Asset and Risk Management I

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Government Bonds

Introduction

- The government bond market is an important asset class.
  - It has the second-highest market capitalization among the major asset classes.
  - A term structure derived from default-risk free bonds is a useful basis to price other assets.
- In this class, you will learn about
  - bond terminology such as yields, forward rates, and returns
  - historical patterns of realized returns and yield curves
  - prediction of bond risk premia using forward rates and inflation

Discount bonds: Definition

Definition: Discount bond

A zero-coupon bond of maturity n (or n-year discount bond) at time t is a promise to pay \$1 at time $t + n$.

- $P_t^{(n)}$ = Price of a n-year discount bond at time t
- $p_t^{(n)}$ = log price of n-year discount bond at time t.
- (n) to distinguish maturity from raising a number to a power.

Discount bonds: Example

- Example: If at time t the 2-year discount rate is 5.13%, annually compounded, then we have

$$P_t^{(2)} = \frac{1}{(1+0.0513)^2} \approx 0.905$$

- Log price: $p_t^{(2)} = \ln P_t^{(2)} = -0.10$
  "10% discount"

Returns and log-returns

- Small letters are used for log of large letters
- Note $\ln(1+x) \approx x$ and $e^x \approx 1+x$ for small x
- Thus $\ln(1+0.1) \approx 0.1 = 10\%$ return
- Why logs?
  - Two year return is $R_1 \cdot R_2$. Two year log return is $r_1 + r_2$

Holding Period Returns

Definition: Holding period return $R^{(n)}_{t,t+1}$

The return you earn if you buy a n-year bond today, at time t, and sell it at time $t+1$:

$$R^{(n)}_{t,t+1} = \frac{P^{(n-1)}_{t+1}}{P^{(n)}_{t}}$$

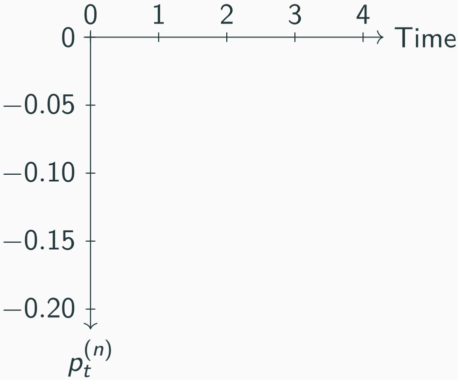
Definition: Log holding period return $r^{(n)}_{t,t+1}$

The continuously compounded return you earn if you buy a n-year bond today, at time t, and sell it at time $t+1$:

$$r^{(n)}_{t,t+1} = p^{(n-1)}_{t+1} - p^{(n)}_{t}$$

Example: Prices and Returns

- Example price path of a bond with initial maturity of 4 years: $p_0^{(4)} = -0.20$, $p_1^{(3)} = -0.20$, $p_2^{(2)} = -0.075$, $p_3^{(1)} = -0.025$



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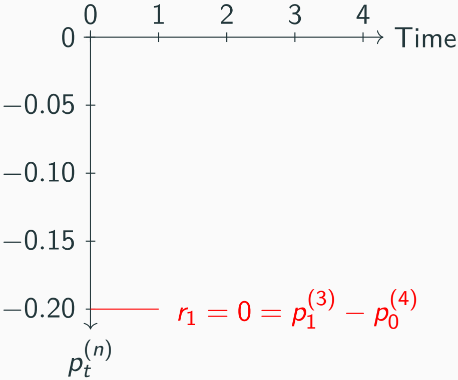

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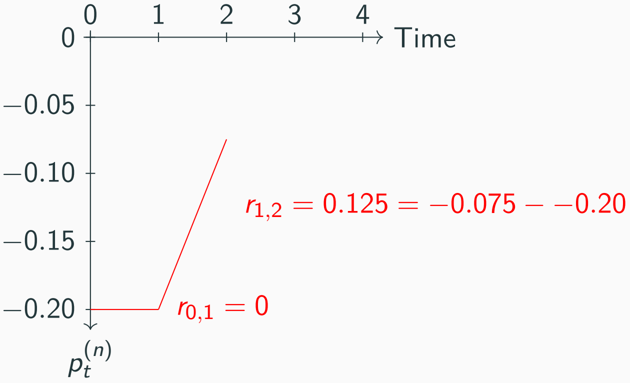

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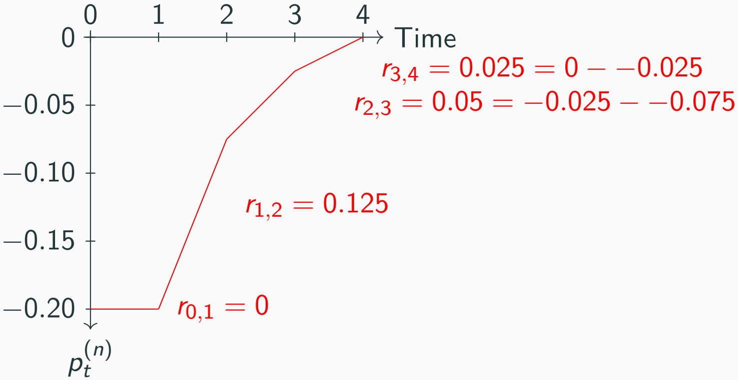

