When Uncertainty Blows in the Orchard: Comovement & Equilibrium Volatility Risk Premia

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Motivation
Index & Individual RV and IV

① The average implied volatility of the constituents is 32.7% and the average realized volatility is 31.8% which yields a volatility risk premium of 0.9%.

② The average implied volatility of the index is 19.2% and the realized volatility amounts to 16.7%, which yields a volatility risk premium of 2.5%.
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Related Literature: Volatility Risk Premium

- Bakshi and Kapadia (2003), Bondarenko (2003): Similar evidence on **naked puts**.
- Du (2011): peso component in the consumption growth rate and time-varying risk aversion through habit formation.
- Yaron and Drechsler (2011), Drechsler (2011): long run risk, small source of (persistent) economic uncertainty can have long run effect under EZ preferences iff $EIS > 1$.

**Few structural studies on the differences between index and individuals or cross-section of individual options.**
Two theories exist so far to explain the difference in index and individual volatility risk premia:

① **Market frictions:** Option market demand and supply drive premia and demand is different in index and single-stock markets.
  
  - Bollen and Whaley (2004): Empirical evidence that net buying pressure is present in index option markets, especially OTM puts. Changes in IV in stock options is smaller and concentrated on calls.
  

② **Risk-based:** Driessen, Maenhout, and Vilkov (2009) argue that priced correlation risk explains the differential pricing of index and individual options. They remain, however, agnostic about how correlation risk premia emerge.
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   - Gârleanu, Pedersen, and Poteshman (2009): Equilibrium option prices are a function of demand pressure. End users have a net **long** position in S&P 500 index options, in particular OTM puts and a net **short** position in single-stock options.

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We study an extension of the Lucas (1978) model to multiple goods and incomplete information. The main focus lies on the impact of belief disagreement on the pricing of options and individual stocks.

Volatility risk premia are a compensation for a risk reallocation induced by disagreement.

Volatility is priced even in absence of EZ preferences.

The model contains three main ingredients:

1. **Uncertain** investment opportunity: Expected growth rate of dividends is stochastic.

2. **Heterogeneous** perception of uncertainty: Agents disagree on the volatility of growth rates.

3. **Limited Attention**: Use of aggregate indicators.
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We find that ...

- Disagreement increases (i) the **wedge** between index and individual volatility risk premia, (ii) the different **slope** of the smile of index and individual options and (iii) the **correlation** risk premium.

- We then study the risk return relationship of **option trading strategies** that exploit the volatility and correlation risk premium and find that disagreement explains a high fraction of the variation in straddle and dispersion portfolios.

- The estimated **factor price** is economically and statistically significant at 5%.

- Using a two pass Fama and MacBeth (1973) approach, we find that disagreement accounts for approximately $\frac{2}{3}$ ($\frac{1}{3}$) of the cross-sectional variation in straddle (dispersion) portfolios.

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Model
There are two firms in the economy which produce their perishable good. **Dividend dynamics** are as follows:

\[
\begin{align*}
    d \log D_i(t) &= \mu_{D_i}(t) dt + \sigma_{D_i} dW_{D_i}(t), \\
    d\mu_{D_i}(t) &= (a_0M + a_1M \mu_{D_i}(t)) dt + \sigma_{\mu_{D_i}} dW_{\mu_{D_i}}(t),
\end{align*}
\]

and a **signal** \( z(t) \), with dynamics:

\[
\begin{align*}
    dz(t) &= (\alpha_{D_1} \mu_{D_1}(t) + \alpha_{D_2} \mu_{D_2}(t) + \beta \mu_z(t)) dt + \sigma_z dW_z(t), \\
    d\mu_z(t) &= (a_0 + a_1 \mu_z(t)) dt + \sigma_{\mu_z} dW_{\mu_z}(t).
\end{align*}
\]

We interpret the signal as an economy-wide **business cycle indicator**. Dividends and the signal are observable, but their expected growth rates are unobservable and have to be **estimated** given the information.

