | 0.02 | 0.01 | 0.50 |
| SWI | 0.03 | 0.01 | 0.02 | 0.00 | 0.01 | 0.05 | 0.01 | 0.02 | 0.00 | 0.00 | 0.03 | 0.01 | 0.02 | 0.03 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.00 | 0.04 | 0.01 | 0.00 | 0.39 |
| U.K. | 0.10 | 0.02 | 0.04 | 0.04 | 0.04 | 0.04 | 0.01 | 0.01 | 0.02 | 0.04 | 0.03 | 0.03 | 0.00 | 0.01 | 0.01 | 0.02 | 0.00 | 0.01 | 0.06 | 0.05 | 0.00 | 0.00 | 0.03 | 0.02 | 0.60 |
| U.S. | 0.02 | 0.00 | 0.02 | 0.01 | 0.04 | 0.03 | 0.01 | 0.03 | 0.01 | 0.01 | 0.03 | 0.01 | 0.00 | 0.00 | 0.01 | 0.03 | 0.02 | 0.00 | 0.02 | 0.01 | 0.00 | 0.01 | 0.01 | 0.04 | 0.39 |
| To | 1.01 | 0.37 | 0.36 | 0.29 | 0.40 | 0.43 | 0.41 | 0.34 | 0.40 | 0.45 | 0.38 | 0.15 | 0.22 | 0.19 | 0.26 | 0.32 | 0.30 | 0.14 | 0.25 | 0.33 | 0.16 | 0.17 | 0.23 | 0.28 | 7.84 |
| Net | 0.53 | 0.09 | 0.02 | 0.15 | 0.30 | 0.06 | 0.23 | 0.07 | -0.34 | 0.17 | 0.31 | 0.13 | -0.26 | -0.15 | -0.09 | 0.20 | -0.38 | -0.05 | -0.18 | 0.22 | -0.34 | -0.22 | -0.38 | -0.11 | |

Table A.IV.2 shows thatthe expectations components of the 24 countries are less connected than the term premium of the same countries. The total connectedness of the expectations is 6.73, while the total connectedness of term premium is 19.39. The largest influence of expectations by a large margin is Australia. Australia has not had a recession in over 27 years so investors may look to Australia as an indicator of expected long-term rates given it did not experience a recession during the global financial crisis. The U.K. and U.S. still do not have much influence on other countries.

Figure A.IV.2 shows the network plot of Table A.IV.2 using the Girvan-Newman algorithm for grouping or identifying clusters.