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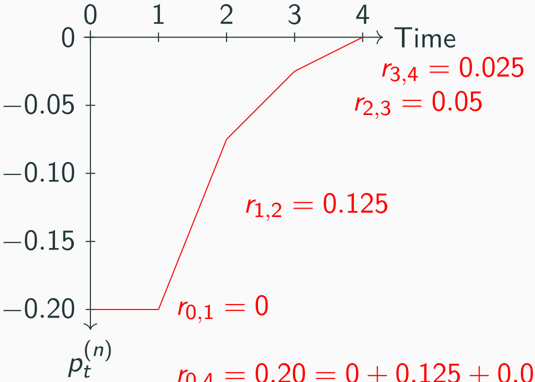


$r_{0,4} = 0.20 = 0 + 0.125 + 0.05 + 0.025$

$r_{0,4} = 5\%$ p.a.

Yields (1)

Definition: Yield (or yield-to-maturity)

For a bond with price P and cash flows CF_j at time j, yield Y solves

$$P = \sum_j \frac{CF_j}{Y^j}$$

- Yield: the discount rate which makes the present value of the bond's future cash flows equal to its market price
- Assumes that we know the future and that no default takes place

Yields (2)

- For discount bonds we have:

$$P_t^{(n)} = \frac{1}{\left[Y_t^{(n)}\right]^n}$$

- Solving $p_t^{(n)} = -ny_t^{(n)}$ for the yield:

$$y_t^{(n)} = -\frac{1}{n} p_t^{(n)}$$

- Example:

$$p_t^{(2)} = -0.1 \quad \rightarrow \quad y_t^{(2)} = 0.05$$

Excess Returns

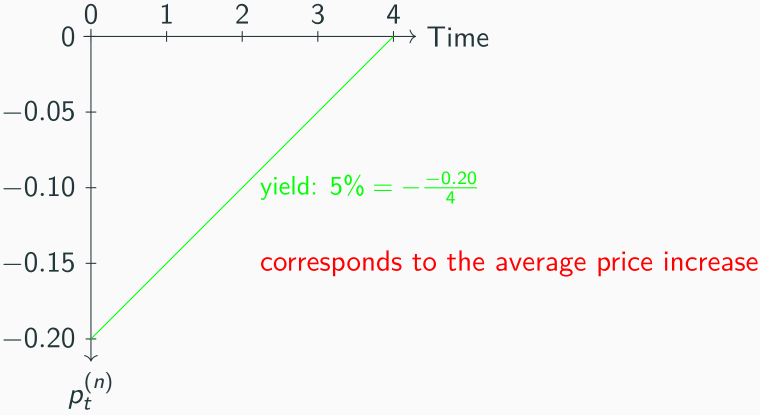
Definition: Log excess holding period return $r^{e(n)}_{t,t+1}$

The log holding period return over the risk free rate:

$$
\begin{aligned}
r^{e(n)}_{t,t+1} &= r^{(n)}_{t,t+1} - y^{(1)}_t \\
&= p^{(n-1)}_{t+1} - p^{(n)}_t + p^{(1)}_t
\end{aligned}
$$

Yield vs. Realized Return

- Yield allows to compare bonds. But it is not necessarily the (holding period) return you will earn every period:
- Example:



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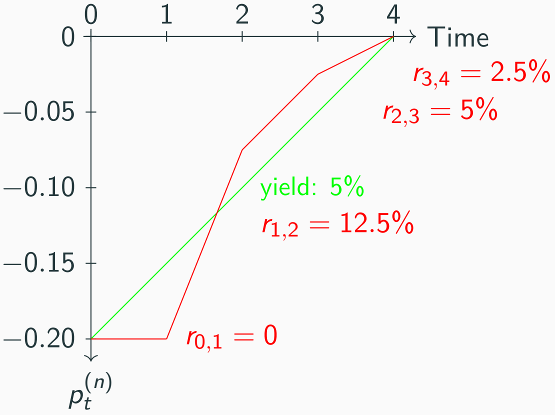
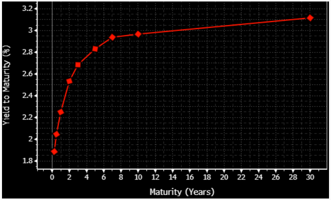