**The informativeness of the signal** (\( \alpha_1 \) and \( \alpha_2 \)):

For \( \beta = 0 \), the signal produces unbiased estimates of the linear combination of firms’ growth rates. For \( \beta \neq 0 \), the signal is biased by another unobservable, orthogonal variable.
The **subjective expected growth rate** of cash flows and signals is 
\[ m^n(t) := E^n \left( (\mu_{D_1}(t), \mu_{D_2}(t), \mu_z(t)) | \mathcal{F}^Y_t \right). \]

Let \( Y(t) = (\log D_1(t), \log D_2(t), z(t)) \). The beliefs dynamics of agent \( n \) have the functional form (Kalman-Bucy filter):
\[
\begin{align*}
\frac{dm^n(t)}{dt} &= (a_0 + a_1 m^n(t))dt + \gamma^n(t) A' B^{-1} dW^Y_n(t), \\
\frac{d\gamma^n(t)}{dt} &= a_1 \gamma^n(t) + \gamma^n(t) a'_1 + b^n b'^n - \gamma^n(t) A'(BB')^{-1} A \gamma^n(t),
\end{align*}
\]
with initial conditions \( m^n(0) = m^n_0 \) and \( \gamma^n(0) = \gamma^n_0 \), where \( dW^Y_n(t) := B^{-1} (dY(t) - A m^n(t) dt) \) is the innovation process induced by investor’s \( n \) belief and filtration.

Heterogeneity in \( \sigma_\mu \) implies heterogeneity in \( \gamma(t) \) and thus in \( m(t) \).
The process

\[ \Psi(t) := (m^A(t) - m^B(t)) B^{-1} \]  

(1)

is the **disagreement process** in the economy.

The dynamics of the disagreement becomes a function of economic uncertainty and the informativeness of the signal (\(\alpha_1\) and \(\alpha_2\) inside \(A\)):

\[
d\Psi(t) = B^{-1} \left( a_1 B + \gamma^B(t) A' B^{-1} \right) \Psi(t) dt + B^{-1} (\gamma^A(t) - \gamma^B(t)) A' B^{-1} dW^A_Y(t).
\]

**Economic uncertainty**

**Diff. in Uncertainty**
We ask how we can generate co-movement given that fundamentals are very weakly linked.

The correlation among firm-specific uncertainty depends crucially on two different quantities:

1. The **informativeness of the signal** about the firms’ dividend growth rates, i.e. the size of the weights used for updating in the signal ($\alpha_{Di}$, $i = 1, 2$ and $\beta$).

2. The **amount of subjective economic uncertainty**. In particular, we study the impact of ...

   (i) ... the **average** subjective uncertainty, defined as 
   $$\bar{\sigma}_{\mu z} \equiv 0.5 \left( \sigma_{\mu z}^A + \sigma_{\mu z}^B \right)$$

   (ii) ... the **difference** in agents’ subjective uncertainty:
   $$\Delta \sigma_{\mu z} \equiv \sigma_{\mu z}^A - \sigma_{\mu z}^B.$$
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Uncertainty & Correlation in DiB

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Economic Uncertainty and DiB

Motivation
Model
$m(t)$
$\Psi(t)$
Uncertainty
Intuition
Preferences
Equilibrium
Return Corr
Simulation
Empirical Analysis
Conclusion
Appendix

1st Moment of Steady–State Distribution of $\Psi$

2nd Moment of Steady–State Distribution of $\Psi$

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Intuition for Common Disagreement

- When $\beta \neq 0$, the signal $z(t)$ is affected by an unobservable variable $\mu_z(t)$, which is independent of dividends.

- Relative size of $\alpha_{D_1}, \alpha_{D_2}$, versus $\beta$ determines the importance of the aggregate indicator to conduct inference.

- Smaller $\beta \Rightarrow$ Inference via the aggregate indicator.

- Limited attention literature:
  - Gilbert, Kogan, Lochstoer, and Ozyildirim (2011): Market response of investors focusing on summary statistics, instead of a wide array of fundamental information, can have an impact on stock prices, volatility, and trading volume.

- Smaller $\beta \Rightarrow$ More co-movement!
Preferences and Financial Market

Preferences:

\[ V^n = \sup_{c^n_{D_1}, c^n_{D_2}} E^n \left( \int_0^\infty e^{-\delta t} \left( \frac{c^n_{D_1}(t)^{1-\gamma}}{1-\gamma} + \frac{c^n_{D_2}(t)^{1-\gamma}}{1-\gamma} \right) \, dt \mid \mathcal{F}_0^Y \right), \]

Cochrane, Longstaff, and Santa-Clara (2008) and Martin (2011), \( U(C') \) with \( C = c_1 + c_2 \). The two goods are **perfectly substitutable** and the relative price is \( p = 1 \). \( \Rightarrow \) In this case, shocks to one tree immediately propagate, by construction, and correlation is hard-wired in preferences.

