Discounting Investments that Save Energy Resources

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When we face the choices between...

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2-5 years

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50+ years

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- They usually involve tradeoffs between
  - higher up-front costs
  - a stream of future energy savings
  - Future outlays should be discount.
- The choice of discount rate is central in the cost-benefit analysis of such investments.

The Discount Rate

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- No agreed-upon discount rate in general
  - Weitzman's (2001) survey on discount rate gives it a range from -3% to 27% with a mean of 3.96%.
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- For energy-related projects
  - CAFE: 3% for inter-generational carbon benefits and 7% for intra-generational gas savings
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- Uncertainty in future discount rate

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  - The difference implies market failure, or at least incomplete markets

Research Question

What is the Market Discount Rate for

Energy-Related Projects under Uncertainty?

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  - uncertainty about the price of energy.
  - uncertainty about overall-market risk premium.
  - uncertain and time-varying risk premia associated with energy savings.

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Costs on Hybrid

Higher up-front cost

Benefits on Hybrid

A stream of future gas savings

Model Setup

Present Value of energy saving over T-period horizon:

$$S = P_1 \cdot exp(-\delta_1) + P_2 \cdot exp(-\delta_1 - \delta_2) + \cdots + P_T \cdot exp(-\sum_{\tau=1}^{T} \delta_\tau)$$

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- Vehicle miles traveled is independent of energy prices
- Per-period savings on amount of gasoline is normalized to one

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To predict P_τ and δ_τ and estimate savings over the next T periods

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To predict P_τ and δ_τ and estimate savings over the next T periods

- Step 1 Model dynamic time series to accommodate the time-variability of variables
- Step 2 Simulate the estimated models 1,000 times for P_τ and δ_τ
- Step 3 Calculate the average savings and the equivalent constant discount rate to get the same savings.

The Capital Asset Pricing Model (CAPM)

Estimating δ

$$\delta_\tau = r_\tau + \gamma_\tau$$

$$E(\gamma_t) = \beta_t \quad E(\gamma_t^m)$$

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Expected Asset Risk Premium

Asset-specific *beta*

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Expected Market Risk Premium

Estimating *Beta* Using Short-Window Regressions

- Estimate $\hat{\alpha}_\tau$ and $\hat{\beta}_\tau$ for each period τ using

$$\gamma_{i,\tau} = \alpha_\tau + \beta_\tau \gamma^m_{i,\tau} + \epsilon_{i,\tau}$$

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  - $\gamma_{i,\tau}$ and $\gamma^m_{i,\tau}$ are i^{th} asset risk premium and market risk premium within period τ.
  - Regression is estimated bi-weekly.

Correcting for Estimating Error

$$\hat{\beta}_t = \beta_t + \epsilon_t \tag{1}$$

$$\beta_t = \phi_0 + \phi_1 \beta_{t-1} + \upsilon_t \tag{2}$$

Correcting for Estimating Error

$$\hat{\beta}_t = \beta_t + \epsilon_t \quad (1)$$

$$\beta_t = \phi_0 + \phi_1 \beta_{t-1} + \upsilon_t \quad (2)$$

- $\epsilon_t | \psi_{t-1} \sim \mathcal{N}(0, h_{1,t})$
- $\upsilon_t | \psi_{t-1} \sim \mathcal{N}(0, h_{2,t})$
- where ψ_{t-1} refers to the information set up to $t-1$
- Modeled using Generalized Autoregressive Conditional Heteroskedasticity (GARCH)

$$h_{1,t} = a_0 + a_1 \epsilon_{t-1}^2 + a_2 h_{1,t-1}$$

$$h_{2,t} = b_0 + b_1 \upsilon_{t-1}^2 + b_2 h_{2,t-1} \quad (3)$$

Price, Market Return and Risk-free Return

Modeled using Vector Autoregressive of Order p

$$y_t = A_0 + A_1 y_{t-1} + \ldots + A_p y_{t-p} + u_t$$

$$y_t = \begin{bmatrix} P_t \\ r_t^m \\ r_t \\ cape_t \end{bmatrix} \quad and \quad u_t = \begin{bmatrix} u_{1,t} \\ u_{2,t} \\ u_{3,t} \\ u_{4,t} \end{bmatrix}$$