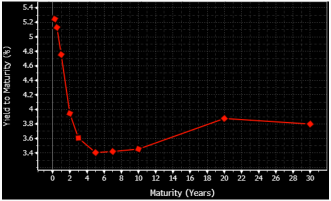
Yield Curves

- Coupon bonds are a bundle of zeros. Thus

$$\text{Coupon bond} = P^{(1)} \cdot CF_1 + P^{(2)} \cdot CF_2 + \cdots$$

US Treasury Bonds: May 10, 2018 and May 10, 2023. Source Bloomberg





- Why are yields different for bonds with different maturities?
- Parsimonious modeling of yield curves: Nelson and Siegel (1987)

Forward Rate

Definition: Forward rate

$F_t^{(n)}$ is the rate at which you can contract today (t) to invest from $t+n-1$ to $t+n$.

$$F_t^{(n)} = F_t^{(t+n-1 \to t+n)} = \frac{P_t^{(n-1)}}{P_t^{(n)}}$$

- One can set up a replication portfolio to obtain the forward rate synthetically.

Replication Portfolio

Transaction	Cash Flow		
	t	$t+n-1$	$t+n$
Buy 1 n-year bond	$-P_t^{(n)}$	0	1
Sell $\frac{P_t^{(n)}}{P_t^{(n-1)}}$ $n-1$-year bonds	$+P_t^{(n)}$	$-\frac{P_t^{(n)}}{P_t^{(n-1)}}$	0
Net cash flow	0	$-\frac{P_t^{(n)}}{P_t^{(n-1)}}$	1

The implied return from investing from $t+n-1$ to $t+n$ equals $\frac{1}{P_t^{(n)}/P_t^{(n-1)}} = \frac{P_t^{(n-1)}}{P_t^{(n)}} = F_t^{(n)}$.

Log Forward Rate

Discrete forward rate $F_t^{(n)}$

$$F_t^{(n)} = F_t^{(t+n-1 \to t+n)} = \frac{P_t^{(n-1)}}{P_t^{(n)}}$$

Log forward rate $f_t^{(n)}$

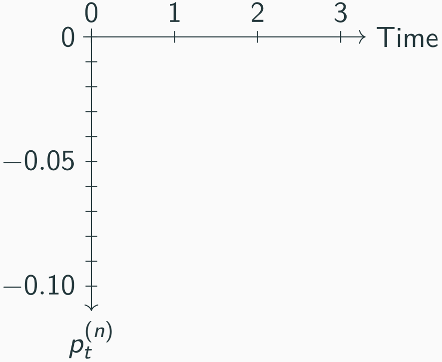
$$f_t^{(n)} = f_t^{(t+n-1 \to t+n)} = p_t^{(n-1)} - p_t^{(n)}$$

Example:

$$p_t^{(3)} = -0.15,\ p_t^{(2)} = -0.10$$
$$f_t^{(3)} = 0.05 = 5\%$$

Example

- Example: Given are prices of bonds with maturities up to three years. Calculate forward rates.
$p_0^{(1)} = -0.01$, $p_0^{(2)} = -0.03$, $p_0^{(3)} = -0.10$



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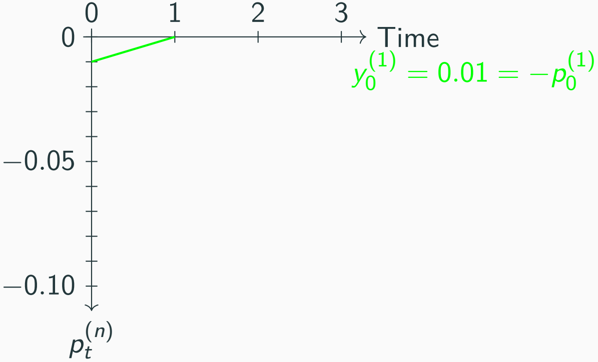

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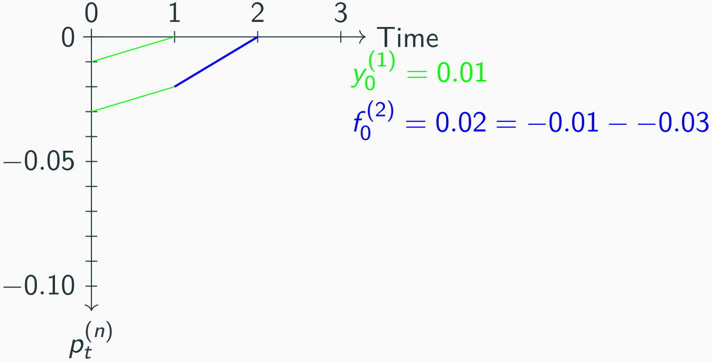

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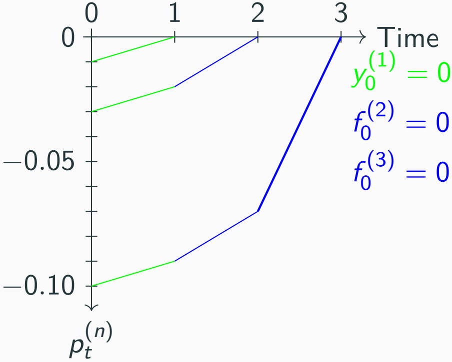


