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The term structure of returns: Facts and theory☆

Jules H. van Binsbergen[a,b,*], Ralph S.J. Koijen[a,c,d,*]

[a] The Wharton School, University of Pennsylvania, 3620 Locust Walk, Philadelphia, PA 19104, United States
[b] National Bureau of Economic Research, United States
[c] Stern School of Business, New York University, 44 West 4th Street, New York, NY 10012, United States
[d] National Bureau of Economic Research, United States, and Center for Economic and Policy Research

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ABSTRACT

We summarize and extend the new literature on the term structure of equity. Short-term equity claims, or dividend strips, have higher average returns and Sharpe ratios than the aggregate stock market. The returns on short-term dividend claims are risky as measured by volatility, but safe as measured by market beta. These facts are hard to reconcile with traditional macro-finance models and we provide an overview of new models that can reproduce some of these facts. We relate our evidence on dividend strips to facts about other asset classes such as nominal and corporate bonds, volatility, and housing. We discuss the broader economic implications of our findings by linking the term structure of returns to real economic decisions such as hiring and investment. We conclude with an outline of empirical and theoretical extensions that we consider interesting avenues for future research.

1. Introduction

The discounted value of future cash flows plays a central role in financial and real investment decisions. As initially pointed out by Brennan (1998), observing assets that pay off a single dividend of a stock index at a future point in time could help to promote rational pricing. Building on these insights, a literature has developed in recent years to measure the term structure of equity. In this paper, we review and extend this literature and discuss both the empirical facts as well as the theoretical explanations that have been proposed. We also connect the properties of the term structure of equity to term structures in other asset classes such as nominal and corporate bonds, volatility, and housing.

Initial measurements of the term structure of equity are based on portfolios of stocks with different cash-flow growth rates and risk properties, see Cornell (1999), Dechow, Sloan and Soliman (2004), Bansal, Dittmar and Lundblad (2005), Lettau and Wachter (2007), Hansen, Heaton and Li (2008), and Da (2009). An important motivation for this literature is the value premium, which refers to the empirical fact that stocks with low market-to-book ratios have higher average returns than stocks with high market-to-book ratios, despite having similar Capital Asset Pricing Model (CAPM) betas. If the cash flows of value stocks have different average growth rates and risk expo-

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* Corresponding authors.
E-mail addresses: julesv@wharton.upenn.edu (J.H. van Binsbergen), rkoijen@stern.nyu.edu (R.S.J. Koijen).

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sures than the cash flows of growth stocks, then comparing the returns on value and growth stocks can indeed be informative about the term structure of equity.

Instead of relying on the cross-section of stock returns and additional assumptions about the dynamics of cash flows and preferences, Binsbergen, Brandt and Koijen (2012, BBK) provide the first direct measurement of dividend strip prices using options data. Binsbergen, Hueskes, Koijen and Vrugt (2013, BHKV) extend this evidence using dividend futures, which were introduced around the turn of the millennium for the Standard and Poor's (S&P) 500, Eurostoxx 50, and the Nikkei 225 indexes. A long position in a dividend futures contract implies that in exchange for a known payment due in n years from now, one receives the dividends paid on the underlying index over the year leading up to the settlement. For the Eurostoxx 50 index, dividend futures are exchange traded since 2008. They allow for direct measurement of dividend strip prices without the need for high-frequency data for options and the stock index. A second important advantage is that dividend futures have longer maturities of up to ten years, although the liquidity declines for the longest maturities. The maximum maturity for options is about three years.

BHKV use dividend futures prices to define equity yields as:

$$ey_{t,n} \equiv \frac{1}{n}\ln(D_t/F_{t,n}) = \theta_{t,n} - g_{t,n}, \qquad (1)$$

where $F_{t,n}$ is the $n-$period dividend futures price and D_t the level of dividends at time t. The equity yield, $ey_{t,n}$ contains a risk premium component $\theta_{t,n}$, which equals the expected log return on a dividend futures contract with maturity n, and a component that reflects expected log dividend growth, $g_{t,n}$. BHKV show that both risk premia and expected growth rates fluctuate over time, and that risk premia are countercyclical. The expected growth component $g_{t,n}$ is useful for predicting future dividends, gross domestic product (GDP) growth, and consumption growth, over and above the predictive power of nominal and real bond yields.

In this paper, we first extend the sample of BHKV in the time series dimension as well as cross-sectionally by adding evidence from the UK (the FTSE 100 index). Using this extended sample, we document three key facts in the data:

1. Both risk premia and Sharpe ratios are higher for short-maturity claims than for the aggregate stock market. If we form a world portfolio of dividend strips by averaging across the four markets for which data exist, the difference in risk premia between this portfolio and a portfolio of index returns is statistically significantly positive at conventional significance levels. The results are strongest for the most liquid market, which is the Eurostoxx 50. The difference is statistically insignificant for the Nikkei 225, the FTSE 100, and the S&P500 individually, the latter of which is consistent with the findings in BBK.
2. The returns on short-term dividend claims are risky as measured by volatility, but safe as measured by market betas. The volatility of dividend strip returns is as high, if not higher, than the volatility of market returns. However, the market betas are well below one and increasing with maturity.
3. The volatility of equity yields is downward-sloping with maturity.

The high volatility of dividend strip returns and the low correlation with the market implies that we have relatively little power to reject the null that dividend strip returns are on average higher than market returns. To gain power, we pool data across indexes and across short-term maturities, leading to statistically significant outperformance of short-maturity dividend strips over index returns.

In the second part of this paper, we discuss tests of the leading macro-finance models that have been successful at explaining many facts about asset markets, including the equity risk premium, excess volatility, and both the level and volatility of the risk-free rate. We propose new tests of these models.[1]

In particular, we compute the average return of dividend strips minus the average return on the aggregate stock market in the data. Next, for each of the models, we simulate samples of the same length as our data and we compute the same statistic for each of the samples. We then plot the distribution of this statistic under the Null that a model is correctly specified. This test shows that it is unlikely that the data are generated by these models.

As a second test, we compute the volatility of equity yields in the data and we provide a comparison to the Campbell and Cochrane (1999) model for illustration. The volatility of equity yields is much higher in the data than in the model. As we measure volatilities more precisely than average returns, this provides a powerful rejection of the model. We also consider an extension of the Campbell and Cochrane (1999) model by allowing dividend growth to be predictable. However, given that short-term risk premia are virtually constant in the model, all variation in equity yields has to be due to expected growth rates. Given the amount of (excess) volatility in short-term equity yields, this implies that dividend growth is almost perfectly predictable, which is counterfactual; see, for instance, Cochrane (2008) and Binsbergen and Koijen (2010).

The third part of the paper extends the empirical evidence across different asset classes, such as Treasuries, corporate bonds, and options (straddles). The idea to use data from multiple asset classes as "out-of-sample" evidence has been used recently by Asness, Moskowitz and Pedersen (2013), Mowkowitz, Ooi and Pedersen (2012), and Koijen, Mowkowitz, Pedersen and Vrugt (2017) in the context of other asset pricing anomalies such as value, momentum, and carry. We find in all asset classes that Sharpe ratios decline with maturity, consistent with the first fact for the term structure of equity. These facts may help in thinking about the credit spread puzzle as well as the determinants of term and variance risk premia.

[1] Lettau and Wachter (2007) provide evidence inconsistent with the Campbell and Cochrane (1999) model, while BBK provide additional evidence that challenges the models of Campbell and Cochrane (1999), Bansal and Yaron (2004), and the rare disaster models of Gabaix (2012) and Wachter (2013).

This leaves us with the question of what the economic interpretation of these new facts is.[2] Lettau and Wachter (2011) are the first to propose a model for the term structure of equity and both nominal and real bonds. An active new literature proposes new equilibrium asset pricing models to explain these findings. In the final part of this paper, we summarize the different mechanisms proposed in these models. The modifications involve changes in the dynamics of cash flows, preferences, or departures from the representative agent model by introducing interesting forms of heterogeneity. We discuss a variety of papers in each of these categories in Section 5.

We conclude this paper by a discussion of interesting avenues for future research using data on the term structure of equities.

2. Facts and new evidence about the term structure of dividend strips

BBK find that short-term dividend strips have performed well over the sample period from 1996 to 2009 relative to the predictions of several leading asset pricing models, which predict a risk premium for short-term strips close to zero. In addition, BBK document that even relative to the index, dividend strips have performed well, suggesting that the risk premium on dividend strips could even be higher than the equity risk premium. This raises the possibility that the term structure of the equity risk premium is downward-sloping for at least part of the maturity space. They further find that CAPM betas of short-term dividend strips are low and around 0.5. As a consequence, relative to commonly used asset pricing models, dividend strips seem to provide attractive Sharpe ratios and alphas. Finally, and perhaps most importantly, BBK find that dividend strip prices are very volatile relative to their subsequent dividend realizations, implying that "excess" volatility also occurs at the short end of the maturity spectrum for stocks, extending the seminal work of Shiller (1981).

2.1. Data

We start this section by extending the findings of BBK using dividend futures prices from four different regions: (1) Europe as represented by the Eurostoxx 50 index (SX5E), (2) Japan as represented by the Nikkei 225 index (NKY), (3) the UK as represented by the FTSE 100 index (FTSE), and finally (4) the US as represented by the S&P500 index (SPX).

We use constant-maturity dividend futures contracts with maturities of one, two, five, and seven years between 2002 and 2014 for continental Europe and the US, between 2003 and 2014 for Japan, and between 2006 and 2014 for the UK.[3] The data are provided by BNP Paribas and Goldman Sachs, which are major players in the dividend futures market. We observe the dividend futures prices at a daily frequency and observe the quoted price and we do not have information on bid-ask spreads. Table E.1 summarizes the dividend futures contracts for which we have data, together with the starting dates for each of the series.

To compute monthly dividends, we obtain monthly index level and total return data from Bloomberg. Cash dividends are then computed as the difference between the return with distributions and the return without, multiplied by the lagged value of the index.

2.2. Computing the term structure of dividend returns

First, we compute constant-maturity dividend future returns. That is, we compute the monthly return on dividend futures of each maturity n, where n is measured in months. Due to the annual issuing cycle, consecutive maturities are 12 months apart. The return is given by:

$$R^F_{t,n} = F_{t,n-1}/F_{t-1,n} - 1. \tag{2}$$

We then form a weighted average of two consecutive maturities to arrive at a constant-maturity return strategy with maturities that are 12 months apart. For example, if in a given month the maturities of the dividend futures contracts are $n = 5$ months, 17 months, 29 months, ..., then we simply take a weighted average between returns on these futures contracts with weights equal to 0.4167 and 0.5833 to construct the 12-month, 24-month, 36-month, ..., constant-maturity returns in that month.

To gain power in our tests, we also form an equal-weighted portfolio of short-term constant-maturity dividend futures returns,

$$R^F_{t,P} \equiv \frac{R^F_{t,12} + R^F_{t,24} + R^F_{t,36} + R^F_{t,48} + R^F_{t,60}}{5}. \tag{3}$$

Note that dividend futures returns are already excess returns. They are in excess of the corresponding government (default-free) bond returns of the same maturity (BHKV). Investors in dividend futures contracts thus forgo the bond risk premium. This provides an important advantage when studying the compensation for dividend risk across different maturities. Dividend futures prices allow us to separate out the risk and risk premiums for time-varying dividends and our measurement is not contaminated by the risk premium that would have accumulated had dividend payments been constant, that is, the bond risk premium.

As a point of reference, we also include the return on the underlying index returns, which, through the present-value relationship, is a weighted average of dividend strip returns of all maturities. To be consistent with dividend futures contracts which forgo the corresponding bond return, we also need to adjust the aggregate index by its corresponding bond return. We show in Appendix A that (up to a first-order approximation) the return on the index, denoted by R^M_t, can be written as the return on a portfolio of

[2] The model proposed by Lettau and Wachter (2007) is consistent with many of the facts we find for equities: the average returns, Sharpe ratios, and volatilities are downward-sloping with maturity, while the CAPM beta of short-term dividend assets is well below one. However, instead of specifying preferences, Lettau and Wachter (2007) directly specify the stochastic discount factor.

[3] Due to the fact that all contracts mature in December, and due to the fact that very close to the maturity we no longer have data on the contract (it arguably stops trading when all the dividends are already announced and price changes are negligible), the 1-year contract is strictly speaking a 1.25-year contract. For ease of exposition, we will refer to it as a 1-year contract from here onwards.