Figure A.IV.2: 10-Year Expectations Components Connectedness



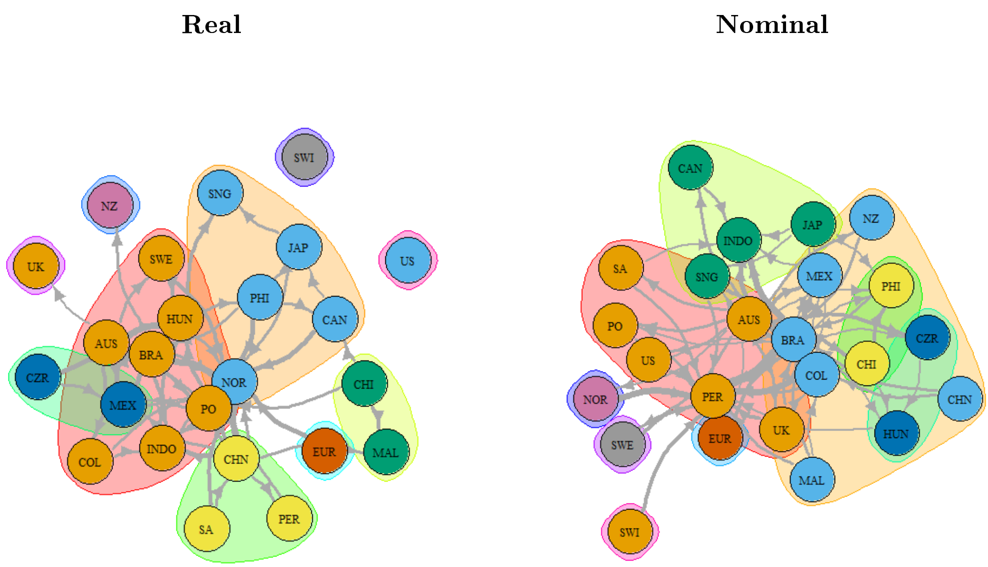

The first country that stands out in Figure A.IV.2 is Japan, which no longer has large IRFs to other countries. This is likely due to its negative interest rates and unconventional monetary policy that no other country has ever done for that long. Other outliers include Singapore, Poland and Switzerland. Singapore is a unique city-state country that is among mostly less advanced nations and it fits that its monetary policy would be unique. Monetary policy and currency have a strong connection within countries and given the Swiss Franc is often considered a safe haven currency, it would follow that Swiss monetary policy is different as well. Central to the network is Australia, Sweden and Canada, which are all a part of a different region and are advanced economies.

## A.IV.3 Real Connectedness

In order to determine whether the connectedness of yields is mostly due to inflation, I calculated real yields by subtracting the respective inflation rate from the nomina yield of each country and compared the networks with each other. Figure A.IV.3 shows the two different networks. First, total connectedness is very similar. Nominal yield total connectedness is 11.87 and real yield total connectedness is 10.57. Thus it is clear that inflation is not the main factor in connecting yields and there are other variables that influence yields.

Looking at the U.S., it appears that it is much less connected after inflation was removed from the yields. Therefore inflation is likely the main driver of connectedness in the global economy for the U.S.. One takeaway of the connectedness analysis isthat inflation is not the only factor behind connectedness., given that the network using real yields excludes inflation and still shows highly connected countries in yields.

Figure A.IV.3: Real and Nominal 10-Year Yield Connectedness

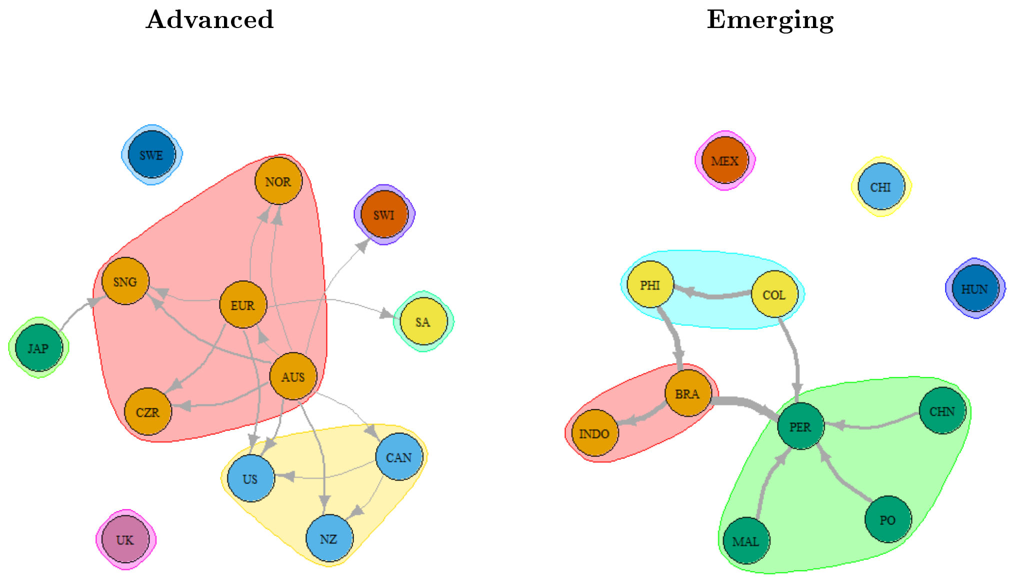



*Note:* Results are from 2007-2019.

## A.IV.4 Advanced and Emerging Country Connectedness

Most advanced economies have a low risk of default and thus the term premium is not representative of the risk of default but mostly inflation or monetary policy risks. In order to decipher these differences, I separated Advanced Economies and Emerging Economies to create networks within each group. I used the IMF's list of advanced economies to make this decision. Of the 24 countries in my sample, the IMF lists Australia, Canada, the Czech Republic, the Euro Area, Japan, Norway, South Africa, Singapore, Sweden, Switzerland, the U.K., the U.S., and New Zealand as Advanced. The remaining countries I considered emerging.

Figure A.IV.4: Advanced and Emerging Economies 10-Year Term Premium Connectedness




*Note:* Results are from 2007–2019.

Figure A.IV.4 shows the network plots for the term premium of each sample of countries. Both network plots have less outliers. For Advanced Economies, initially Japan was a central node, however now Australia and the Euro Area, which both were not central, are the most central nodes in the term premium network.