$y_0^{(1)} = 0.01$

$f_0^{(2)} = 0.02$

$f_0^{(3)} = 0.07 = -0.03 - -0.10$

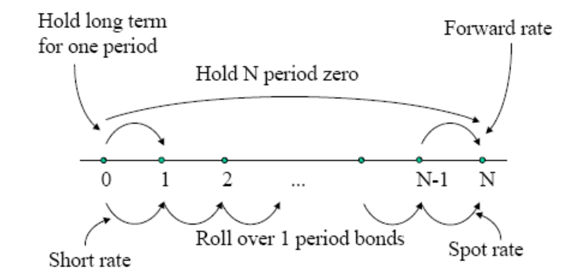
Expectations Hypothesis

- Expectations Hypothesis (the following are equivalent statements):
    a) Long maturity yield = average of expected future short rates
    b) Forward rate = expected future spot rate
    c) Expected holding period returns should be equal across maturities

$\rightarrow$ Yield curve rises if people expect short rates to be higher in the future!

Expectations Hypothesis

- Expectations hypothesis is related to the random walk for stock prices, and risk neutral arbitrageurs. Alternative ways of getting money from one date to another must have the same expected value (plus risk premium).



Term Structure

- Two ways of getting money from now (0) to N:
  1. Buy a N-year zero bond

$$r_{0,N}^{(N)} = -p_0^{(N)} = y_0^{(N)} N$$

  2. Roll over one year bonds

$$\text{Rollover} = y_0^{(1)} + y_1^{(1)} + y_2^{(1)} + \cdots + y_{N-1}^{(1)}$$

- Expected return should be the same

$$y_0^{(N)} = \mathbb{E}[y_0^{(1)} + y_1^{(1)} + y_2^{(1)} + \cdots + y_{N-1}^{(1)}] \cdot \frac{1}{N} \ (+ \text{ risk premium})$$

- Long yield = average short yields (+ risk premium)

Forward Rate

- Two ways of getting money from $N-1$ to N: lock it in now, or wait and borrow (or invest) at the future spot interest rate

$\rightarrow$ Forward rate = expected future spot rate

$$f_t^{(N)} = \mathbb{E}_t[y_{t+N-1}^{(1)}] + \text{ risk premium}$$

Forward Rate

$$Y_t^{(1)} = 1.02$$
$$Y_t^{(2)} = 1.021$$
$$Y_t^{(3)} = 1.024$$
$$Y_t^{(4)} = 1.025$$
$$Y_t^{(5)} = 1.0255$$

- According to the expectations hypothesis, what must the market expect for future one-year yields?

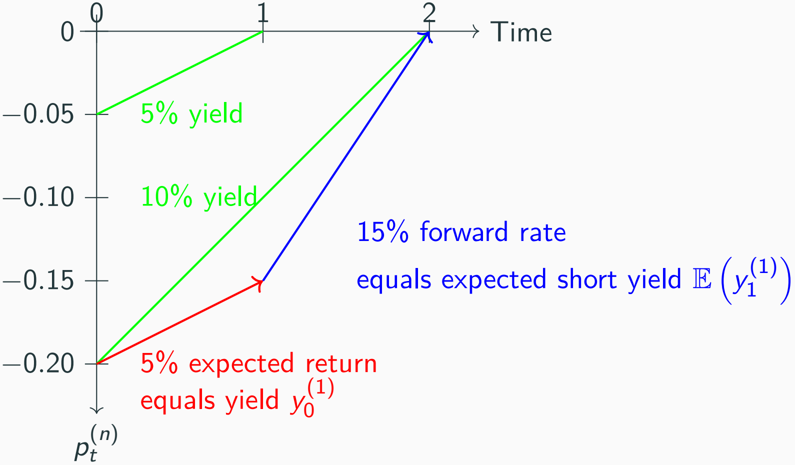
Example: Holding Period Return

- Two ways of getting money from t to $t+1$: hold a long bond with maturity N for one period, or buy a one-period bond.
- Expected holding period returns should be equal across maturities:

$$\mathbb{E}_t[r_{t,t+1}^{(N)}] = \mathbb{E}_t[r_{t,t+1}^{(1)}] \text{ (+ risk premium)}$$

- Example: One year yield = 5%. Two year yield = 10%.
  - What are the prices of a one-year and a two-year zero (in logs)?
  - Does this mean you expect to earn more on two year bonds (using the strict expectation hypothesis)?
  - What would you earn if, in contrast to the expectations hypothesis, the yield curve stays unchanged?