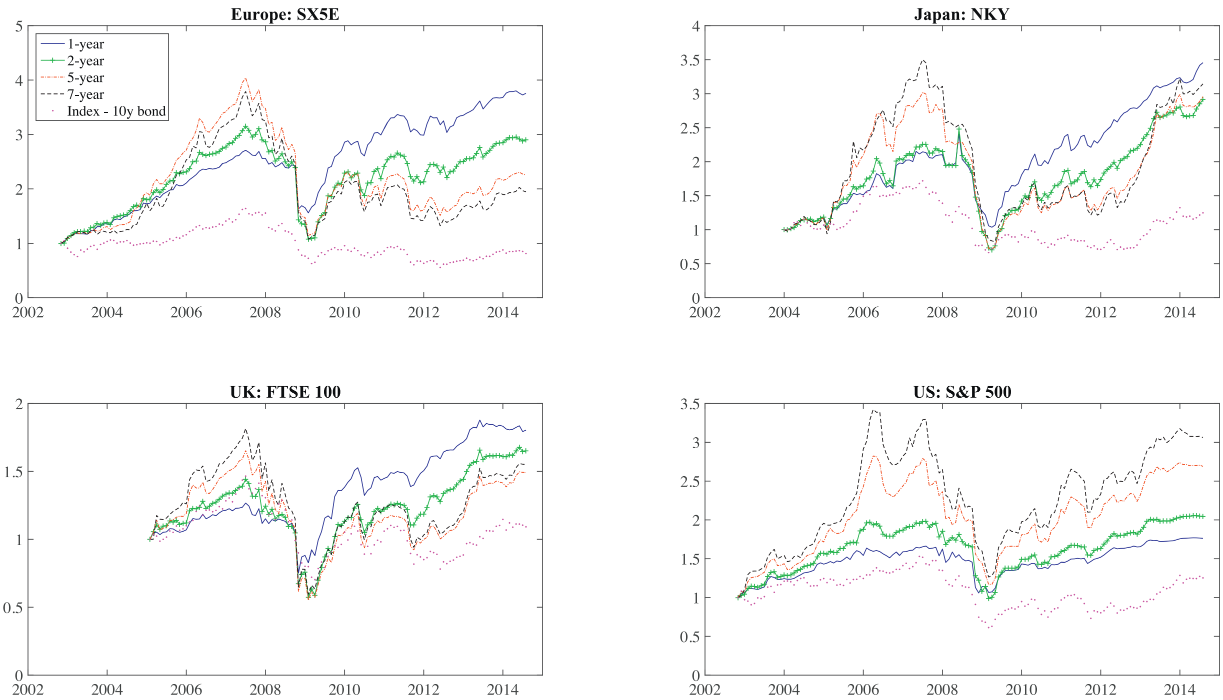

Fig. 1. The four panels in the figure display the cumulative performance of constant maturity dividend futures contracts with maturities of one, two, five, and seven years between 2002 and 2014 for the Europe and the US, between 2003 and 2014 for Japan, and between 2006 and 2014 for the UK. Dividend futures returns are excess returns in excess of their corresponding constant maturity zero-coupon bond return. As a comparison we also plot the performance of the index in excess of the long-term (10-year) bond return.

dividend futures returns plus the return on a portfolio of bonds:

$$R_t^M \approx \sum_{n=1}^{\infty} w_{t-1,n} R_{t,n}^F + \sum_{n=1}^{\infty} w_{t-1,n} R_{t,n}^B, \tag{4}$$

where the weights $w_{t,n}$ are given by:

$$w_{t,n} = \frac{P_{t,n}}{S_t}$$

and S_t is the index level, which by no arbitrage is given by:

$$S_t = \sum_{n=1}^{\infty} P_{t,n}.$$

Given the long duration of stocks, we simply approximate the portfolio of bond returns (that is, the second term in (4)) by the 10-year (120-month) constant-maturity bond return, but arguably even longer maturities could be considered as well.[4] The long-term-bond-adjusted market return, $R_{B,t}^M$ is then given by:

$$R_{B,t}^M \equiv \frac{1 + R_t^M}{1 + R_{t,120}^B} - 1, \tag{5}$$

which corresponds to the basket of dividend futures returns.

Using a similar logic, we then use these dividend futures returns to construct dividend spot returns. Let $P_{t,n}$ denote the spot price of a dividend claim that matures in n periods. Then spot and futures prices are linked by the standard no-arbitrage condition:

$$F_{t,n} = P_{t,n} \exp\left(n y_{t,n}\right). \tag{6}$$

Let $R_{t,n}^B$ denote the one-month return at time t of a bond with maturity n, given by:

$$R_{t,n}^B = \frac{\exp\left((n-1) y_{t,n-1}\right)}{\exp\left(n y_{t-1,n}\right)} - 1. \tag{7}$$

The no-arbitrage relationship in (6) implies that the dividend spot return $R_{t,n}^S$ can be computed as:

$$R_{t,n}^S = \frac{P_{t,n-1}}{P_{t-1,n}} - 1 = (1 + R_{t,n}^F)(1 + R_{t,n}^B) - 1. \tag{8}$$

We then also form a portfolio of short-term dividend spot contracts using the first five maturities:

$$R_{t,P}^S \equiv \frac{R_{t,12}^S + R_{t,24}^S + R_{t,36}^S + R_{t,48}^S + R_{t,60}^S}{5}. \tag{9}$$

2.3. Results

Fig. 1 plots the cumulative return on constant-maturity dividend futures contracts with maturities of one, two, five, and seven years. For all four regions, dividend strips have performed well suggesting that short-term dividend risks earn a large positive risk premium. As argued above, this finding was first documented by BBK for the US using options data between 1996 and 2009 and seems challenging for many leading asset pricing models. The results in Fig. 1 are consistent with this finding. For all regions and

[4] For the sample period we consider, picking a longer-maturity bond would lower the relative performance of the index.

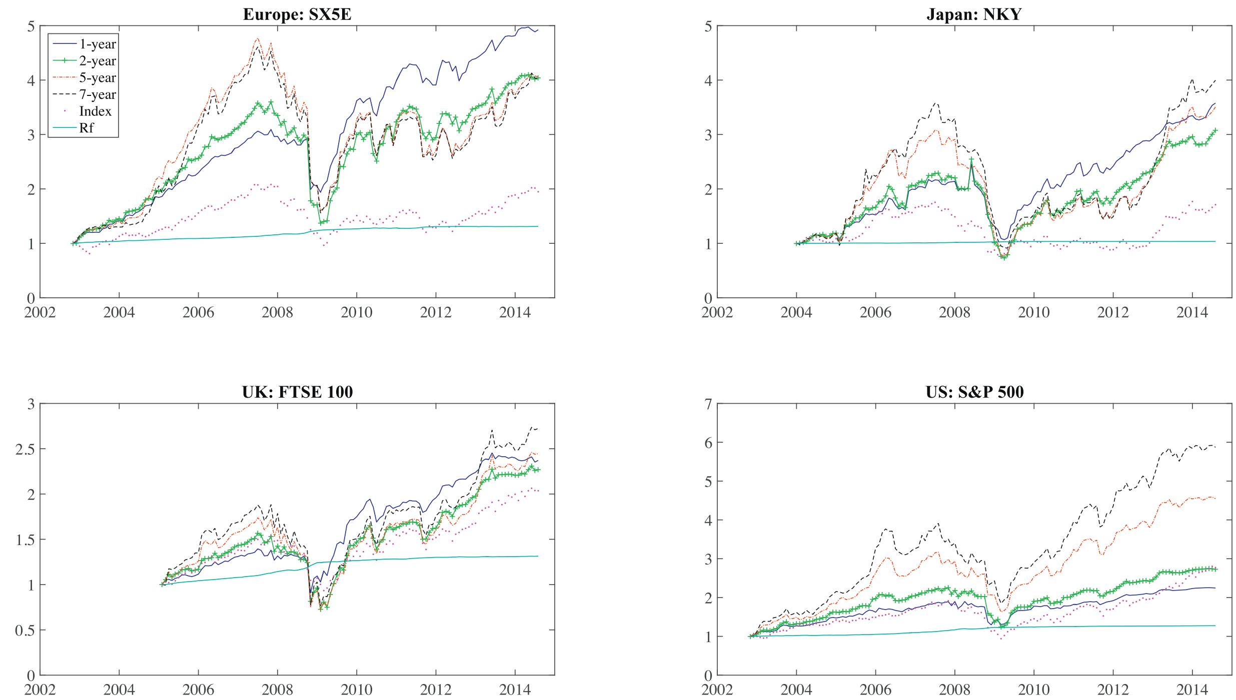

Fig. 2. The four panels in the figure display the cumulative performance of constant-maturity dividend spot contracts (i.e., dividend futures contract returns plus the corresponding zero-coupon bond return) with maturities of one, two, five, and seven years between 2002 and 2014 for the Europe and the US, between 2003 and 2014 for Japan, and between 2006 and 2014 for the UK. As a comparison we also plot the cumulative performance of the index as well as the performance of the risk-free rate as proxied for by the constant maturity 1-year bond return.

for all four maturities, dividend futures have outperformed their corresponding index. The findings in BBK therefore do not seem to be a US-specific finding and hold across all four regions.

Due to the limited maximum maturity of index options, BBK only compute dividend strip returns for very short-term maturities and compared the average returns of 1.3–1.8 year dividend strips to those of the index, providing only two points along the maturity spectrum, the short-term (1.3–1.8 year dividend strips) and the long-term (the index). Now that we have dividend futures data available for various maturities and regions, we can also compare the average returns of dividend futures contracts of various maturities. By comparing the four graphs in Fig. 1, it becomes clear that given the available sample, not one consistent pattern arises, and averaging across the regions, the term structure appears pretty flat over the first five years.

One may also be interested in how dividend spot contracts perform. We add to each dividend futures return the corresponding zero-coupon bond return (and thus the estimated bond risk premium of that maturity over the sample period). The results are plotted in Fig. 2. As a comparison we also plot the return on the corresponding index, as well as the return on the risk-free rate. We include the cumulative performance on the risk-free rate because the risk-free return is close to the average return predicted for short-maturity dividends by two of the three leading asset pricing models we consider. The results are generally very similar to those of dividend futures contracts. The performance of the index relative to the dividend spot contracts improves somewhat, but with the exception of the 1-year contract in the US, the index still matches or underperforms dividend spot contracts of all maturities across all regions. For maturities longer than one year, the futures contract is fully exposed to dividend risk. By comparing Figs. 1 and 2, it becomes clear that even though the S&P500 index has performed very well recently in absolute terms, it has not performed that well when compared to long-term bonds, suggesting that the average recent good performance of the index is not a compensation for dividend risk, but rather a reflection of very low long-term risk-free discount rates.

In Table 1, we summarize the properties of dividend futures returns, including their mean, standard deviation, and Sharpe ratio. The Sharpe ratios for each of the indexes are lower than for their corresponding short-term dividend strips for all four regions, consistent with the downward-sloping pattern of risk premia.

BBK document that US dividend strips exhibit excess volatility, that is, dividend futures prices move more than their corresponding dividend realizations. In Fig. 3 we plot for each of the four regions the 2-year dividend futures price against the corresponding annual dividend realization two years later, that is, we plot the dividend realization in year $t+2$ at time t in the graph so that the eventual dividend realization for the contract is lined up with the dividend futures price at time t. The graph shows that for all four regions, the dividend futures prices are more volatile than their corresponding dividend realization, illustrating that dividend futures exhibit excess volatility. Also, the graph shows that, on average, the dividend fu-

Table 1
We summarize the average return, standard deviation, and Sharpe ratio of dividend strip returns across maturities of one to seven years, and regions: Europe, Japan, the United Kingdom, and the United States.