In this paper, \( U(C') = U(c_1) + U(c_2) \) and goods are **not perfect substitutes**. Preferences do not help in creating correlation. In this case, in absence of an uncertainty channel, correlation can be negative: Harder to explain positive correlation with complementary goods.

**Financial Market Structure:** Markets are **completed** by the firms’ capital structure: (i) Equity on each firm (tree) in positive net supply, (ii) option on equity, and (iii) and a risk-free asset.
Equilibrium in our economy:

The probabilistic approach originally developed by Cox and Huang (1986) is extended to the case of heterogeneous beliefs; see among others Cuoco and He (1994), Karatzas and Shreve (1998), and Basak and Cuoco (1998).

⇒ The equilibrium can be conveniently attained by constructing a representative investor with a stochastic weighting process that captures the impact of the beliefs disagreement:

Representative investor’s utility function: Separability of investors’ preferences over the consumption goods yields a separable utility function for the representative investor:

\[ U^n (c(t), \lambda(t)) = \sup_{c_{D_i}(t) = c_{A_i}(t) + c_{B_i}(t)} \left\{ \frac{c_{D_i}^A (t)^{1-\gamma}}{1-\gamma} + \lambda(t) \frac{c_{D_i}^B (t)^{1-\gamma}}{1-\gamma} \right\} , \]

where \( \lambda(t) > 0 \) is the stochastic weight that captures the impact of beliefs heterogeneity.
Standard computations yield the equilibrium quantities: The investors' **state price densities** are:

\[
\xi^A(t) = e^{-\delta t} D_1(t)^{-\gamma} \left[ \omega^A(\lambda_t) \right]^{-\gamma},
\]

Risk Sharing due to DiB

\[
\xi^B(t) = e^{-\delta t} D_1(t)^{-\gamma} \left[ \omega^A(\lambda_t) \right]^{-\gamma} \lambda(t)^{-1}.
\]

With \( \omega^A = c^A/c^B \) function of the **weighting process** \( \lambda(t) \) which follows:

\[
\frac{d\lambda(t)}{\lambda(t)} = - \left( \sum_{i=1}^{2} \Psi_{D_i}(t) dW^A_{D_i}(t) + \left( \sum_{i=1}^{2} \alpha_{D_i} \Psi_{D_i}(t) \frac{\sigma_{D_i}}{\sigma_z} + \beta \Psi_{z}(t) \right) dW^A_{z}(t) \right).
\]

We have **two sources** of risk:

1. **Aggregate endowment risk** ...
2. **Consumption share risk**: The optimist consumes less in bad states of the world. In exchange for absorbing risk of the pessimist, she requires a risk premium.
Endogenous Stock Return Correlation

Stock returns correlate because of a ...

① A **market-clearing** effect (see Cochrane et al., 2008). For symmetric economies this effect tends to be small.

② A **risk-sharing** effect. A higher $\Psi(t)$ implies a higher demand of the pessimist for protection from the optimist.