Example: Holding Period Return
. . . and Expectation Hypothesis (1)



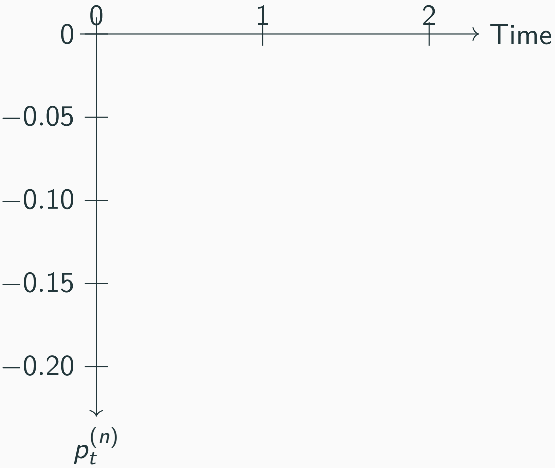
Example: Holding Period Return ... and Expectation Hypothesis (2)

- Long yield (10%) = average of expected future short yields (5%, 15%).
- The expected two year return is the same from rolling over (5% + 15%) as from holding the two year bond (20%).
- The expected one-year return is the same (5%) whether you hold the one period bond or the two period bond.
- Forward rate $= p_t^{(1)} - p_t^{(2)} = -0.05 - (-0.20) = 0.15 =$ expected rate one year out (=15%)

Example: Holding Period Return
. . . and Expectation Hypothesis (3)

- The graph emphasizes how different statements of the expectations hypothesis are equivalent.
- There is one thing we don't know ahead of time — where $p_1^{(1)}$ will end up (red triangle in the middle of the graph).
- The red and blue line is how the expectations hypothesis says things will work out.
- That's not necessarily the true expected path, and it certainly isn't the actual outcome.

Example: Holding Period Return
. . . and Expectations Failure (1)



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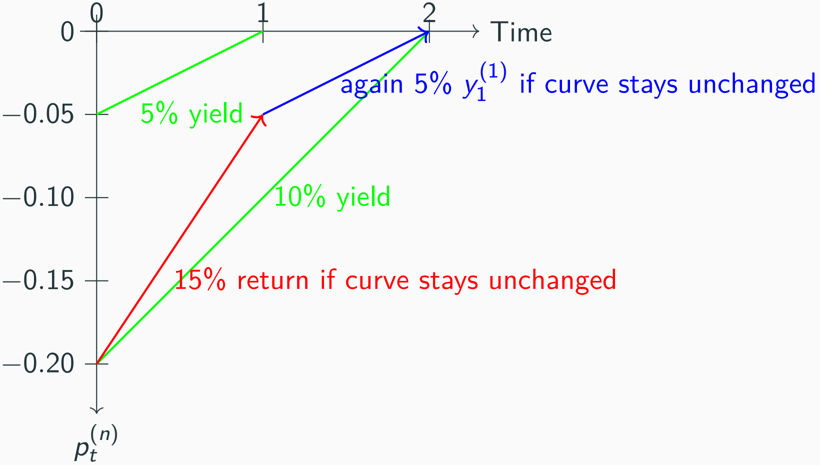


Example: Holding Period Return ...and Expectation Failure (2)

- The graph shows a variant of ‘complete’ failure of the expectation hypothesis.
- In the example, the yield curve does not change. So the price of the 1-year bond at $t+1$ (which used to be a 2-year bond at t) is the same as the 1-year bond at t.
- This is what carry traders in various asset classes ‘expect’.
- In this situation, the investor earns the forward rate not in the future, but right away!

Risk Premia

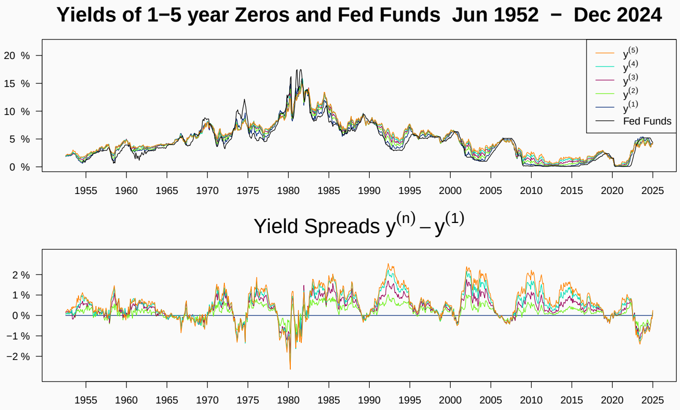
- What should we expect?
  - Think of one year holding period. It seems that the long term bond is riskier, long yields should be higher to compensate. (This is the usual idea).
  - How about a 10 year holding period? For a 10 year horizon, it seems the 10 year bond is safer. Rolling over, interest rates could rise and decline.
  - That suggests that 10 year yields should be lower — yield curves should decline on average!
  - What if variation in interest rates is all due to changes in inflation not changes in real interest rates? When inflation rises, the short term rates rise.
  - In this case, the real 10 year return is safer if you roll over nominal short term bonds (money market) rather than hold nominal 10 year bonds.