Maturity in years	1	2	3	4	5	6	7	Index - 10y bonds
Europe: SX5E (Nov 2002 - Jul 2014)								
mean	0.0104	0.0097	0.0085	0.0082	0.0085	0.0079	0.0075	0.0004
stdev	0.0420	0.0624	0.0689	0.0708	0.0713	0.0719	0.0721	0.0600
Sharpe	0.2478	0.1556	0.1239	0.1152	0.1200	0.1096	0.1046	0.0060
Japan: NKY (Jan 2003 - Jul 2014)								
mean	0.0109	0.0107	0.0107	0.0115	0.0115	0.0119	0.0124	0.0056
stdev	0.0541	0.0701	0.0738	0.0772	0.0771	0.0809	0.0821	0.0609
Sharpe	0.2025	0.1526	0.1450	0.1489	0.1490	0.1473	0.1511	0.0914
UK: FTSE (Jan 2005 - Jul 2014)								
mean	0.0063	0.0065	0.0062	0.0063	0.0065	0.0067	0.0072	0.0020
stdev	0.0457	0.0610	0.0675	0.0703	0.0729	0.0746	0.0775	0.0498
Sharpe	0.1367	0.1059	0.0916	0.0893	0.0894	0.0900	0.0933	0.0405
US: SPX (Nov 2002 - Jul 2014)								
mean	0.0046	0.0059	0.0067	0.0072	0.0084	0.0090	0.0095	0.0031
stdev	0.0333	0.0405	0.0482	0.0496	0.0513	0.0544	0.0559	0.0546
Sharpe	0.1383	0.1464	0.1390	0.1453	0.1633	0.1645	0.1707	0.0568

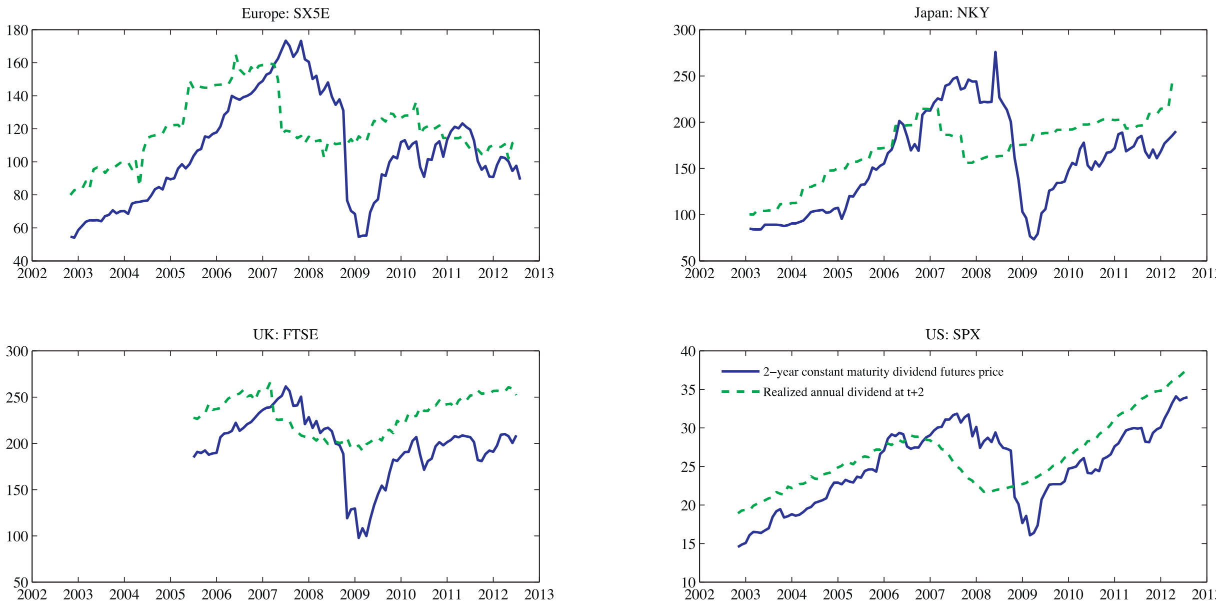

Fig. 3. The four panels in the figure display the 2-year constant maturity dividend futures price and plot it against the realized annual dividend two years later for all four regions.

tures price is substantially lower than the corresponding realization, illustrating once again that short-term dividend risk carries a large risk premium. The graph also illustrates that during the crisis, a long position in dividend futures experienced large losses.

In Fig. 4, we summarize the CAPM betas relative to their own market index for each region for each of the seven maturities, as well as for the strategy that goes long the index and short the 10-year bond. The graph shows a consistent pattern across the four regions. CAPM betas for short-maturity dividend futures contracts are low and around 0.5 and for longer maturities these CAPM betas gradually converge to a CAPM beta of one. Note that the strategy that goes long the index and short the 10-year bond has a CAPM beta slightly higher than one for all four regions over this sample period.

Finally, we use the dividend futures and spot returns to test a variety of hypotheses regarding the slope of the term structure of the equity risk premium. The results are summarized in Table 2. We test whether various portfolios of dividend futures and spot returns outperform their corresponding index returns. We focus on one-sided tests as the leading theoretical models that we discuss in Section 3 all imply that the term structure of expected returns is increasing with maturity, implying that the average return on the market exceeds the average return on the portfolio of short-term dividend claims.

The table shows that for the Eurostoxx 50 index, we can reject the null hypothesis that average dividend futures returns are lower or equal than the corresponding average index return. For spot returns, we can also reject the null that the 1-year and 2-year average dividend strip returns are lower or equal than those of the index. This implies

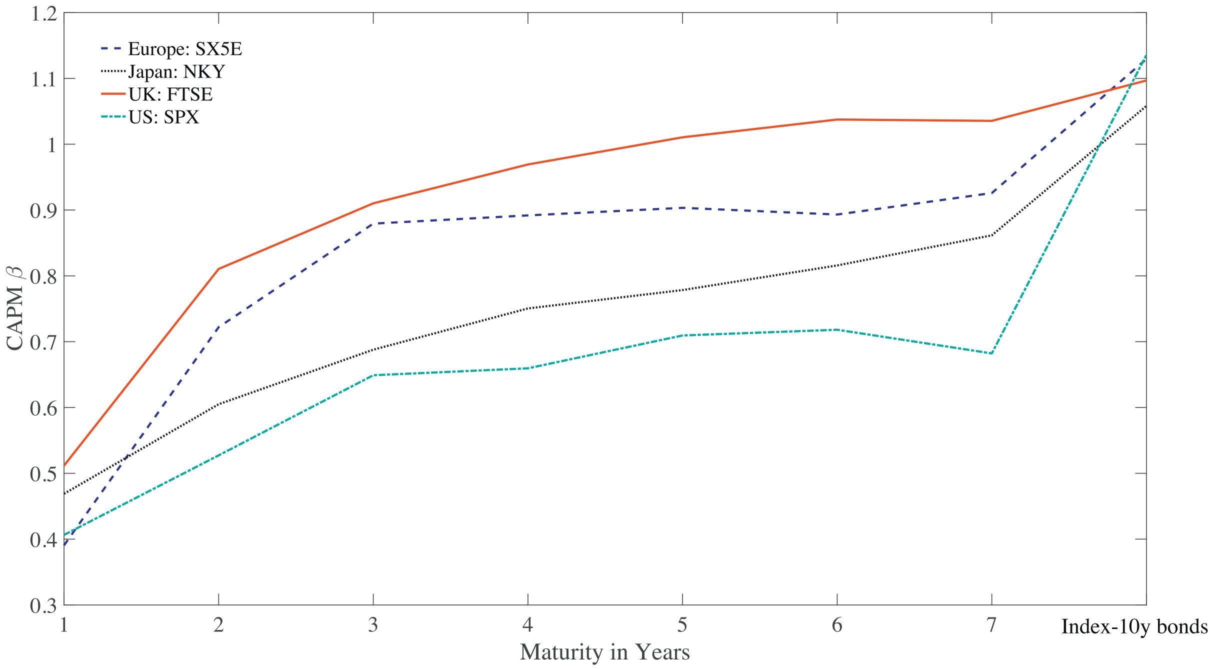

Fig. 4. The graph plots the unconditional CAPM betas for dividend futures for all seven maturities, as well as for the strategy that goes long in the index and short in the 10-year bond. Each line represents one of the four regions.

Table 2
The table provides point estimates as well as one-sided *p*-values (using HAC standard errors) for each of the Null hypotheses listed in the first column.

	Europe		Japan		UK		US		World	
	Estimate	*p*-value	Estimate	*p*-value	Estimate	*p*-value	Estimate	*p*-value	Estimate	*p*-value
Null hypothesis Dividend futures monthly returns										
$E[R^F_{t,12} - R^M_{t,B}] = 0$	0.0101	0.0064	0.0054	0.1417	0.0043	0.1637	0.0015	0.3314	0.0059	0.0439
$E[R^F_{t,24} - R^M_{t,B}] = 0$	0.0094	0.0089	0.0051	0.1638	0.0044	0.1111	0.0028	0.1724	0.0061	0.0282
$E[R^F_{t,36} - R^M_{t,B}] = 0$	0.0082	0.0178	0.0051	0.1593	0.0042	0.1093	0.0036	0.1288	0.0059	0.0304
$E[R^F_{t,48} - R^M_{t,B}] = 0$	0.0078	0.0254	0.0059	0.1221	0.0043	0.0926	0.0041	0.1182	0.0062	0.0273
$E[R^F_{t,60} - R^M_{t,B}] = 0$	0.0082	0.0276	0.0059	0.1358	0.0045	0.0814	0.0053	0.0678	0.0068	0.0231
Portfolio $E[R^F_{t,P} - R^M_{t,B}] = 0$	0.0087	0.0092	0.0055	0.1261	0.0043	0.0879	0.0035	0.1353	0.0062	0.0199
Dividend spot monthly returns										
$E[R^S_{t,12} - R^M_t] = 0$	0.0063	0.0336	0.0038	0.2090	0.0016	0.3177	−0.0018	0.7485	0.0030	0.1390
$E[R^S_{t,24} - R^M_t] = 0$	0.0060	0.0427	0.0036	0.2310	0.0021	0.2384	−0.0002	0.5285	0.0035	0.0949
$E[R^S_{t,36} - R^M_t] = 0$	0.0053	0.0644	0.0039	0.2165	0.0024	0.2151	0.0012	0.3243	0.0038	0.0862
$E[R^S_{t,48} - R^M_t] = 0$	0.0055	0.0663	0.0049	0.1589	0.0030	0.1632	0.0022	0.2299	0.0046	0.0603
$E[R^S_{t,60} - R^M_t] = 0$	0.0065	0.0513	0.0051	0.1641	0.0037	0.1193	0.0039	0.1126	0.0056	0.0389
Portfolio $E[R^S_{t,P} - R^M_t] = 0$	0.0059	0.0351	0.0043	0.1752	0.0026	0.1755	0.0011	0.3401	0.0041	0.0568

that, despite the fact that the bond risk premium is increasing with maturity, we still find that the average total return on short-term dividend strips is statistically significantly higher than the total return of the index.

In terms of statistical significance, the results for the other indexes individually are weaker than those of the Eurostoxx 50 index. As argued before, because dividend strips and futures returns are risky, we have relatively little power to reject the Null over the short data sample that we have. However, if we pool data across the first five maturities and across the four regions, we still find strong evidence that the term structure of the equity risk premium is downward-sloping, with a *p*-value of 0.020 for dividend futures returns and 0.057 for dividend spot returns.

3. Macro-finance models and the term structure of dividend strips

In this section we summarize the theoretical implications of leading macro-finance models for dividend strip returns. As a point of reference, we start with the canonical consumption CAPM.

3.1. Consumption CAPM

We start from the most basic consumption CAPM as proposed by Lucas (1978), where the preferences of the representative agent are

$$\max \sum_{s=0}^{\infty} E_t(\beta^s u(C_{t+s})), \tag{10}$$

where $u(x) = x^{1-\gamma}/(1-\gamma)$. Consumption growth is assumed to be identically and independently distributed (i.i.d.) and given by:

$$\Delta c_{t+1} = \mu_c + \sigma_c \epsilon_{c,t+1}. \tag{11}$$

Dividends are a levered claim on consumption, $D_t = C_t^{\lambda}$, where $\lambda > 1$. The price of dividend strips in this case is given by:

$$P_{t,n} = E_t(M_{t:t+n} D_{t+n}) = \phi_n D_t, \tag{12}$$

where $M_{t:t+n} = \beta^n (C_{t+n}/C_t)^{-\gamma}$ denotes the n–period stochastic discount factor and ϕ_n a constant that depends on maturity. The expected geometric return for strips of all maturities is constant.

However, the consumption CAPM fails in important dimensions, such as the equity risk premium, the dynamics of the risk-free rate, and excess volatility. To address these shortcomings, three key models have been proposed that are successful at reconciling these puzzles. We briefly discuss each of these models and summarize their predictions for risk premia, Sharpe ratios, and volatilities of dividend strips. More detailed calculations can be found in BBK.

3.2. External habit formation: Campbell and Cochrane (1999)

Campbell and Cochrane (1999) modify the preferences in (10) to external habit formation preferences. As consumption falls, the ratio of marginal utility in period t to marginal utility in period $t-1$ increases, and risk premia rise accordingly. However, long-term dividend strips are more sensitive to discount rate shocks and risk premia. Sharpe ratios and volatilities are therefore upward-sloping with maturity, keeping the holding period fixed.