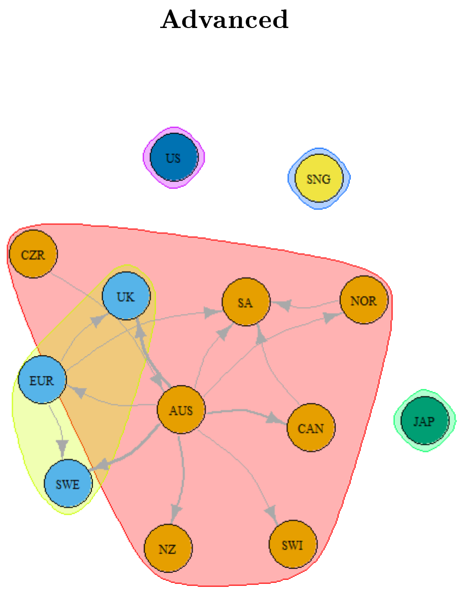
Comparing the Advanced nations to the Emerging nations, the thickness of the arrows indicate strength of the connection (i.e., magnitude of IRF). Figure A.IV.4 shows significantly thicker lines and hence a much stronger connection for the emerging markets than the Advanced nations. This implies that term premium, hence risk is much more connected for emerging nations than advanced.

Next, looking at expectation connectedness between Advanced and Emerging nations in Figure A.IV.5, Australia is the most central for Advanced economies and Hungary and Mexico are the most central of the Emerging nations. All of these countries were also central in Figure A.IV.2.

The connection strength of the Advanced nations is much higher than the strength of the Emerging nations. This indicates that the expectations component is much more connected between the Advanced nations than the emerging nations.

Looking both at Figure A.IV.4 and Figure A.IV.5, it follows that term premium, hence risk is much more connected in emerging nations than Advanced nations. Emerging nations have a higher risk of hyper inflation or default. However, the opposite is true for the expectations component. The expectations component, hence expected future monetary policy between Advanced nations is highly connected, but only loosely linked in Emerging nations. These results imply that risk connects emerging nations through the term premium and expected monetary policy connects Advanced economies through the expectations channel.

Figure A.IV.5: Advanced and Emerging Economies 10-Year Expectations Connectedness




*Note:* Results are from 2007--2019.

CHAPTER A.V

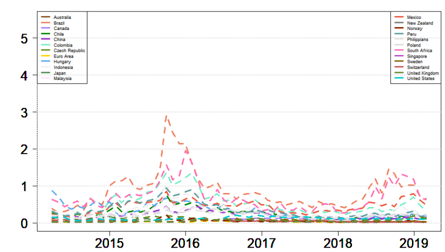
# Appendix: Robustness and Other Analysis

## A.V.1 Pricing Risk

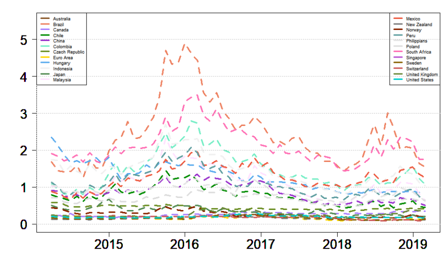
Figure A.V.1 shows credit default swap (CDS) yields for different duration. As expected, the yield and expected risk of default increases with duration. This adds more evidence to the fact that term premium should not be negative if it is accounting for this excess risk. Brazil is a clear outlier for the CDS and has a much higher cost of insurance than other developing countries.

Figure A.V.1: Credit Default Swap Yields (%)

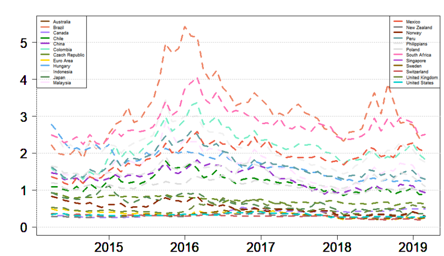
**1-Year Yield (%)**




**5-Year Yield (%)**




**10-Year Yield (%)**




Next, in order to further investigate the price of risk and how it relates to the term premium, I ran individual OLS and panel regressions of term premium different maturities on CDS yields.

Looking at Table A.V.1, most coefficients have a positive coefficient with CDS yield, however this is not true for all countries. This implies there is much more to term premium than just risk of default even for emerging markets.