Data

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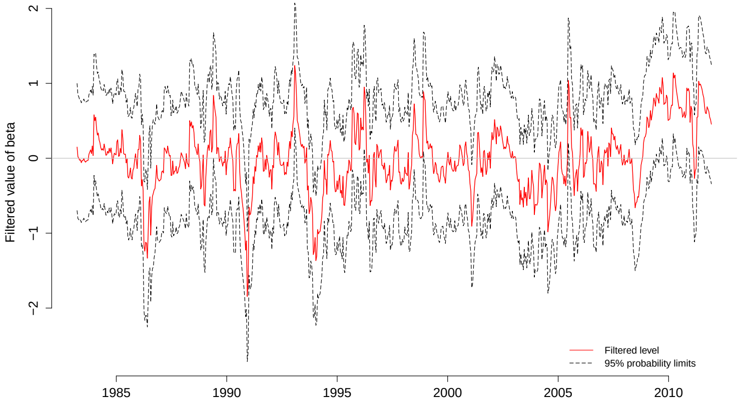
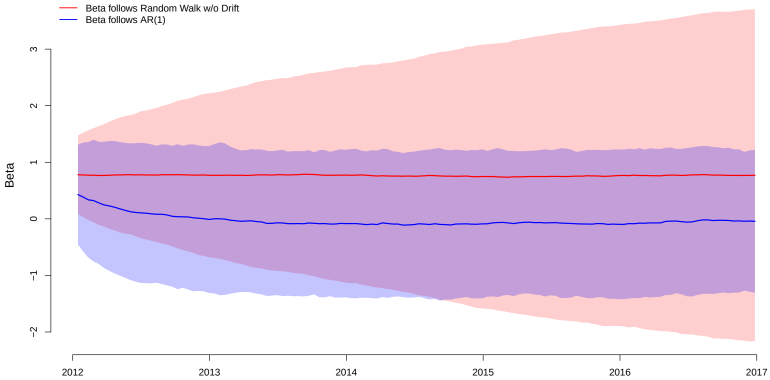
- Cyclically adjusted price earnings ratio interpolated from Shiller's monthly data

Filtered Beta 1983-2011

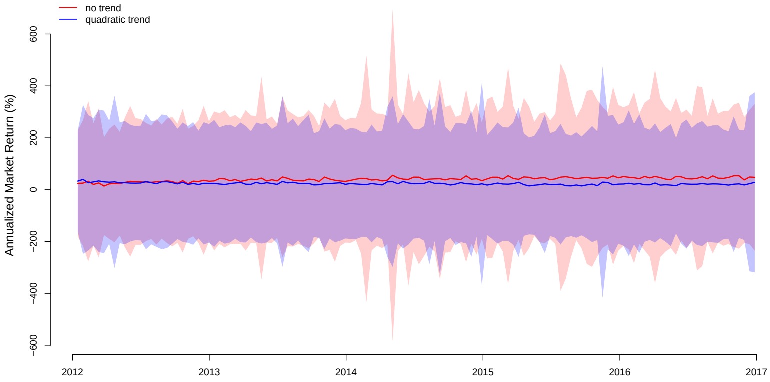
$$\beta_t = -0.0057 + 0.9234\beta_{t-1} + \upsilon_t$$



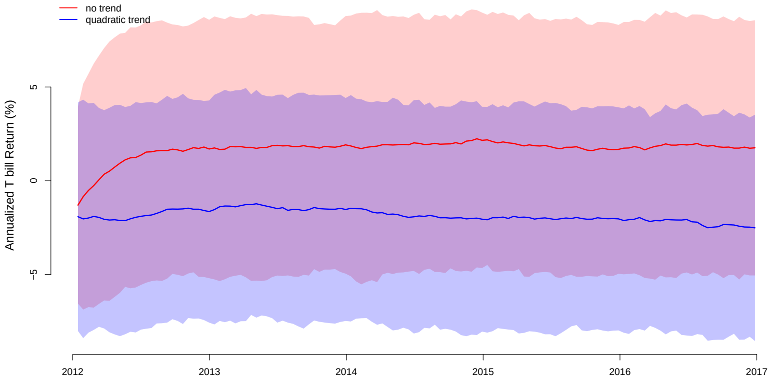
Average Predicted Beta with 95% ci



Average Predicted Market Return (%)