In the model, the stochastic discount factor is given by:

$$M_{t+1} = \delta \exp(-\gamma \bar{g}) e^{-\gamma(s_{t+1}-s_t+v_{t+1})}, \tag{13}$$

where $\bar{g}$ represents log average consumption growth, γ is the curvature parameter, v_{t+1} is unexpected consumption growth, and s_t is the log consumption surplus ratio whose dynamics are given by:

$$s_{t+1} = (1-\phi)\bar{s} + \phi s_t + \lambda(s_t) v_{t+1}. \tag{14}$$

$\lambda(s_t)$ is the sensitivity function that is chosen such that the risk-free rate is constant. Using the dynamics of the log consumption surplus ratio, we can rewrite the stochastic discount factor as follows (see Campbell and Cochrane (1999) for further details):

$$M_{t+1} = \delta \exp(-\gamma \bar{g}) e^{-\gamma((1-\phi)\bar{s}+(\phi-1)s_t+[1+\lambda(s_t)]v_{t+1})}. \tag{15}$$

Dividend growth in the model is given by:

$$\Delta d_{t+1} = \bar{g} + w_{t+1}. \tag{16}$$

We solve the model using the solution method described in Wachter (2005). Let $P_{t,n}$ denote the price of a dividend at time t that is paid n periods in the future. Let D_{t+1} denote the realized dividend in period $t+1$. The price of the first dividend strip is simply given by:

$$P_{t,1} = E_t(M_{t+1} D_{t+1}) = D_t E_t\left(M_{t+1} \frac{D_{t+1}}{D_t}\right). \tag{17}$$

The following recursion then allows us to compute the remaining dividend strips:

$$P_{t,n} = E_t(M_{t+1} P_{t+1,n-1}). \tag{18}$$

The (spot) return on the n^{th} dividend strip is given by:

$$R_{t,n}^S = \frac{P_{t,n-1}}{P_{t-1,n}} - 1. \tag{19}$$

Because the interest rate is constant in the model, bond returns of all maturities are equal to the risk-free rate R_f:

$$R_{t,n}^B = R_f, \tag{20}$$

and hence, futures returns $R_{t,n}^F$ are computed as:

$$R_{t,n}^F = \frac{1 + R_{t,n}^S}{1 + R_f} - 1. \tag{21}$$

We simulate 1,000 samples of 146 months from the model and compute $R_{t,P}^F$ (the return on an equal-weighted portfolio of dividend futures with maturities of one, two, three, four, and five years), $R_{t,P}^S$ (the return on an equal-weighted portfolio of dividend spot contracts with maturities of one, two, three, four, and five years), R_t^M (the return on the market portfolio), and $R_{t,B}^M$ (the return on the market portfolio minus the 10-year bond return).

Panel A of Table 3 summarizes the distribution of the sample mean in the model for the above-listed quantities, and compares them with their data point estimates. The table illustrates that in the habit formation model, it is very unlikely that dividend strips match the performance of the index; see also Lettau and Wachter (2007).

The habit formation model also has predictions for the volatility of equity yields by maturity that we can test. In the data, we find that the volatility of equity yields is strictly decreasing with maturity, with values of 10 to 18% for 1-year yields (depending on the region), and values of 3 to 6% for 7-year yields.

In Fig. 5, we plot the volatility across the four regions by maturity, and contrast these values with the predicted values of the habit formation model. As before, we simulate the model 1,000 times for 146 months, and for each simulation we compute the volatility of equity yields by maturity. The graph shows the median volatility (solid line) by maturity across the 1,000 simulations, as well as the 95% confidence bound (the dotted line). As is clear from the figure, the volatility of equity yields is much too low in the external habit model as short-term risk premia are low and virtually constant. This is a powerful test of the model as volatilities can be measured more precisely than average returns. Moreover, in the data the volatility of equity yields declines with maturity, while it is upward-sloping in the external habit model.

3.3. Campbell and Cochrane (1999) with predictable dividend growth

The original specification of Campbell and Cochrane (1999) assumes that dividend growth is unpredictable. In this section, we explore whether relaxing this assumption

Table 3

The table provides the percentiles of the simulated mean of a portfolio of dividend futures and dividend spot returns (in absolute terms as well as in excess of the market) in the habit formation model, two calibrations of the long-run risk model, and the variable rare disaster model, where the number of monthly simulations corresponds to the number of observations in the data (146 months). The last four columns report the estimated means in the data for the four geographic regions. The estimates are expressed in basis points per month.

Panel A: Campbell and Cochrane (1999) habit formation model										Data			
Percentile	1	2.5	5	10	50	90	95	97.5	99	Eur	Japan	UK	US
$E[R^F_{t,P}]$	−48	−39	−34	−24	14	48	57	64	73	90	111	63	65
$E[R^F_{t,P} - R^M_{t,B}]$	−60	−56	−53	−47	−32	−16	−11	−6	−2	94	81	49	44
$E[R^S_{t,P} - R^M_t]$	−60	−56	−53	−47	−32	−16	−11	−6	−2	60	64	26	11
Panel B: Bansal and Yaron (2004) long-run risk model										Data			
Percentile	1	2.5	5	10	50	90	95	97.5	99	Eur	Japan	UK	US
$E[R^S_{t,P} - R^M_t]$	−47	−42	−39	−35	−20	−5	−1	2	6	60	64	26	11
Panel C: Bansal, Kiku and Yaron (2012) long-run risk model										Data			
Percentile	1	2.5	5	10	50	90	95	97.5	99	Eur	Japan	UK	US
$E[R^S_{t,P} - R^M_t]$	−60	−54	−50	−45	−26	−15	−11	−7	−2	60	64	26	11
Panel D: Wachter (2013) variable rare disaster model										Data			
Percentile	1	2.5	5	10	50	90	95	97.5	99	Eur	Japan	UK	US
$E[R^S_{t,P} - R^M_t]$	−159	−134	−107	−83	−21	9	15	20	24	60	64	26	11

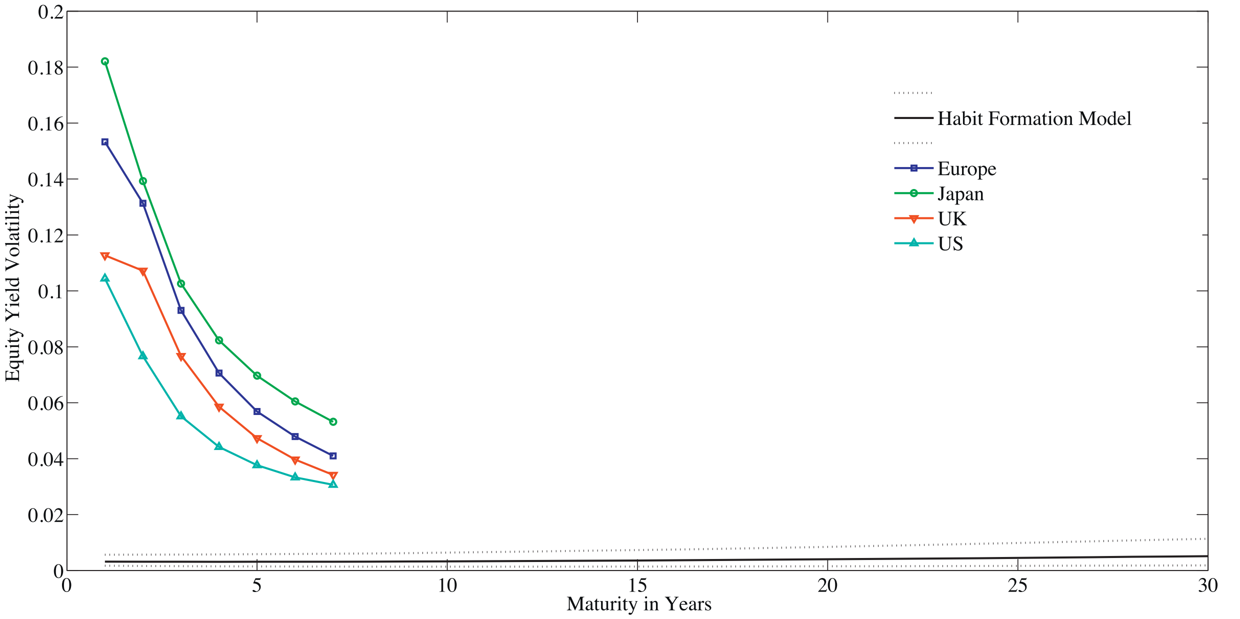

Fig. 5. The graph shows the estimated yield volatility in the data and contrasts it with the estimated yield volatility in the simulated Campbell and Cochrane (1999) habit formation model. We simulate the model 1,000 times for 146 months, and for each simulation compute the volatility of the equity yields. The solid black line reports the median across 1,000 simulations, and the dotted lines indicate the 95% confidence bound.

can help to explain the volatility of equity yields.[5] We change the dynamics of dividend growth by adding a predictable component,

$$\Delta d_{t+1} = g_{t,1} + w_{t+1},$$

where $g_{t,\,1}$ is a stationary process with mean $\bar{g}$. The question is how predictable dividend growth needs to be to reconcile the variation in equity yields. We focus on the 1-period strip for which we can do all calculations analytically.

We keep the variation in consumption growth the same as in the original model, which implies that the stochastic discount factor is unaffected. In Appendix C, we show that the 1-period (forward) equity yield is now given by

$$ey_{t,1} \equiv \ln\left(\frac{D_t}{F_{t,1}}\right) = \sigma_{vw}\gamma[1+\lambda(s_t)] - \frac{1}{2}\sigma_w^2 - g_{t,1},$$

implying that the risk premium component is given by

[5] We thank the referee for suggesting to explore this extension.

$$\theta_{t,1} = \sigma_{vw}\gamma[1+\lambda(s_t)] - \frac{1}{2}\sigma_w^2.$$

The variance decomposition of the 1-period strip is therefore

$$var(ey_{t,1}) = \sigma_{vw}^2\gamma^2 var(\lambda(s_t)) + var(g_{t1}) - 2\gamma\sigma_{vw}cov(\lambda(s_t), g_{t,1}). \quad (22)$$

We provide an upperbound for these terms. First, assuming that the covariance (σ_{vw}) does not change, which is conservative if part of dividend growth is predictable, the calibration (annualized) in Campbell and Cochrane (1999) implies $\sigma_{vw}\gamma = \gamma\rho\sigma_v\sigma_w = 2 \times 0.2 \times 0.015 \times 0.115 = 6.9$ basis points (bp). The simulated standard deviation of $\lambda(s_t)$ equals 4.2, which leads to a standard deviation of the risk premium, which is the first term, of 29bp.[6] This highlights our earlier observation that under the Null of the model, the risk premium variation (as well as the contribution of the covariance term $cov(\lambda(s_t), g_{t1})$) is close to zero.

Hence, the only way to generate significant variation in equity yields is via the second term, $var(g_{t1})$. To this end, we define the R-squared value of the regression of dividend growth on the predictable component as

$$R^2 := \frac{var(g_{t,1})}{var(\Delta d_{t+1})} = \frac{var(g_{t,1})}{var(g_{t,1}) + var(w_{t+1})}.$$

Given that the average standard deviation across the four regions of one-year equity yields over the data sample varies between 10% and 11% for the US and UK, 15% for Europe, and 18% for Japan and given that the standard deviation of realized dividend growth rates over this sample period across the four regions is about the same magnitude as the equity yield volatility (with values of 11% for the US, 15% for Europe, 10% for the UK, and 14% for Europe), this shows that we would need dividend growth to be almost perfectly predictable (with the exception of Japan) to match the data. Such high R-squared values are counterfactual to the analyses in, among others, Cochrane (2008) and Binsbergen and Koijen (2010).

This analysis is merely a restatement of the excess volatility point made in Fig. 3, which indicates that equity yields are more volatile than their dividend realizations. In that case, even perfect dividend growth predictability is insufficient to reconcile the variation in equity yields.

If dividend growth is almost perfectly predictable, then 1-period shocks to dividends are substantially less volatile than what the model of Campbell and Cochrane (1999) suggests. That is, if we wish to keep the variance of Δd_{t+1} in line with the data, increasing the variance of $g_{t,1}$, in the model, implies a decrease in the variance of w_{t+1} which is an important driver of the risk premium. One way to offset this lower variance of w_{t+1} is to increase the risk aversion coefficient γ. However, such a recalibration of the model is beyond the scope of this paper. We can conclude that substantial variation in $\theta_{t,n}$ seems required to match the data, and the habit formation model does not generate this variation.

3.4. Long-run consumption risks: Bansal and Yaron (2004)

Bansal and Yaron (2004) make two modifications to the standard consumption CAPM. First, they modify the time additive preferences to recursive Epstein and Zin (1989) preferences, which introduces a preference for early resolution of uncertainty.[7] Second, they introduce a small, but highly persistent, predictable component in consumption growth, which modifies Eq. (11). Also, they allow for heteroskedasticity in consumption growth, which generates time variation in risk premia. In line with the external habit model, longer-term dividend strips are more sensitive to the predictable component in consumption growth and to changes in the volatility of consumption growth. As a result, risk premia, Sharpe ratios, and volatilities are therefore upward-sloping with maturity, keeping the holding period fixed.[8]

In Panels B and C of Table 3, we repeat the same test as for the habit model; see Appendix D for derivations. Panel B corresponds to the original calibration of Bansal and Yaron (2004), while Panel C corresponds to the more recent calibration of Bansal, Kiku and Yaron (2012); see also Beeler and Campbell (2012) for comparison of both calibrations. For these calibrations, the calculations are fairly close and similar to the results for the habit model and in particular for the calibration of Bansal, Kiku and Yaron (2012). In conclusion, it is unlikely that the data are generated from the long-run risks model.

3.5. Variable rare disasters: Gabaix (2012) and Wachter (2013)

Gabaix (2012) extends the rare disaster model of Rietz (1988) to allow for a persistent, time-varying probability of disasters. Gabaix (2012) assumes that the representative agent still has power utility preferences and, as a result, expected returns do not depend on the maturity as in the standard consumption CAPM. However, volatilities of returns are upward-sloping with maturity, while Sharpe ratios are downward-sloping with maturity. Wachter (2013) extends Gabaix (2012) and uses Epstein and Zin preferences instead. In this case, expected returns are upward-sloping as well, as recursive preferences price the low-frequency variation in the disaster probability, which is more important for long-horizon claims.