Table A.V.1: Term Premium Regression Coefficients on Credit Default Swap Yields

| | **1y CDS** | | | **5y CDS** | | | **10y CDS** | | |
|---|---|---|---|---|---|---|---|---|---|
| | 1y | 5y | 10y | 1y | 5y | 10y | 1y | 5y | 10y |
| Australia | 1.47*** | -1.745*** | 1.958 | 0.5*** | -0.359*** | 0.295 | 0.27*** | -0.178*** | 0.098 |
| Brazil | 0.289*** | 1.37*** | 1.817*** | 0.215*** | 0.789*** | 1.058*** | 0.223*** | 0.742*** | 0.97*** |
| Canada | 0.061 | 8.954*** | 2.461 | 0.053 | 2.281 | 0.076 | -0.151 | -2.075 | -2.447 |
| Chile | 0.208*** | 0.771*** | 0.893*** | 0.141*** | 0.476*** | 0.549*** | 0.171*** | 0.433*** | 0.417*** |
| China | -1.013*** | -2.362*** | -2.586*** | -0.395*** | -0.932*** | -0.993*** | -0.359*** | -0.795*** | -0.837*** |
| Colombia | 0.33*** | 1.066*** | 1.732*** | 0.196*** | 0.548*** | 0.882*** | 0.187*** | 0.461*** | 0.746*** |
| Czech Republic | -0.59 | -2.461· | -4.936*** | 0.039 | -1.274 | -1.277 | -0.085 | -1.643*** | -1.985*** |
| Euro Area | -0.288 | -4.617*** | -6.346*** | 0.11· | -0.348 | 0.022 | 0.078*** | -0.083 | 0.176 |
| Hungary | 0.296*** | 1.129*** | 0.707· | 0.141*** | 0.544*** | 0.358· | 0.132*** | 0.513*** | 0.35· |
| Indonesia | 0.914*** | 2.391*** | 2.556*** | 0.473*** | 1.126*** | 1.218*** | 0.452*** | 1.126*** | 1.216*** |
| Japan | -0.171*** | 0.64*** | 1.918*** | -0.049*** | 0.103 | 0.405*** | -0.031*** | 0.086· | 0.292*** |
| Malaysia | -0.224· | 0.042 | 0.408*** | -0.111*** | -0.044 | 0.12· | -0.099*** | -0.039 | 0.131*** |
| Mexico | -0.051*** | 0.608 | 0.344 | -0.01 | 0.044 | -0.098 | 0.01 | -0.391*** | -0.424*** |
| New Zealand | 0.632 | -2.561*** | -4.634*** | 0.445 | -1.61*** | -2.886*** | 0.472 | -1.372*** | -2.417*** |
| Norway | 0.027 | 0.218 | 0.279 | -0.067 | 0.314 | 0.484 | -0.063 | 0.228 | 0.358 |
| Peru | 0.39 | 2.849*** | 5.125*** | 0.436*** | 1.849*** | 3.287*** | 0.594*** | 1.984*** | 3.577*** |
| Philippines | -0.421 | -1.518 | -3.083· | -0.33*** | -1.119*** | -2.066*** | -0.348*** | -1.185*** | -2.076*** |
| Poland | 0.026 | -0.92*** | -1.071*** | 0.043 | -0.363 | -0.422 | 0.08 | -0.382 | -0.527 |
| South Africa | -0.001 | 0.021 | 0.059 | -0.038*** | -0.164*** | -0.099 | -0.04*** | -0.235*** | -0.24*** |
| Sweden | -0.542*** | -1.148*** | -2.461*** | -0.128 | -0.45*** | -0.907· | 0.057 | -0.109 | -0.151 |
| Switzerland | -1.533*** | -4.247*** | -4.251*** | -0.525 | -2.058*** | -2.138*** | -0.413 | -1.755*** | -1.815*** |
| United Kingdom | -0.671*** | -1.376*** | -2.755*** | -0.067 | -0.367*** | -0.363 | 0.037 | -0.149 | 0.043 |
| United States | -0.401 | -2.529*** | -3.168*** | -0.673*** | -3.14*** | -3.958*** | -0.62*** | -0.484 | -0.293 |
| Panel | 0.221*** | 1.009*** | 1.374*** | 1.009*** | 0.535*** | 0.448*** | 1.374*** | 0.745*** | 0.623*** |

Note: Significance levels indicated as follows: * at the .05% level, ** at the 0.01% level, and *** at the .001% level.