- The sign of risk premium can go either way.
- It depends on investor's horizon relative to supply of bonds, and whether real interest rates or inflation are the source of interest rate risk.
- What does theory predict:

$$\mathbb{E}_t[R^e_{t+1}] = -\gamma_t Cov[R^e_{t+1}, m_{t+1}]$$

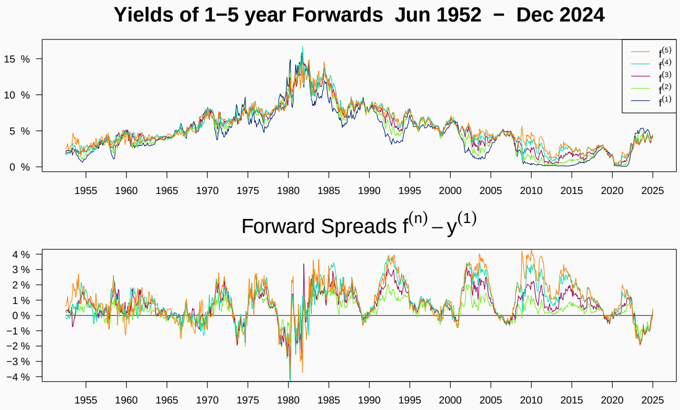
- Strict expectations hypothesis: no risk premium
- More sensible definition: risk premium is small and fairly constant over time.
- What do the data say?

Facts



Data source: Fama Bliss discount bonds obtained from WRDS.

Facts



Data source: Fama Bliss discount bonds obtained from WRDS.

Facts

- The dominant movement is “level shift” — all yields up and down together.
- The low-frequency dynamics in yields is connected to high inflation in the 1970ies and early 1980ies and subsequent reversal.
- Around the trend, there is business cycle variation in the level. This is connected to the Fed typically raising interest rates in expansions and lowering in recessions.

Facts

- The yield curve does change shape. Sometimes rising, sometimes falling. This is the "slope" factor. There is a business cycle pattern: inverted at peaks, rising at troughs.
- When the yield/forward curve is upward sloping, interest rates subsequently rise; when yield curve is inverted, interest rates do subsequently fall. The expectations hypothesis looks fairly reasonable.
- In 03-04, expectations hypothesis forecast big increases in rates. In 04 and 05 the 1 year rate did rise!

Facts

- Is there a risk premium on average?

U.S. Treasury Bond Data Jan 1964 – Dec 2024

Maturity n	1	2	3	4	5
$\mathbb{E}[y^{(n)}]$	4.89	5.07	5.24	5.39	5.50
$\mathbb{E}[y^{(n)} - y^{(1)}]$	0.00	0.18	0.35	0.50	0.60
$\mathbb{E}[r^{(n)} - y^{(1)}]$	0.00	0.35	0.67	0.95	1.02
$\sigma(r^{(n)} - y^{(1)})$	0.00	1.70	3.12	4.34	5.37
'Sharpe'	0.00	0.21	0.21	0.22	0.19

Own calculations. Data source: Fama Bliss discount bonds obtained from WRDS.

- Small average risk premium for long term bonds. But it seems small on average. Compare to the Sharpe of ≈0.5 of the stock market portfolio.

Facts

- Expectations failures – Fama Bliss (AER, 1987, pp. 680-692). Updated for 1964-2024.

	$r^{e(n)}_{t,t+1} = a + b\left(f^{(n)}_t - y^{(1)}_t\right) + \epsilon_{t+1}$			$y^{(1)}_{t+n-1} - y^{(1)}_t = a + b\left(f^{(n)}_t - y^{(1)}_t\right) + \epsilon_{t+n-1}$		
n	b	$\sigma(b)$	R^2	b	$\sigma(b)$	R^2
2	0.77	0.26	0.10	0.23	0.26	0.01
3	1.04	0.28	0.11	0.51	0.35	0.04
4	1.24	0.30	0.13	0.72	0.34	0.10
5	1.04	0.36	0.07	0.73	0.24	0.12
	forecasting *one* year returns on n-year bonds			forecasting *one* year rates from $n-1$ to n years from t		

Own calculations. Newey-West standard errors. Data source: Fama Bliss discount bonds obtained from WRDS.

Facts
Left-hand Panel

- Expectation hypothesis: $b = 0$! But $b \approx 1$! Over one year, expected excess returns on n-year bonds move one for one with the $f_t^{(n)} - y^{(1)}$ spread!
- The "fallacy of yield" seems to be right.
- Example: suppose we observe the following information:
  - One-year riskless rate $= 2\%$
  - One-year forward rate to invest 12 months from now: 3.5%.
  - One-year forward rate to invest 24 months from now: 4%.
- What is the expected return from investing over the next year in
  - a 1-year zero
  - a two year zero
  - a three year zero?
- Use the regression results from the previous slide (ignoring a).