Panel D of Table 3 reports the results for the Wachter (2013) calibration. The median is again negative and quite similar to the other models at -21bp per month. However, the distribution of the estimates is substantially wider. Indeed, the 90%-percentile equals 9bp and the 95%-percentile equals 15bp. The estimate in the data for the S&P500 is 11bp, while it is substantially higher for other markets. Hence, it is still unlikely that the variable rate disaster model is consistent with the data.

[6] Because the Campbell and Cochrane (1999) model is a monthly model not an annual model, the 1-period annual computation done here is an approximation. However, given how flat the implied term structure of equity yield volatility is in the model, this approximation is accurate.

[7] See Epstein, Farhi and Stralezcki (2014) for a detailed discussion of the timing premium in the long-run risks model.

[8] In terms of properties of dividend strip returns across maturities, the model with preference shocks proposed by Albuquerque, Eichenbaum and Rebelo (2016) behaves similarly to a long-run risks model.

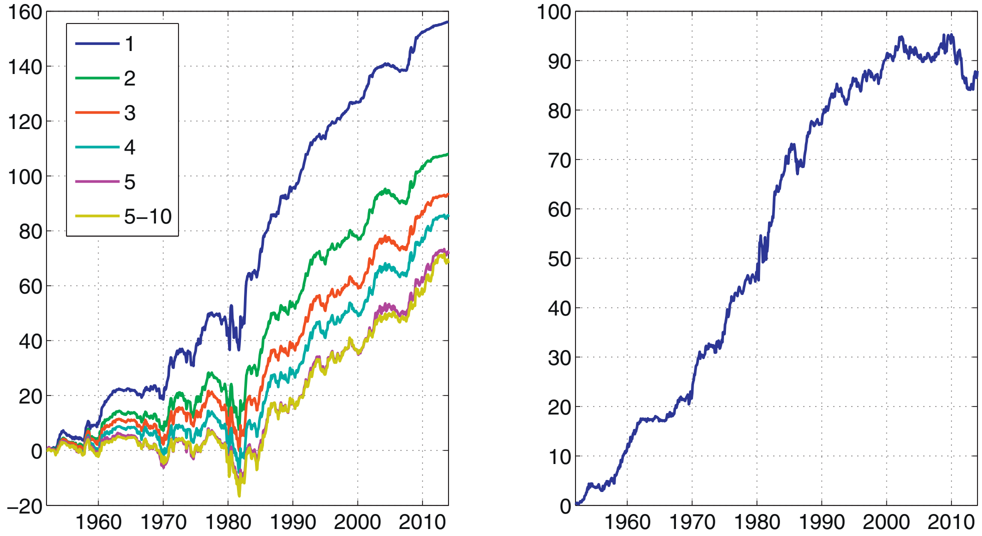

Fig. 6. The left panel displays the cumulative excess returns for various maturities of Treasury portfolios. All strategies are scaled by their full-sample standard deviations. The right panel displays the returns to a strategy that buys the shortest-maturity bonds and shorts the longest-maturity bonds. The sample period is from January 1952 until December 2013.

Table 4
We summarize the annualized average excess return, standard deviation, and Sharpe ratios of nominal Treasury bond returns. The maturities (in months) are summarized in the first row of the table. The sample period is from January 1952 until December 2013.

	1–12	13 –24	25–36	37–48	49–60	61–120
Average excess return	0.58%	1.03%	1.36%	1.56%	1.56%	1.83%
Standard deviation	0.80%	2.05%	3.13%	3.95%	4.67%	5.76%
Sharpe ratio	0.73	0.50	0.43	0.40	0.33	0.32

4. The term structure of Sharpe ratios in other asset classes

In this section, we summarize the evidence in other asset classes, such as nominal bonds, corporate bonds, volatility, and housing.

4.1. Nominal bonds

First, we analyze the properties of returns on nominal Treasury bonds by maturity. We use the Center for Research in Security Prices (CRSP) Treasury bond portfolios for which there are six maturity buckets from January 1952 until December 2013, which correspond to 1–12 months, 13–24 months, 25–36 months, 37–48 months, 49–60 months, and 61–120 months, respectively.[9]

The results are presented in Table 4. We find that the average returns and standard deviations increase with maturity. However, this is to some extent a mechanical effect as a result of the longer duration of long-term bonds. The Sharpe ratio corrects for differences in duration.

The Sharpe ratios are strongly downward-sloping in maturity, consistent with Duffee (2010). The short-term Sharpe ratios are as high as 0.73, while the long-term Sharpe ratios decline to 0.32. This finding also relates to the observation by Hansen and Jagannathan (1991) whose figures point to an attractive risk-return trade-off for short-maturity bonds.[10]

In Fig. 6, the left panel, we plot the cumulative excess returns on the various Treasury portfolios. To make the portfolios comparable, we scale them by their volatilities measured over the entire sample period. The right panel displays the returns to a strategy that buys the shortest-maturity bonds and shorts the longest-maturity bonds, where both portfolios are again scaled to have the same volatility.

4.2. Corporate bonds

Next, we turn to corporate bond returns. We use the Barclays corporate bond indexes for "Intermediate" (average duration about five years) and "Long-term" (average duration about 10 years) maturities. In terms of credit quality, we consider AAA, AA, A, and BAA ratings. The sample period is January 1973 to August 2014.

The results are presented in Table 5. We find, for each level of credit quality, that average returns and standard deviations increase with maturity. However, the Sharpe ratios decline by around 25% when we move from intermediate to long-term bonds. In Fig. 7, we plot the cumulative excess returns to a strategy that buys intermediate-term corporate bonds of a given credit quality and shorts long-term corporate bonds of the same credit quality. The long and short portfolios are scaled to have the same volatility.

[9] There is a return series for bonds with maturities longer than ten years, but these returns are sometimes missing.

[10] Luttmer (1996) tries to rationalize these findings with trading frictions. However, we show that the downward-sloping pattern in Sharpe ratios holds across the entire maturity spectrum and in multiple asset classes.

Table 5
We summarize the annualized average excess return, standard deviation, and Sharpe ratios of corporate bond returns. The credit quality is summarized in the first row of each panel. The top panel displays the results for the intermediate maturity (duration around five years) and the bottom panel for the long-term maturity (duration around ten years). The sample period is from January 1973 until August 2014.

Intermediate	AAA	AA	A	BAA
Average excess return	2.38%	2.53%	2.76%	3.44%
Standard deviation	5.02%	4.99%	5.28%	5.48%
Sharpe ratio	0.47	0.51	0.52	0.63
Long term	AAA	AA	A	BAA
Average excess return	3.12%	3.80%	3.75%	4.60%
Standard deviation	10.45%	9.74%	9.67%	9.82%
Sharpe ratio	0.30	0.39	0.39	0.47

The results for corporate bonds resonate with recent findings in the literature on credit default swaps (CDS), where Palhares (2012) documents that short-maturity CDS contracts have much higher Sharpe ratios than long-maturity CDS contracts.

4.3. Variance risk

The next asset class that we consider is volatility. We use a portfolio of index options that is particularly exposed to variance risk by writing a put and a call option with a strike price as close as possible to the current stock price, that is, a straddle strategy. We consider five maturity groups: 30 to 90 days, 90 to 180 days, 180 to 270 days, 270 to 360 days, and all options with a maturity longer than 360 days. We focus on S&P500 index options, which is among the most liquid option markets.

The results for a (short) straddle position are reported in Table 6. We find, consistent with the other asset classes, that Sharpe ratios decline with maturity. What is particularly interesting in the case of options is that the Sharpe ratios are large and that the Sharpe ratios decline more rapidly in comparison to the other asset classes. Sharpe ratios are 1.62 for the short-maturity contracts and decline to 0.30 for contracts with a maturity longer than a year. In Fig. 8, we plot the cumulative excess return of shorting the short-term straddle and buying a long-term straddle. The long and short portfolios are scaled to have the same volatility using full-sample volatility of the excess return series.

Table 6
We summarize the annualized average excess return, standard deviation, and Sharpe ratios of short straddle returns. The sample period is from February 1996 until August 2013.

Maturity in days:	30–90	90–180	180–270	270–360	> 360
Average excess return	185%	61%	30%	17%	8%
Standard deviation	114%	47%	34%	29%	27%
Sharpe ratio	1.62	1.30	0.89	0.58	0.30

Our findings are consistent with Ait-Sahalia, Karaman and Mancini (2014), Dew-Becker, Giglio, Le and Rodriguez (2017), and Andries, Eisenbach, Schmalz and Wang (2015). Dew-Becker, Giglio, Le and Rodriguez (2017) show that the Sharpe ratios of a short position in variance swaps declines rapidly with maturity and is insignificant for maturities longer than two months. Andries, Eisenbach, Schmalz and Wang (2015) focus on the Sharpe ratios of at-the-money index straddles instead, which is closely related to the results that we report in Table 6.

4.4. Housing

The final market that we discuss is housing. Recently, Giglio, Maggiori and Stroebel (2015) study the differences in asset prices of leaseholds and freeholds in the United Kingdom and Singapore. The difference between leasehold and freehold prices reflects the present value of perpetual rental income starting at leasehold expiry.

Under assumptions about future rent growth, one can back out the long-term discount rate to reconcile price differences between leaseholds and freeholds (see also Badarinza and Ramadorai (2014)). Giglio, Maggiori and Stroebel (2015) find that long-run discount rates must be

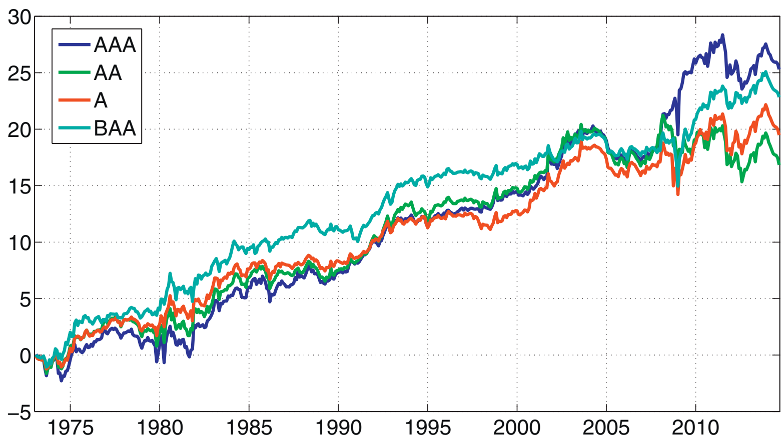

Fig. 7. We plot the cumulative excess returns to a strategy that buys intermediate-term corporate bonds of a given credit quality and shorts long-term corporate bonds of the same credit quality. The long and short portfolios are scaled to have the same volatility. The sample period is from January 1973 until August 2014.

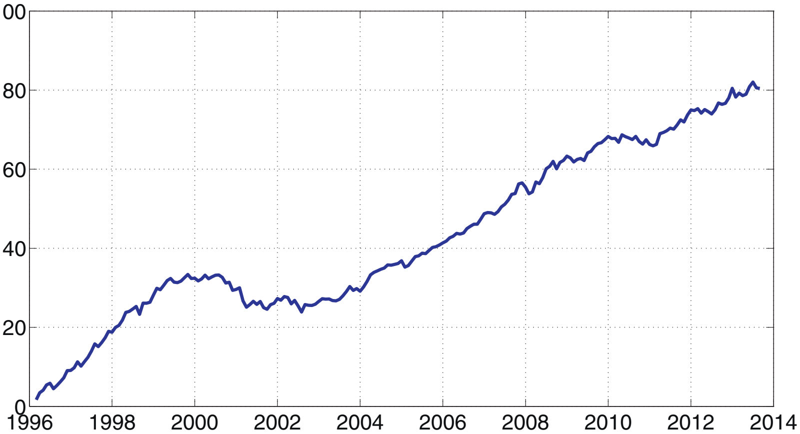

Fig. 8. We plot the cumulative excess return of shorting the short-term straddle and buying a long-term straddle. The long and short portfolios are scaled to have the same volatility. The sample period is from February 1996 until August 2013.

Table 7
We summarize the annualized Sharpe ratios for short- and long-maturity claims in equity, nominal bond, corporate bond, and option markets. We also report the test statistic on the difference in Sharpe ratios, which has a standard normal distribution.