## A.V.2 Yields, Term Premia, Expectations, and Inflation: First Differences

Table A.V.2: First Difference Regression Coefficients on First Difference of Inflation

| | 10y TP | 10y Exp. | 10y Yield | 5y TP | 5y Exp. | 5y Yield | 1y TP | 1y Exp. | 1y Yield |
|---|---|---|---|---|---|---|---|---|---|
| Australia | -0.006 | 0.082 | 0.078 | -0.028*** | 0.111*** | 0.081 | -0.008 | 0.174*** | 0.178*** |
| Brazil | 0.322 | 0.046 | 0.334 | 0.255 | 0.092 | 0.389*** | 0.082 | 0.256*** | 0.388*** |
| Canada | -0.003 | 0.027 | 0.029 | -0.021 | 0.035 | 0.011 | -0.001 | 0.057 | 0.054 |
| Chile | -0.052 | -0.007 | -0.012 | 0.028 | -0.014 | -0.001 | 0.031 | 0.087 | 0.128 |
| China | -0.002 | 0.003 | 0.006 | 0.003 | 0.006 | 0.006 | 0.005 | 0.017 | 0.021 |
| Colombia | 0.153 | 0.126*** | 0.246 | -0.076 | 0.207*** | 0.143 | 0.111*** | 0.373*** | 0.437*** |
| Czech Republic | 0.057 | 0.022 | 0.057 | 0.007 | 0.034 | 0.055 | 0.024*** | 0.064*** | 0.097*** |
| Euro Area | 0.036 | 0.081*** | 0.138*** | 0.03 | 0.118*** | 0.136*** | 0.014*** | 0.164*** | 0.185*** |
| Hungary | -0.158*** | 0.06 | -0.089 | -0.128*** | 0.079 | -0.056 | -0.027*** | 0.086 | 0.075 |
| Indonesia | 0.074 | 0.007 | 0.115*** | 0.063 | 0.015 | 0.065 | 0.003 | 0.034 | 0.025 |
| Japan | 0.019 | 0.05*** | 0.062*** | 0.017 | 0.058*** | 0.075*** | 0.004 | 0.065*** | 0.071*** |
| Malaysia | 0.071*** | 0.004*** | 0.075*** | 0.04*** | 0.007*** | 0.051*** | 0.037*** | 0.034*** | 0.089*** |
| Mexico | 0.02 | 0.023 | 0.018 | -0.028 | 0.033 | 0.01 | 0.003 | 0.067 | 0.109 |
| New Zealand | 0.035 | -0.023 | -0.012 | 0.022 | -0.034 | -0.022 | 0.034*** | -0.036 | 0.035 |
| Norway | -0.013 | -0.008 | -0.018 | -0.009 | -0.007 | -0.019 | -0.002 | 0.003 | 0.002 |
| Peru | 0.339 | 0.028*** | 0.247*** | 0.243*** | 0.057*** | 0.272*** | 0.036 | 0.219*** | 0.243*** |
| Philippines | 0.248*** | 0.032 | 0.296*** | 0.148 | 0.041 | 0.191 | -0.013 | 0.01 | -0.051 |
| Poland | 0.046 | 0.004 | 0.051 | 0.035 | 0.005 | 0.043 | -0.005 | -0.006 | -0.023 |
| South Africa | -0.062*** | 0.062 | -0.001 | -0.058*** | 0.094*** | 0.038 | -0.009 | 0.179*** | 0.194*** |
| Singapore | 0.034 | -0.007 | 0.037 | 0.011 | -0.011 | -0.002 | -0.001 | -0.014 | -0.01 |
| Sweden | 0.053*** | 0.047 | 0.074*** | 0.017*** | 0.052 | 0.079*** | 0.025*** | 0.092*** | 0.124*** |
| Switzerland | -0.054 | 0.045 | -0.006 | -0.068 | 0.061 | -0.004 | -0.089 | 0.15 | 0.058 |
| United Kingdom | 0.046 | 0.235*** | 0.277*** | 0.006 | 0.267*** | 0.276*** | -0.004 | 0.294*** | 0.278*** |
| United States | 0.163*** | 0.023 | 0.187*** | 0.119*** | 0.036 | 0.159*** | 0.035*** | 0.085*** | 0.121*** |