③ A **DiB-comovement** effect.
## Simulated Option Strategies

<table>
<thead>
<tr>
<th></th>
<th>DiB Strdl</th>
<th>Low DiB Disp</th>
<th>High DiB Disp</th>
<th>Short Put</th>
<th>Index</th>
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<tbody>
<tr>
<td><strong>Mean</strong></td>
<td>0.081</td>
<td>0.127</td>
<td>0.087</td>
<td>0.117</td>
<td>0.010</td>
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<td><strong>StDev</strong></td>
<td>0.273</td>
<td>0.231</td>
<td>0.242</td>
<td>0.653</td>
<td>0.038</td>
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<td><strong>Kurtosis</strong></td>
<td>6.938</td>
<td>7.532</td>
<td>7.146</td>
<td>8.477</td>
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<td><strong>Skewness</strong></td>
<td>1.102</td>
<td>-3.127</td>
<td>-4.154</td>
<td>-8.239</td>
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<tr>
<td><strong>Sharpe Ratio</strong></td>
<td>1.03</td>
<td>1.90</td>
<td>1.25</td>
<td>0.62</td>
<td>0.91</td>
</tr>
<tr>
<td><strong>Alpha</strong></td>
<td>0.081</td>
<td>0.079</td>
<td>0.065</td>
<td>0.091</td>
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<tr>
<td></td>
<td>(1.77)</td>
<td>(1.89)</td>
<td>(1.87)</td>
<td>(2.02)</td>
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<td><strong>MRKT</strong></td>
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<td>-0.889</td>
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<td></td>
<td>(1.25)</td>
<td>(-0.99)</td>
<td>(-1.04)</td>
<td>(2.00)</td>
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<td>$\epsilon^D$</td>
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<td>4.105</td>
<td>3.475</td>
<td>3.144</td>
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<tr>
<td></td>
<td>(2.67)</td>
<td>(3.04)</td>
<td>(2.48)</td>
<td>(2.07)</td>
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<td>$(\epsilon^D)^2$</td>
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<td></td>
<td>(-1.88)</td>
<td>(-1.61)</td>
<td>(-1.55)</td>
<td>(-1.64)</td>
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</table>
Empirical Analysis
For each firm $i$ in each month $t$, we calculate the cross-sectional standard deviation and consensus estimate of analysts forecasts of earnings per share from the unadjusted I/B/E/S database. **Firm specific disagreement** is then defined as:

$$ DiB_i(t) = \frac{\text{Cross-Sectional StDev}_i(t)}{\text{Consensus}_i(t)}. $$

**Common disagreement** is proxied using a market capitalization weighted average of firm individual disagreement:

$$ DiB = \frac{\sum_i \text{Mrkt Cap}_i(t) \times DiB_i(t)}{\text{Mrkt Cap}_i(t)}. $$
### Empirical Evidence VolRP & CorrRP

**Difference in VRP**

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient 1</th>
<th>Coefficient 2</th>
<th>Coefficient 3</th>
<th>Coefficient 4</th>
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<td>0.008***</td>
<td>0.009***</td>
<td>0.003***</td>
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<tr>
<td>DiB</td>
<td>0.131***</td>
<td>0.127***</td>
<td>0.127***</td>
<td>0.104***</td>
<td>0.105***</td>
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<tr>
<td>Common DiB</td>
<td>0.099**</td>
<td>0.082**</td>
<td>0.075**</td>
<td>0.101**</td>
<td>0.072**</td>
</tr>
<tr>
<td>Market Vola</td>
<td>0.104***</td>
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</tr>
<tr>
<td>ATM Vol Index</td>
<td>0.104**</td>
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<td>0.402**</td>
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<td>ATM Vol Individual</td>
<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Macro Factor</td>
<td>-0.098**</td>
<td>-0.101*</td>
<td>-0.101*</td>
<td>-0.105*</td>
<td>-0.107***</td>
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<td>CAPM Beta</td>
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<td>0.018*</td>
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<td>-0.101*</td>
<td>-0.105*</td>
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## Returns on Straddles and Dispersion Trades

<table>
<thead>
<tr>
<th></th>
<th>Straddles (Low)</th>
<th>Straddles (High)</th>
<th>LmH</th>
<th>Dispersion Trades (Low)</th>
<th>Dispersion Trades (High)</th>
<th>LmH</th>
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<tr>
<td><strong>Mean</strong></td>
<td>0.0719</td>
<td>-0.0872</td>
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<td><strong>Alpha</strong></td>
<td><strong>0.083</strong>**</td>
<td><strong>-0.104</strong></td>
<td><strong>0.186</strong></td>
<td><strong>0.094</strong></td>
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<td><strong>0.027</strong></td>
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<td>(2.01)</td>
<td>(-1.75)</td>
<td>(1.92)</td>
<td>(2.58)</td>
<td>(2.04)</td>
<td>(1.87)</td>
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<td><strong>MRKT</strong></td>
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<td>(-1.24)</td>
<td>(1.04)</td>
<td>(-0.42)</td>
<td>(-0.33)</td>
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<td><strong>SMB</strong></td>
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<td><strong>HML</strong></td>
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<td>(0.94)</td>
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<td><strong>MOM</strong></td>
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<td>(0.41)</td>
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<td>(1.38)</td>
<td>(-0.39)</td>
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<tr>
<td><strong>$\epsilon^D$</strong></td>
<td>0.934**</td>
<td>0.680**</td>
<td>0.252**</td>
<td>4.841***</td>
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<td>(1.67)</td>
<td>(1.98)</td>
<td>(2.58)</td>
<td>(2.14)</td>
<td>(1.99)</td>
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<tr>
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<td>0.903</td>
<td>-0.202</td>
<td>-0.372</td>
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<tr>
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<td>(0.97)</td>
<td>(1.02)</td>
<td>(-0.22)</td>
<td>(-0.28)</td>
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<tr>
<td><strong>$\epsilon^V$</strong></td>
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<td>1.235</td>
<td>-1.430</td>
<td>-2.184**</td>
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<td></td>
<td>(-1.04)</td>
<td>(1.03)</td>
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<td>(-1.84)</td>
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<td><strong>$\epsilon^S$</strong></td>
<td>0.287**</td>
<td>0.302**</td>
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<td>3.833**</td>
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<td><strong>$\epsilon^C$</strong></td>
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<td><strong>-0.199</strong>**</td>
<td><strong>0.016</strong></td>
<td><strong>-0.005</strong>***</td>
<td><strong>-0.011</strong>***</td>
<td><strong>0.006</strong>***</td>
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<td>(1.69)</td>
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<td><strong>Adj. $R^2$</strong></td>
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</table>