Facts
Right-hand Panel

- Row 1
  - Expectation hypothesis: $b = 1$! But we find $b \approx 0$!
  - A forward rate 1% higher than the spot should mean that the future spot should rise. Instead it simply means that the one-year expected return of the two-year bond is 1% higher
- Lower rows
  - Expectation hypothesis now seems to work better
  - Expectation hypothesis works in the long run.

Interpretation

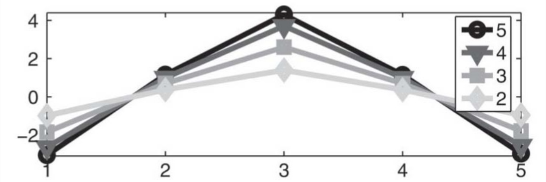
- This is like D/P that forecasts returns, not dividend growth. $f - y$ must either forecast yield changes or returns. Surprise in both cases: it is due to returns!
    - Stocks: P/D high? D should rise.
      It doesn't. "Buy yield" ("value").
    - Bonds: $f - y$ high? Yields should rise.
      They don't. "Buy yield".
- There are big risk premia and they vary over time.
    - There are times when you expect much better returns on long term bonds, and other times when you expect better returns on short term bonds. (An upward sloping yield curve results in rising rates, but not soon enough — you earn the yield in the meantime.) High expected returns happen in bad times.
    - Interpretation: Business cycle related variation in risk, expected returns. Who wants to hold long-term bonds in the bottom of a recession?

Cochrane Piazzesi

- Cochrane Piazzesi (AER, 2005, pp. 138 – 160) generalizes Fama-Bliss

$$r_{t,t+1}^{e(n)} = a^n + b_1^n y_t^{(1)} + b_2^n f_t^{(2)} + \cdots + b_5^n f_t^{(5)} + \epsilon_{t+1}^n$$

- Regressions of bond excess returns on all forward rates, not just matched $f - y$ as in Fama-Bliss (i.e. could go beyond 5 years)
- It turns out that a very similar combination of forward rates forecasts all maturities returns:



Cochrane Piazzesi

- A single factor approach:

$$r^{e(n)}_{t,t+1} = b_n \left(\gamma_0 + \gamma_1 y^{(1)}_t + \gamma_2 f^{(2)}_t + \cdots + \gamma_5 f^{(5)}_t \right) + \epsilon^{(n)}_{t+1}$$

- One common combination of forward rates, $\boldsymbol{\gamma' f_t}$ tells you where all expected returns are going at any date.
- Two-step estimation: first γ, then b:

$$\begin{aligned} \bar{r}^{e}_{t,t+1} = \frac{1}{4} \sum_{n=2}^{5} r^{e(n)}_{t+1} &= \gamma_0 + \gamma_1 y^{(1)}_t + \gamma_2 f^{(2)}_t + \cdots + \gamma_5 f^{(5)}_t + \bar{\epsilon}_{t+1} \\ &= \boldsymbol{\gamma' f_t} + \bar{\epsilon}_{t+1} \end{aligned}$$

- Then

$$r^{e(n)}_{t,t+1} = b_n \left(\boldsymbol{\gamma' f_t} \right) + \epsilon^{(n)}_{t+1}$$

Cochrane Piazzesi
Results

Table 1: Estimates of the single-factor model

Estimates of the return-forecasting factor $\bar{r}^e_{t,t+1} = \boldsymbol{\gamma}' \boldsymbol{f_t} + \bar{\epsilon}_{t+1}$

	γ_0	γ_1	γ_2	γ_3	γ_4	γ_5	R^2	$\chi^2(5)$
OLS estimates	-3.24	-2.14	0.81	3.00	0.80	-2.08	0.35	105.5

Individual bond regression

	Restricted		Unrestricted	
	$r^{e(n)}_{t,t+1} = b_n \left(\boldsymbol{\gamma}' \boldsymbol{f_t}\right) + \epsilon^{(n)}_{t+1}$		$r^{e(n)}_{t,t+1} = \beta_n f_t + \epsilon^{(n)}_{t+1}$	
n	b_n	R^2	R^2	$\chi^2(5)$
2	0.47	0.31	0.32	121.8
3	0.87	0.34	0.34	113.8
4	1.24	0.37	0.37	115.7
5	1.43	0.34	0.35	88.2

Source: Cochrane and Piazzesi (2005)

Cochrane Piazzesi

- γ's capture tent shape.
- b_n increase steadily with maturity, stretch the tent shape out.
- Restricted model almost perfectly matches unrestricted coefficients. $R^2 = 0.34 - 0.37$ up from $0.15 - 0.17$ in Fama and Bliss $\rightarrow$ a very significant rejection of $\gamma = 0$
- R^2 are almost unaffected by the single-factor restriction.
- Bottom line: it's highly significant; Expectations hypothesis is rejected, improvement on Fama Bliss is significant.
- Adding lagged forward rates improves regression results even further, i.e. the pattern suggests moving averages:

$$\bar{r}^e_{t,t+1} = a + \gamma' \left(f_t + f_{t-1} + f_{t-2} + \cdots \right) + \epsilon_{t+1}$$

Cochrane and Piazzesi Update

- Over the very recent period, the Cochrane and Piazzesi factor is not doing so well.
- It failed to predict the massive rate changes that we have witnessed over the past years.
- Strange things seem to have happened to the yield curves during the crisis!
- Huge demand since those securities could be repoed to finance other stuff.
- These developments are not captured by the Fama-Bliss or Cochrane Piazzesi factors.