Asset class	Sharpe ratios		Test statistic	Sharpe ratios		Test statistic
	Short	Long		Short	Long	
Equity	Dividend futures	Index		1y	7y	
Europe	0.50	-0.02	2.27	0.77	0.36	1.78
Japan	0.55	0.27	1.07	0.75	0.52	1.12
UK	0.35	0.10	1.37	0.42	0.32	0.60
US	0.54	0.13	1.74	0.42	0.59	-0.76
Global	0.62	0.12	2.00	0.81	0.58	1.05
Nominal bonds	0.73	0.32	4.05			
Corporate bonds						
AAA	0.47	0.30	2.50			
AA	0.51	0.39	1.95			
A	0.52	0.39	2.23			
BAA	0.63	0.47	3.33			
Options (straddles)	1.62	0.30	4.15			

very low. As we cannot compute realized returns, it is not clear how to compute the volatility of returns. This implies that we cannot compare Sharpe ratios across maturities, which is the robust finding that we document across asset classes.

4.5. Tests on the slope of Sharpe ratios

In this section, we provide formal tests on the slope of Sharpe ratios across maturities. In Appendix B, we derive a test on the difference in Sharpe ratios. The Null hypothesis, as motivated by the leading asset pricing models, is that the Sharpe ratios of long-maturity claims are higher than the Sharpe ratios of short-maturity claims. The alternative is that short-maturity claims have higher Sharpe ratios. Under the Null hypothesis, the test statistic has (asymptotically) a standard normal distribution.

The results are reported in Table 7 for equities, nominal bonds, corporate bonds, and options. For equities, we provide two tests. First, we test an equally-weighted portfolio of dividend strips of the first five years against the aggregate stock market index. We consider this to be the best test of the models as we have the largest dispersion in maturities. Second, we test the 1-year strip against the 7-year strip. We provide the results for each of the four regions separately, as well as a global test.

For the first test, that is, comparing dividend strips to the aggregate stock market, we find that the Null is rejected for two of the four markets (Europe and US). For the second test, the Null is only rejected for Europe. This result is still of interest given that the European market is the largest and most liquid market of dividend futures. For the US, we find that the Sharpe ratio of the 7-year strip is somewhat higher than the Sharpe ratio of the 1-year strip (0.42 versus 0.59), but this difference is insignificant.

When we pool returns across countries, we find that the Sharpe ratios are significantly higher for dividend futures (the short-maturity claims) than for the market (the long-maturity claims). Within the dividend futures market, we again find that Sharpe ratios decline, but the difference is insignificant.

The remainder of the table reports the results for the other asset classes. In all cases, we find that the Null hypothesis of increasing Sharpe ratios is rejected at conventional significance levels. In the case of corporate bonds, this is true for all credit ratings as well.

We conclude that Sharpe ratios significantly decline with maturity in equity, nominal bond, corporate bond, and option markets.

5. New theories about the term structure of discount rates

In this section, we summarize an emerging literature of macro-finance models that provide potential explanations for some of the facts that we discussed in earlier sections. We start with homogeneous agent models and focus on models that adjust either preferences or the technology process. Next, we discuss models that depart from the representative agent models by introducing an interesting form of heterogeneity. We conclude with a discussion of explanations based on market microstructure noise or taxation.

5.1. Alternative models of preferences

Eisenbach and Schmalz (2014) modify the preferences so that the representative agent is more risk averse with respect to imminent risks than distant risks. Such preferences find support in a series of lab experiments. Eisenbach and Schmalz (2014) develop a 2-period model, which is extended to an infinite-horizon economy by Andries, Eisenbach and Schmalz (2014). In terms of technology, Andries, Eisenbach and Schmalz (2014) follow the long-run risks literature and allow for a slow-moving predictable component, as well as stochastic volatility, in consumption growth.

Andries, Eisenbach and Schmalz (2014) find that these preferences generate a decreasing term structure of risk premia if and only if volatility is stochastic. The model therefore implies that the term structure of risk premia for dividend strips is driven by a downward-sloping term structure of the price of volatility risk.[11]

Andries (2014) studies a model in which the agent has loss-aversion preferences. This induces important nonlinearities in expected excess returns as a function of the exposure to the consumption shocks. The risk premium is higher for assets that are relatively "safe" (with low exposure to the consumption shocks) than for assets that are relatively "risky" (with large exposure to the consumption shocks). This feature of loss aversion generates a downward-sloping term structure of Sharpe ratios. Curatola (2015) combines a model of loss aversion and habit formation. The model produces an upward-sloping real term structure, but risk premia and volatilities on dividend strips are downward-sloping in maturity. Intuitively, long-horizon dividend strips have higher expected payoffs that are further from the kink. As a result, the effective risk aversion is lower. Berrada, Detemple and Rindisbacher (2013) consider a regime-switching model where the preferences change with the regimes. The agent does not directly observe the regimes and needs to learn about the state of the economy. The model is able to reproduce the high volatility of short-term dividend strip prices and the first and second moments of bond yields.

Building on the model with demand shocks as developed by Albuquerque, Eichenbaum and Rebelo (2016), Marfe (2014) introduces demand shocks that are correlated with endowment shocks and that cannot be perfectly observed by the agent. Otherwise, the model resembles a homoscedastic long-run risks model. Marfe (2014) derives general conditions on the properties of demand shocks and preference parameters to ensure the correct slopes of the term structures of equity yields and real bond yields.

5.2. Alternative models of technology

A second class of models modifies the technology process for consumption and dividends. Nakamura, Steinsson, Barro and Ursua (2013) and Hasler and Marfe (2016) extend the disaster model as developed by Barro (2006) to allow for recoveries following a disaster; see also Gourio (2008). The model is successful in generating risk premia for dividend strips that decline with maturity.

The model's intuition can be illustrated with a simple example in which consumption and dividends at time $t+1$ falls if a disaster strikes in that period, but fully recovers the subsequent period. If an agent prices dividend strips at time t, then the 1−period dividend strip is fully exposed to the $t+1$ disaster risk, but the 2−period dividend strip is not. As a result, the risk premium on the 2−period dividend strip is lower.

Belo, Collin-Dufresne and Goldstein (2015) and Marfe (2016a) also modify the dynamics of the dividend process. Belo, Collin-Dufresne and Goldstein (2015) model the earnings process and assume, in addition, that leverage ratios are stationary. In the model, shareholders are forced to divest (invest) when leverage is low (high), which shifts long-horizon growth risk of earnings to short-horizon dividends. As a result, dividends are more volatile than earnings over short horizons, but they are equally volatile over long horizons as dividends and earnings are cointegrated. In this model, the consumption dynamics and preferences, and hence the stochastic discount factor, are unaffected. The main modification is the exposure of dividends to shocks to the stochastic discount factor at various horizons.

Belo, Collin-Dufresne and Goldstein (2015) illustrate the mechanism in the context of the long-run risks model and the external habit model. They show that the calibrated model can reproduce the low market betas of short-maturity strips, and hence the high alphas, as well as the downward-sloping Sharpe ratios. A key implication is that leverage ratios forecast long-term dividend growth rates, for which Belo, Collin-Dufresne and Goldstein (2015) provide some evidence at very long horizons.

Marfe (2016a) proposes a similar mechanism, but instead of assuming stationary leverage ratios, he assumes that the labor share is stationary. The implications for dividends strips are very similar, although now the labor share

[11] See also Chabi-Yo (2016) for a model explaining the term structure of the price of volatility risk.

has to forecast future dividend growth. Marfe (2016a) provides some support in favor of this mechanism as well. He also concludes that the dividend share conveys additional information, beyond financial leverage, concerning the properties of short-run dividend risk.

Lopez, Lopez-Salido and Vazquez-Grande (2015) consider a model with habit formation and nominal rigidities. The dividend share in the model is stationary and pro-cyclical, and short-term dividends are therefore more exposed to technology shocks than long-term dividends. A slow-moving external habit then produces large and counter-cyclical prices for these risks. The model is able to match features of the term structures of equity, nominal, and real bonds.

Ai, Croce, Diercks and Li (2012) consider a production economy with different vintages of capital. They assume that newer vintages of capital are less exposed to productivity shocks than older vintages. Current dividends are largely produced by older vintages of capital, making short-term dividends riskier than medium-term dividends. In the long-run, all vintages are exposed to productivity shocks in the same way. As a result, the model produces a U-shaped pattern in the term structure of risk premia on dividend strips. Corhay, Kung and Schmid (2015) study a model with endogenous firm entry and exit, and also find a U-shaped term structure of equity risk premia. In this model, the entry-exit margin drives countercyclical price markups, which increases the volatility and procyclicality of cash flows in the short-run.

5.3. Alternative models of beliefs

Croce, Lettau and Ludvigson (2015) develop a model with both short-term and long-run shocks to consumption growth. Instead of assuming that investors have full information about both components, Croce, Lettau and Ludvigson (2015) consider a representative decision maker who optimizes based on a cash-flow model that is sparse in the sense that it ignores cross-equation restrictions that are difficult (if not impossible) to infer in finite samples. Because of this behavioral assumption about the learning process, assets that have a small exposure to long-run consumption risk, but are highly exposed to short-run (even i.i.d.) consumption risk can command high risk premiums in the bounded rationality limited information case but not under full information. As a result, the term structure of equity risk premia can be downward-sloping under the boundedly-rational model, while it is upward-sloping under full information as in the long-run risks models.

5.4. Heterogeneous agent models

The models discussed so far are all representative agent models. Lustig and Nieuwerburgh (2006) are the first to propose a heterogeneous-agents model that produces a downward-sloping term structure of dividend strip risk premia. Agents differ in their histories of labor income shocks. In the model, the risk sharing of income shocks is limited by the amount of housing collateral that agents have. Agents face both shocks to the wealth distribution, which fluctuates at the business cycle frequency, and shocks to housing collateral, which fluctuates at lower frequencies. A negative consumption shock temporarily increases discount rates, but it does not affect housing collateral, which governs discount rates in the long run. As a result, the price of consumption strips of longer maturity is insulated from bad consumption shocks today, but they do affect short-maturity consumption strips.

Marfe (2016b) builds on Danthine and Donaldson (2002) and considers a model with two groups of agents, workers and shareholders. Wages do not correspond to the marginal product of labor, but incorporate income insurance that workers exploit within the firm. In turn, the labor-share has countercyclical dynamics and, hence, the riskiness of owning capital increases. This increases the riskiness of short-term dividends, which leads to a downward-sloping term structure of dividend strip risk premia.

Favilukis and Lin (2016) introduce sticky wages and a CES production function over capital and labor in an otherwise standard heterogeneous agent production economy. In a frictionless model, wages are too volatile as wages are equal to the marginal product of labor and dividends (and stock returns) are too smooth. Sticky wages reduce the volatility of wages, which turns out to have important implications for a series of asset pricing puzzles, including the term structure of dividend risk premia. The main intuition is that although wages can adjust in the long run,[12] they cannot in the short run. This implies that productivity shocks need to be absorbed by short-term dividends, which makes dividends highly pro-cyclical and gives rise to a downward-sloping term structure of dividend strip risk premia.

5.5. Asset pricing models with an exogenous stochastic discount factor

A last class of models that we discuss are not general equilibrium models as they exogenously specify the stochastic discount factor rather than deriving it from preferences. However, such models may give important insights in what a specification of preferences must deliver.

Three key examples are Lettau and Wachter (2007); 2011) and Lynch and Randall (2011). Lettau and Wachter (2007) allow for a temporary component in dividends that receives a high risk price. This risk price fluctuates over time to generate return predictability, but shocks to this risk price are uncorrelated with the stochastic discount factor, which would, for instance, be counterfactual from the perspective of the external habit model. Lettau and Wachter (2007) assume interest rates to be constant. The model matches many of the features that we have documented in this paper, such as risk premia, Sharpe ratios, and CAPM alphas and betas. The volatility of the returns on short-maturity dividend strips also exceeds the volatility of market returns.

[12] In fact, wages and output are co-integrated in the model, implying that they are equally risky in the long run.

Lynch and Randall (2011) develop a related model, but allow the risk price to be correlated with the stochastic discount factor. However, this is only consistent with the evidence on dividend strips, as they show, if the risk price, which Lynch and Randall (2011) interpret as the habit level, is not too persistent. Lynch and Randall (2011) provide interesting micro evidence consistent with the fact that habits are more fast moving than what has been assumed by Campbell and Cochrane (1999).

Lettau and Wachter (2011) extend the model of Lettau and Wachter (2007) by introducing variation in the real interest rate and both expected and unexpected inflation. The key to the model's success is to assume that the real risk-free rate is negatively correlated with fundamentals, which generates an upward-sloping real term structure, and a price-of-risk shock that has zero correlation with fundamentals. In the case of nominal bonds, there is an additional effect arising from the negative correlation between fundamentals and expected inflation. This negative correlation implies that nominal bond prices fall when fundamentals are low, leading to a positive inflation risk premium.

5.6. Risk prices and exposures

Our discussion of the models above makes it clear that there are by now a wide variety of different mechanisms that have been proposed to generate some of the facts related to the term structure of asset prices. However, some models change the technology side of the models, while others rely on preferences or beliefs.