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Common disagreement explains about **two third (one third)** of the total cross-sectional variation of 15% (6%) in the excess returns of straddle (dispersion) portfolios.
Conclusion
The $\alpha$ in Goyal and Saretto is not market inefficiency; It is due to a priced risk and a mispecified regression.

Also, limited support for Bollen and Whaley demand pressure hypothesis.

We find significant risk channel due to disagreement. This drives the second moments of stock returns and the wedge between volatility risk premia of individual and index options and their volatility slopes.

Stochastic correlation arises endogenously in our economy due to diverging optimal consumer policies.

The wedge between the index and constituents volatility risk premia is driven by a correlation risk premium. This premium depends positively on disagreement, the amount of economic uncertainty, and the precision of the business-cycle indicator.

We find an economically significant price of disagreement risk which can explain two third of the cross-sectional variation of these trading strategies.
Appendix
Cochrane, Longstaff, and Santa-Clara (2008): Two trees with homogeneous agent with log utility and IID log dividend growth. Prices are hypergeometric functions of the dividend share.

Martin (2011): Power utility with $N \geq 2$ trees where dividend growth follows an IID Lévy process. The approach to solve for prices is the same as in our paper (and as in Dumas, Kurshev, and Uppal, 2009).

- Recover the conditional density of the state variables through Fourier inversion of the conditional characteristic function which in turn can be calculated using transform analysis.

In our setting, we have non IID state variables.

Chen and Joslin (2011) treat non IID state variables. Their approach avoids the intermediate Fourier inversion step.

Problem: Dynamics of $\Psi(t)$ are not affine. Solution: Extend state dynamics to include the quadratic variation of $\Psi(t)$.

This leads to an impossible to handle large state space!
The 2001 Twin-Tower Shock
The 2008 Credit Crisis: Correlation of DiB
The 2008 Credit Crisis: The Level of DiB

---

**Jul 07**: Bear Stearns unwinds two hedge funds. Ben Bernanke warns that U.S. sub-prime crisis could cost up to $100bn.

**9 Aug 07**: BNP Paribas tells it cannot value (and take money out of) two of its structured product funds. ECB pumps 95bn euro into banking sector.

**17 Aug 07**: Fed cuts rate and warns credit crunch could be a risk to economic growth.

**13 Sep 07**: Northern Rock asks emergency financial support from the BoE. A day later depositors withdraw £11bn: biggest run on a British bank for more than a century.

**15 Sep 08**: Lehman Brothers files for Chapter 11.

**16 Sep 08**: Rescue of AIG.


---

**Mar 08**: Collapse of Bear & Sterns. DJIA hits lowest level since 2006.

**11 July 08**: IndyMac fails (second largest financial bankruptcy in US history). Fannie Mae and Freddie Mac share prices drop 50%.

**14 Jul 08**: Emergency intervention to help Fannie Mae and Freddie Mac.

**7 Sep 08**: Federal takeover of the GSEs.

**15 Sep 08**: Lehman Brothers files for Chapter 11.

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