Cieslak and Povala (2015)

- Cieslak and Povala (2015) decompose Treasury yields into inflation expectations and maturity-specific interest-rate cycles
  - They measure trend inflation τ_t^{CPI} as the moving weighted average over 120 months of the log change in core CPI
  - Then they regress yields on trend inflation:

$$y_t^{(n)} = a_n + b_n^{\tau} \tau_t^{CPI} + \epsilon_t$$

  - Next, they define the residual from the above regression as the maturity-specific cycle:

$$c_t^{(n)} = y_t^{(n)} - \left(\hat{a}_n + \hat{b}_n^{\tau} \tau_t^{CPI} \right)$$

- Bond excess returns can be well predicted using the short time cycle $c_t^{(1)}$ and the average cycle $\bar{c}_t = \frac{1}{19} \sum_{i=2}^{20} c_t^{(i)}$.

Cieslak Povala Results

- The first step regression $\bar{r}^e_{t,t+1} = \gamma_0 + \gamma_1 \bar{c}_t + \gamma_2 c_t^{(1)} + \epsilon_{t+1}$ works as well as using both 6 maturities of bond yields and trend inflation as regressors.
  - The estimated loading γ_2 on the short cycle $c_t^{(1)}$ is -0.61
  - The estimated loading γ_1 on the average cycle $\bar{c}_t$ is $+1.45$
- The cycle factor is the fitted value $\hat{cf}_t = \hat{\gamma}_0 + \hat{\gamma}_1 \bar{c}_t + \hat{\gamma}_2 c_t^{(1)}$
- Running regressions of individual excess returns $r^{e(n)}_{t+1}$ on the cycle factor shows that it explains excess returns of all maturities
  - Note the differences to Cochrane Piazzesi. For example, Cieslak and Povala use maturities up to 20 years, and for taking averages, they duration-standardize returns as $\bar{r}^e_{t,t+1} = \frac{1}{19} \sum_{k=2}^{20} r^{e(k)}_{t,t+1} / k$.

Cieslak Povala Results

Table 4
Predicting returns with the cycle factor

	$rx^{(2)}$	$rx^{(5)}$	$rx^{(7)}$	$rx^{(10)}$	$rx^{(15)}$	$rx^{(20)}$
A. Cycle factor						
$rx_{t+1}^{(n)} = \beta_0 + \beta_1 \widehat{cf}_t + \varepsilon_{t+1}^{(n)}$, where $\widehat{cf}_t = \hat{\gamma}_0 + \hat{\gamma}_1 c_t^{(1)} + \hat{\gamma}_2 \bar{c}_t$						
$\widehat{cf}_t$	0.62	0.68	0.70	0.73	0.74	0.72
	(3.80)	(4.64)	(4.92)	(5.16)	(5.26)	(5.06)
t-stat (SS,[5%,95%])	[1.31, 4.27]	[2.05, 4.91]	[2.38, 5.16]	[2.56, 5.38]	[2.72, 5.47]	[2.66, 5.30]
$\bar{R}^2$	0.38	0.46	0.49	0.53	0.54	0.51

Source: Cieslak and Povala (2015), Table 4

Convenience Yields

- A recent insight is that a safe asset earns a convenience yield.
- Under this view, the price of the safe asset is

$$P_t = \mathbb{E}_t[PV_t(cashflow)] + \mathbb{E}_t[PV_t(serviceflow)]$$

  - A safe asset preserves value and is liquid in bad times. It can also be used as collateral. Thus, it gives its owner not only future cash flows, but also services.
- This means that such a a bond pays a yield *lower* than the risk-free rate!

U.S. Treasuries and Convenience Yields

- U.S. Treasury bonds are considered the world's safe asset. Thus, they earn a convenience yield.
- In addition, their safe asset status allows the government to pay back maturing bonds with freshly printed ones indefinitely – as long as $r < g$.
- Further, timing is also favorable for the issuer of the safe asset: In bad times, its price $\uparrow$ (hence, yield $\downarrow$), so it allows the government to do fiscal stimulus at low cost.
- *Current debate about the safe asset status of U.S. treasuries.* Why? What could be likely effects on the term spread? What about European government bonds?