We think that future work can disentangle and test these mechanisms more carefully by decomposing risk premia and Sharpe ratios into risk prices and risk exposures, both in the data and the models, using the tools developed by Hansen and Scheinkman (2009), Hansen, Heaton and Li (2008), and Borovicka, Hansen, Hendricks and Scheinkman (2011). Decomposing risk premia and Sharpe ratios in the data into risk prices and exposures provides valuable guidance for the design of future macro-finance models.

5.7. Market microstructure, tax effects, and the role of institutional investors

The last set of potential explanations relate to frictions that are outside of the models that we have discussed so far, such as microstructure effects, taxes, and market segmentation.

Boguth, Carlson, Fisher and Simutin (2011) argue that when BBK synthetically replicate dividend strip prices using option prices, small amounts of microstructure noise can be exacerbated when computing returns. Qualitatively, this increases the mean and volatility of measured returns and lowers the estimated CAPM betas. Although this explanation might apply to dividend strip prices recovered from option prices, it does not apply to dividend futures. The results documented in Section 2, while based on a shorter sample due to the availability of dividend futures data than the original BBK findings, therefore pose a challenge to this explanation. Going forward, it will be interesting to test this theory directly using data on dividend futures and options data as more data on dividend futures are available.

Schulz (2013) argues that taxes could potentially explain the average high return on synthetically replicated strips. Because dividends are taxed at a higher rate than capital gains, and because dividends make up a larger part of the total return for dividend strips relative to the index, this could potentially explain part of the high average return. To measure the quantitative effect of taxes, Schulz (2013) uses the price drop on ex-dividend days. The implied tax rates are noisy and sometimes exceed 100%, and routinely violate the theoretical bounds imposed by the difference in marginal tax rates on dividends and capital gains. When using these theoretical bounds, the quantitative effect is small (Binsbergen and Koijen (2016)). In addition, dividend futures are not subject to dividend taxation. Again, the findings in Section 2 appear to provide a challenge for a tax-based explanation.

Lastly, it may be the case that the market for dividend futures is segmented. Banks selling structured products to retail consumers end up with a net long dividend exposure. In response, banks sell dividend futures to share this risk with other investors, which is absorbed by a small group of specialized institutions (e.g., hedge funds and pension funds). It may be possible to link the fluctuations in dividend futures prices to the sales of structured products and to the capital of buyers of dividend futures. Such a theory follows a recent literature emphasizing the role of institutions and segmentation in asset markets.[13]

6. Concluding remarks and broader economic implications

In this paper, we have summarized the basic facts about the term structure of returns in various asset classes and discussed various new theories that have been proposed to explain some of these facts. We can conclude that many of the recently documented puzzles in the asset pricing literature related to the equity premium, variance risk premium, excess volatility, return predictability, and credit spreads are predominantly short-term puzzles rather than long-term puzzles. This gives important guidance about the types of models (beliefs, preferences, and technology) and/or frictions that are most likely to explain these puzzles. We conclude this paper by discussing several potential avenues for future research in this area.

First, it would be interesting to extend the large literature on real and nominal term structure models[14] to match equity yields as well. This is particularly interesting given the ongoing debate about the determinants of the time variation in the correlation between bond and stock

[13] See, for instance, Dasgupta, Prat and Verardo (2011), Basak and Pavlova (2013), He and Krishnamurthy (2013), Vayanos and Woolley (2013), Berk and van Binsbergen (2014), and Koijen and Yogo (2015).

[14] See, for instance, Dai and Singleton (2003), and Ang and Piazzesi (2003). See Duffee (2012) for a recent summary of the literature.

markets, see, for instance, Baele, Bekaert and Inghelbrecht (2010) and Campbell, Sunderam and Viceira (2013), and the extent to which stocks are real assets Katz, Lustig and Nielsen (2016). Kragt, de Jong and Driessen (2014) develop a pricing model for equity yields only. In recent work, Ang and Ulrich (2012) propose a joint pricing model for nominal bonds, real bonds, and dividend strips, although no direct data on dividend prices are used in estimation. Recently, Yan (2014) estimates an affine term structure model using data on nominal bonds and dividend strips. By modeling the inflation process, one can study directly whether stocks are a hedge against inflation across horizons. Moreover, looking at the bond-stock correlation across maturities could be useful to test various theories that make predictions about both bond and equity markets.

Second, BHKV show that equity yields predict future growth rates, such as dividend growth, GDP growth, and even consumption growth. For the same sample period, which is obviously fairly short, equity yields predict growth better than traditional predictor variables such as nominal and real bond yields. Given the large literature in macro on forecasting macroeconomic growth using big data, see, for instance, Stock and Watson (2014) and Beber, Brandt and Luisi (2015), it would be interesting to explore whether equity yields add information beyond the traditional set of forecast variables.

Third, understanding the link between asset markets and real economic decisions, such as hiring and investment, is at the heart of the macro-finance research agenda. Recent work by Hall (2014) suggests that variation in short-term discount rates may help to explain why hiring is much more volatile than the difference between wages and the marginal product of capital; see Shimer (2005).[15]

The same argument holds for investment, where investment is much more volatile than the marginal product of capital. Moreover, investment does not align well with the market-to-book ratio, which is the failure of Q-theory. Following the logic in Hall (2014), investment decisions are more sensitive to short-term discount rates than overall firm value as a result of depreciation. A firm's overall value includes future growth options, which have a much longer maturity than current investments. *Firm-level* equity yields, which are currently exchange traded in Europe, can be used to study whether hiring and investment are better aligned with short-term discount rates than market-to-book ratios.

Appendix A. Decomposing index returns

Let the stock index level P_t be given by the sum of dividend strip (spot) prices $P_{t,n}$:

$$S_t = \sum_{n=1}^{\infty} P_{t,n}.$$

Further define the maturity 0 dividend spot price as:

$$P_{t,0} \equiv D_t,$$

where D_t is the dividend paid out at time t. Recall that dividend strip spot returns are given by:

$$R^S_{t,n} = \frac{P_{t,n-1}}{P_{t-1,n}} - 1,$$

and dividend futures returns by:

$$R^F_{t,n} = \frac{F_{t,n-1}}{F_{t-1,n}} - 1.$$

Now we can write total returns on the index R^M_t as:

$$\begin{aligned} 1 + R^M_t &= \frac{S_t + D_t}{S_{t-1}} \\ &= \frac{\sum_{n=1}^{\infty} P_{t,n-1}}{\sum_{n=1}^{\infty} P_{t-1,n}} \\ &= \sum_{n=1}^{\infty} w_{t-1,n} \frac{P_{t,n-1}}{P_{t-1,n}} \\ &= \sum_{n=1}^{\infty} w_{t-1,n} \left(1 + R^S_{t,n}\right) \end{aligned}$$

where

$$w_{t-1,n} = \frac{P_{t-1,n}}{S_{t-1}}$$

and thus:

$$\sum_{n=1}^{\infty} w_{t-1,n} = 1.$$

Now using that:

$$P_{t,n} = F_{t,n} \exp\left(-n y_{t,n}\right)$$

we have for each dividend strip return:

$$\begin{aligned} R^S_{t,n} &= \frac{P_{t,n-1}}{P_{t-1,n}} = \frac{F_{t,n-1} \exp\left(-(n-1) y_{t,n-1}\right)}{F_{t,n} \exp\left(-n y_{t-1,n}\right)} \\ &= \left(1 + R^F_{t,n}\right)\left(1 + R^B_{t,n}\right) \approx 1 + R^F_{t,n} + R^B_{t,n}. \end{aligned}$$

Therefore, we can write for the index return:

$$R^M_t = \sum_{n=1}^{\infty} w_{t-1,n} R^S_{t,n} \approx \sum_{n=1}^{\infty} w_{t-1,n} R^F_{t,n} + \sum_{n=1}^{\infty} w_{t-1,n} R^B_{t,n}.$$

Rearranging, we find:

$$\sum_{n=1}^{\infty} w_{t-1,n} R^F_{t,n} = R^M_t - \sum_{n=1}^{\infty} w_{t-1,n} R^B_{t,n}.$$

Now the only question left is how we approximate the return on the bond portfolio:

$$\sum_{n=1}^{\infty} w_{t-1,n} R^B_{t,n}.$$

We approximate this bond portfolio by the 10-year bond return, but given the high duration of stocks, higher maturities could easily be used.

[15] See also Kehoe, Midrigan and Pastorino (2015).

Appendix B. Test on Sharpe ratios

Let R^e_{1t} denote the excess returns on the short-maturity portfolio and R^e_{2t} the excess returns on the long-maturity portfolio. We are interested in testing the hypothesis

$$H_0: \frac{E(R^e_{1t})}{\sigma(R^e_{1t})} \leq \frac{E(R^e_{2t})}{\sigma(R^e_{2t})},$$

as predicted by leading asset pricing models, versus the alternative

$$H_1: \frac{E(R^e_{1t})}{\sigma(R^e_{1t})} > \frac{E(R^e_{2t})}{\sigma(R^e_{2t})}.$$

To derive the test, we define $\mu_{ij} \equiv E(R^{ej}_{it})$. We want to compute the asymptotic distribution of the estimator of $\mathcal{T}$, $\widehat{\mathcal{T}}$, where

$$\mathcal{T} = \frac{\mu_{11}}{\sqrt{\mu_{12} - \mu_{11}^2}} - \frac{\mu_{21}}{\sqrt{\mu_{22} - \mu_{21}^2}}.$$

We define $\mu \equiv (\mu_{11}, \mu_{12}, \mu_{21}, \mu_{22})'$, which we estimate via GMM. The asymptotic distribution of the estimator of μ, $\widehat{\mu}$, is given by

$$\sqrt{T}(\widehat{\mu} - \mu) \to_d N(0, V),$$

where

$$V = \sum_{j=-\infty}^{\infty} E(f_t f'_{t-j}),$$

and $f_t \equiv (R^e_{1t} - \mu_{11}, R^{e2}_{1t} - \mu_{12}, R^e_{2t} - \mu_{21}, R^{e2}_{2t} - \mu_{22})'$. Using the delta method, the asymptotic distribution of $\widehat{\mathcal{T}}$ is given by

$$\sqrt{T}(\widehat{\mathcal{T}} - \mathcal{T}) \to_d N(0, G'VG),$$

where

$$G \equiv \frac{\partial \mathcal{T}}{\partial \mu} = \begin{bmatrix} (\mu_{12} - \mu_{11}^2)^{-1/2} + \mu_{11}^2(\mu_{12} - \mu_{11}^2)^{-3/2} \\ -0.5\mu_{11}(\mu_{12} - \mu_{11}^2)^{-3/2} \\ -(\mu_{22} - \mu_{21}^2)^{-1/2} - \mu_{21}^2(\mu_{22} - \mu_{21}^2)^{-3/2} \\ 0.5\mu_{21}(\mu_{22} - \mu_{21}^2)^{-3/2} \end{bmatrix},$$

which we estimate by replacing population moments by their sample counterparts. We denote the estimated vector by $\widehat{G}$.

We estimate V using a k-month Newey and West (1987) estimator

$$\widehat{V} = \sum_{j=-k}^{k} \left(\frac{k+1-|j|}{k+1}\right) \frac{1}{T} \sum_{t=1+\max\{0,j\}}^{T+\min\{0,j\}} f_t f'_{t-j}.$$

We use $k = 12$ months to compute $\widehat{V}$.

The test statistic that we report is $\widehat{\mathcal{T}}\left(\widehat{G}'\widehat{V}\widehat{G}/T\right)^{-1/2}$ and it has a standard normal distribution.

Appendix C. Calculations for the Campbell and Cochrane (1999) model

In this appendix, we provide additional calculations for the Campbell and Cochrane (1999), with predictable growth as in Section 3.3. The 1-period geometric dividend strip return equals

$$r^S_{t+1,1} = \ln\left(\frac{D_{t+1}}{\mathcal{P}_{t,1}}\right) = \ln\left(\frac{D_{t+1}}{D_t}\frac{D_t}{\mathcal{P}_{t,1}}\right)$$
$$= g_{t,1} + w_{t+1} + \ln\left(\frac{D_t}{\mathcal{P}_{t,1}}\right).$$

As we have not changed the dynamics of consumption growth (and thus the stochastic discount factor), the Euler equation is given by

$$E_t\left[M_{t+1}\exp\left(r^S_{t+1,1}\right)\right] = \delta\exp(-\gamma\bar{g})$$
$$\times \exp(-\gamma(\varphi-1)(s_t-\bar{s}))\exp\left(g_{t,1} + \ln\left(\frac{D_t}{\mathcal{P}_{t,1}}\right)\right)$$
$$\times E_t[\exp(-\gamma[1+\lambda(s_t)]v_{t+1} + w_{t+1})] = 1,$$

which, using the conditional normality can be rewritten as:

$$\delta\exp\left(-\gamma\bar{g} - \gamma(\varphi-1)(s_t-\bar{s}) + g_{t,1} + \ln\left(\frac{D_t}{\mathcal{P}_{t,1}}\right)\right)$$
$$\times \exp\left(\left\{\frac{1}{2}\gamma^2[1+\lambda(s_t)]^2\sigma_v^2 + \frac{1}{2}\sigma_w^2 - \gamma[1+\lambda(s_t)]\sigma_{vw}\right\}\right) = 1.$$

Taking logs we obtain:

$$\ln\left(\frac{D_t}{\mathcal{P}_{t,1}}\right) = -\ln\delta + \gamma\bar{g} + \gamma(\varphi-1)(s_t-\bar{s}) - g_{t,1} - \frac{1}{2}\gamma^2$$
$$\times\left\{[1+\lambda(s_t)]^2\sigma_v^2\right\} - \frac{1}{2}\sigma_w^2 + \gamma[1+\lambda(s_t)]\sigma_{vw}.$$

Because the risk-free rate is given by,

$$r_f = -\ln\delta + \gamma\bar{g} + \gamma\{(\varphi-1)(s_t-\bar{s})\}$$
$$-\frac{1}{2}\gamma^2[1+\lambda(s_t)]^2\sigma_v^2,$$

the 1-period (forward) equity yield is given by the following simple expression:

$$ey_{t,1} \equiv \ln\left(\frac{D_t}{F_{t,1}}\right) = \ln\left(\frac{D_t}{\mathcal{P}_{t,1}}\right) - r_f$$
$$= \sigma_{vw}\gamma[1+\lambda(s_t)] - \frac{1}{2}\sigma_w^2 - g_{t,1}.$$

Appendix D. Calculations for the Bansal and Yaron (2004) model

We follow the notation and derivations of Beeler and Campbell (2012), and add the calculations of dividend strip prices. The technology processes are given by

$$\Delta c_{t+1} = \mu_c + x_t + \sigma_t\eta_{t+1},$$
$$x_{t+1} = \rho x_t + \varphi_e\sigma_t e_{t+1},$$
$$\sigma^2_{t+1} = \bar{\sigma}^2 + \nu\left(\sigma_t^2 - \bar{\sigma}^2\right) + \sigma_w w_{t+1},$$
$$\Delta d_{t+1} = \mu_d + \phi x_t + \varphi\sigma_t u_{t+1} + \pi\sigma_t\eta_{t+1},$$
$$w_{t+1}, e_{t+1}, u_{t+1}, \eta_{t+1} \sim N(0,1).$$

The representative agent's preferences are

$$m_{t+1} = \theta\ln\delta - \frac{\theta}{\psi}\Delta c_{t+1} + (\theta-1)r_{a,t+1},$$

where $\theta = (1-\gamma)/\left(1-\psi^{-1}\right)$ and $r_{a,t+1}$ is the return on total wealth. Innovations to the stochastic discount factor are given by

$$m_{t+1} - E_t(m_{t+1}) = -\lambda_\eta \sigma_t \eta_{t+1} - \lambda_e \sigma_t e_{t+1} - \lambda_w \sigma_w w_{t+1},$$

where $\lambda\eta = \gamma$, $\lambda_e = (1-\theta)\kappa_1 A_1 \varphi_e$, and $\lambda_w = (1-\theta)A_2\kappa_1$.

The log wealth-consumption ratio is affine in both state variables

$$z_t = A_0 + A_1 x_t + A_2 \sigma_t^2,$$

where

$$A_0 = \frac{\ln\delta + \mu_c\left(1-\psi^{-1}\right) + \kappa_0 + \beta_{a,w}\bar{\sigma}^2(1-\nu) + \frac{1}{2}\theta\beta_{a,w}^2\sigma_w^2}{1-\kappa_1},$$

$$A_1 = \frac{1-\psi^{-1}}{1-\kappa_1\rho},$$

$$A_2 = \frac{\frac{1}{2}\left[\left(\theta - \theta\psi^{-1}\right)^2 + \left(\theta\beta_{a,e}\right)^2\right]}{\theta(1-\kappa_1\nu)},$$

and

$$\beta_{a,w} = \kappa_1 A_2,$$
$$\beta_{a,e} = \kappa_1 A_1 \varphi_e.$$

The log return on total wealth equals

$$r_{a,t+1} = \kappa_0 + \kappa_1 z_{t+1} - z_t + \Delta c_{t+1},$$

where

$$\kappa_1 = \frac{\exp(\bar{z})}{1+\exp(\bar{z})},$$
$$\kappa_0 = \ln(1+\exp(\bar{z})) - \kappa_1\bar{z}.$$

The coefficient $\bar{z}$ is determined as a fixed point to the problem

$$\bar{z} = A_0(\bar{z}) + A_2(\bar{z})\bar{\sigma}^2.$$

The log price-dividend ratio on the aggregate stock market is also affine in both state variables

$$z_{m,t} = A_{0,m} + A_{1,m}x_t + A_{2,m}\sigma_t^2,$$

where

$$A_{0,m} = \frac{\begin{bmatrix}\theta\ln\delta + \mu_c(\theta - \theta\psi^{-1} - 1) - \lambda_w\bar{\sigma}^2(1-\nu) \\ +(\theta-1)[\kappa_0 + A_0(\kappa_1 - 1)] + \kappa_{0,m} \\ +\beta_{m,w}\bar{\sigma}^2(1-\nu) + \mu_d + \frac{1}{2}(\beta_{m,w} - \lambda_w)^2\sigma_w^2\end{bmatrix}}{1-\kappa_{1,m}},$$

$$A_{1,m} = \frac{\phi - \psi^{-1}}{1-\kappa_{1,m}\rho},$$

$$A_{2,m} = \frac{(1-\theta)A_2(1-\kappa_1\nu) + \frac{1}{2}[(\pi-\lambda_\eta)^2 + (\beta_{m,e}-\lambda_e)^2 + \varphi^2]}{1 -_{1,m} \nu},$$

and

$$\beta_{m,e} = \kappa_{1,m}A_{1,m}\varphi_e,$$
$$\beta_{m,w} = \kappa_{1,m}A_{2,m}.$$

The log return on the aggregate stock market is given by

$$r_{m,t+1} = \kappa_{0,m} + \kappa_{1,m}z_{m,t+1} - z_{m,t} + \Delta d_{t+1},$$

where

$$\kappa_{1,m} = \frac{\exp(\bar{z}_m)}{1+\exp(\bar{z}_m)},$$

$$\kappa_{0,m} = \ln(1+\exp(\bar{z}_m)) - \kappa_{1,m}\bar{z}_m.$$

The coefficient $\bar{z}_m$ is determined as a fixed point to the problem

$$\bar{z}_m = A_{0,m}(\bar{z}_m) + A_{2,m}(\bar{z}_m)\bar{\sigma}^2.$$

The real risk-free rate equals

$$\begin{aligned} r_t^f &= -E_t(m_{t+1}) - \frac{1}{2}V_t(m_{t+1}) \\ &= c_0 + c_1 x_t + c_2\sigma_t^2, \end{aligned}$$

where

$$\begin{aligned} c_0 &= -\theta\ln\delta + \theta\psi^{-1}\mu_c - \frac{1}{2}\lambda_w^2\sigma_w^2 \\ &\quad -(\theta-1)\left[\kappa_0 + (\kappa_1 - 1)A_0 + \kappa_1 A_2\bar{\sigma}^2(1-\nu) + \mu_c\right], \\ c_1 &= \theta\psi^{-1} - (\theta-1)[1 + A_1(\kappa_1\rho - 1)], \\ c_2 &= -(\theta-1)(\kappa_1\nu - 1)A_2 - \frac{1}{2}\left(\lambda_\eta^2 + \lambda_e^2\right). \end{aligned}$$

Log dividend strip prices, scaled by the current dividend, are also affine in the state variables

$$pd_t^{(n)} = C_{0,n} + C_{1,n}x_t + C_{2,n}\sigma_t^2.$$

To derive the recursion, we first compute the price of a 1-period strip

$$\begin{aligned} pd_t^{(1)} &= \ln E_t(M_{t+1}\exp(\Delta d_{t+1})) \\ &= -r_t^f + E_t(\Delta d_{t+1}) + \frac{1}{2}V_t(\Delta d_{t+1}) \\ &\quad + Cov_t(\Delta d_{t+1}, m_{t+1}) \\ &= C_{0,1} + C_{1,1}x_t + C_{2,1}\sigma_t^2, \end{aligned}$$

where

$$\begin{aligned} C_{0,1} &= -c_0 + \mu_d, \\ C_{1,1} &= -c_1 + \phi, \\ C_{2,1} &= -c_2 + \frac{1}{2}\left(\varphi^2 + \pi^2\right) - \lambda_\eta\pi. \end{aligned}$$

For the n–period strip, the calculations are

$$\begin{aligned} pd_t^{(n)} &= pd_t^{(1)} + E_t\left(pd_{t+1}^{(n-1)}\right) + \frac{1}{2}V_t\left(pd_{t+1}^{(n-1)}\right) \\ &\quad + Cov_t\left(pd_{t+1}^{(n-1)}, m_{t+1}\right) + Cov_t\left(pd_{t+1}^{(n-1)}, \Delta d_{t+1}\right) \\ &= C_{0,n} + C_{1,n}x_t + C_{2,n}\sigma_t^2, \end{aligned}$$

where

$$\begin{aligned} C_{0,n} &= C_{0,1} + C_{0,n-1} + C_{2,n-1}\bar{\sigma}^2(1-\nu) \\ &\quad + \frac{1}{2}C_{2,n-1}^2\sigma_w^2 - C_{2,n-1}\sigma_w^2\lambda_w, \\ C_{1,n} &= C_{1,1} + C_{1,n-1}\rho, \\ C_{2,n} &= C_{2,1} + C_{2,n-1}\nu + \frac{1}{2}C_{1,n-1}^2\varphi_e^2 - C_{1,n-1}\lambda_e\varphi_e. \end{aligned}$$

Appendix E. Additional table

See Table E.1

Table E.1
For each of the indexes, we report all the dividend futures contracts for which we have data. The first column of each index reports the expiration date of the contract. The second column reports the first day where we observe the futures price. We observe the futures prices at a daily frequency.

S&P 500		EuroStoxx 50		Nikkei 225		FTSE 100	
Expiration	Start date	Expiration	Start date	Expiration	Start date	Expiration	Start date
20-Dec-02	07-Oct-02	20-Dec-02	07-Oct-02	16-Dec-05	14-Jan-03	15-Dec-06	03-Jan-05
19-Dec-03	07-Oct-02	19-Dec-03	07-Oct-02	15-Dec-06	14-Jan-03	21-Dec-07	03-Jan-05
17-Dec-04	07-Oct-02	17-Dec-04	07-Oct-02	21-Dec-07	14-Jan-03	19-Dec-08	03-Jan-05
16-Dec-05	07-Oct-02	16-Dec-05	07-Oct-02	19-Dec-08	14-Jan-03	18-Dec-09	03-Jan-05
15-Dec-06	07-Oct-02	15-Dec-06	07-Oct-02	18-Dec-09	14-Jan-03	17-Dec-10	03-Jan-05
21-Dec-07	07-Oct-02	21-Dec-07	07-Oct-02	17-Dec-10	14-Jan-03	16-Dec-11	03-Jan-05
19-Dec-08	07-Oct-02	19-Dec-08	07-Oct-02	16-Dec-11	14-Jan-03	21-Dec-12	03-Jan-05
18-Dec-09	07-Oct-02	18-Dec-09	07-Oct-02	21-Dec-12	14-Jan-03	20-Dec-13	03-Jan-05
17-Dec-10	07-Oct-02	17-Dec-10	07-Oct-02	20-Dec-13	14-Jan-03	19-Dec-14	03-Jan-05
16-Dec-11	07-Oct-02	16-Dec-11	07-Oct-02	19-Dec-14	02-Jan-04	18-Dec-15	03-Jan-05
21-Dec-12	07-Oct-02	21-Dec-12	07-Oct-02	18-Dec-15	03-Jan-05	16-Dec-16	05-Jan-05
20-Dec-13	07-Oct-02	20-Dec-13	07-Oct-02	16-Dec-16	03-Jan-05	15-Dec-17	05-Jan-05
19-Dec-14	02-Jan-04	19-Dec-14	07-Oct-02	15-Dec-17	03-Jan-05	21-Dec-18	05-Jan-05
18-Dec-15	03-Jan-05	18-Dec-15	07-Oct-02	21-Dec-18	03-Jan-05	20-Dec-19	05-Jan-05
16-Dec-16	02-Jan-06	16-Dec-16	07-Oct-02	20-Dec-19	03-Jan-05	19-Dec-20	05-Jan-05
15-Dec-17	02-Jan-07	15-Dec-17	07-Oct-02	19-Dec-20	03-Jan-05	18-Dec-21	05-Jan-05
21-Dec-18	01-Jan-08	21-Dec-18	05-Feb-04	18-Dec-21	03-Jan-05		
20-Dec-19	07-Dec-09	20-Dec-19	05-Feb-04				
19-Dec-20	01-Apr-11	19-Dec-20	01-Apr-11				
18-Dec-21	01-Apr-11	18-Dec-21	01-Apr-11				

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