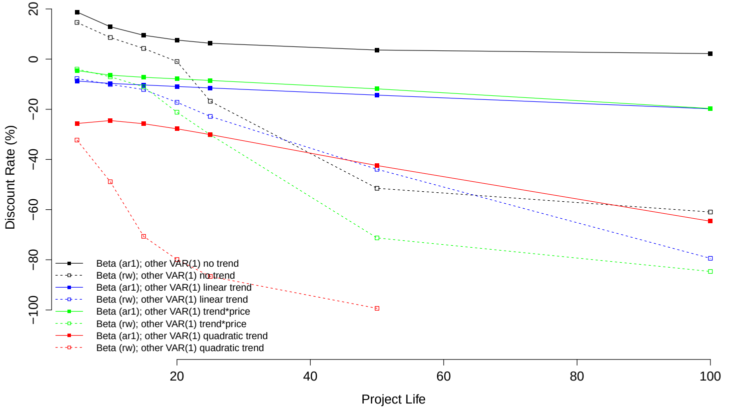


Average Predicted T Bill Return (%)



Equivalent Discount Rate by Project Life

The equivalent discount rate is the constant discount rate that gives us the same total present value of energy savings assuming energy price fixed at 2012 level.



Conclusion

- The market discount rate differ a lot from implicit rate
  - The longer the time horizon, the lower the discount rate
  - The more uncertainty, the lower the discount rate
- Why are we not investing more in renewable energy like solar and wind?

State Space Model with GARCH

$$\hat{\beta}_t = \begin{bmatrix} 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} \beta_t \\ \epsilon_t \\ \upsilon_t \end{bmatrix}$$

$$(\hat{\beta}_t = \quad H \quad \beta_t^*)$$

$$\begin{bmatrix} \beta_t \\ \epsilon_t \\ \upsilon_t \end{bmatrix} = \begin{bmatrix} \phi_0 \\ 0 \\ 0 \end{bmatrix} + \begin{bmatrix} \phi_1 & 0 & 0 \\ 0 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} \beta_{t-1} \\ \epsilon_{t-1} \\ \upsilon_{t-1} \end{bmatrix} + \begin{bmatrix} 0 & 1 \\ 1 & 0 \\ 0 & 1 \end{bmatrix} \begin{bmatrix} \epsilon_t \\ \upsilon_t \end{bmatrix}$$

$$(\beta_t^* = \mu^* + F \quad \beta_{t-1}^* + G \quad \upsilon_t^*)$$

Kalman Filter

Prediction Equations

$$
\begin{aligned}
\beta^*_{t|t-1} &= E(\beta^*_t | \psi_{t-1}) \\
&= \mu^* + F\beta^*_{t-1|t-1} \\
P^*_{t|t-1} &= E\left[(\beta^*_t - \beta^*_{t|t-1})(\beta^*_t - \beta^*_{t|t-1})'\right] \\
&= FP^*_{t-1|t-1}F' + GQ_tG' \\
\eta_{t|t-1} &= \hat{\beta}_t - E(\hat{\beta}_t | \psi_{t-1}) \\
&= \hat{\beta}_t - H\beta^*_{t|t-1} \\
f_{t|t-1} &= E(\eta^2_{t|t-1}) \\
&= HP^*_{t|t-1}H' \qquad (4)
\end{aligned}
$$

Kalman Filter (cont'd)

Updating equations:

$$\begin{aligned} \beta^*_{t|t} &= E(\beta^*_t | \psi_t) \\ &= \beta^*_{t|t-1} + P^*_{t|t-1} H' f^{-1}_{t|t-1} \eta_{t|t-1} \\ P^*_{t|t} &= E\left[(\beta^*_t - \beta^*_{t|t})(\beta^*_t - \beta^*_{t|t})'\right] \\ &= P^*_{t|t-1} - P^*_{t|t-1} H' f^{-1}_{t|t-1} \eta_{t|t-1} \end{aligned} \tag{5}$$

Maximum Likelihood Function:

$$ln(L) = -0.5 \sum_{t=1}^{T} ln\left[2\pi f^{-1}_{t|t-1}\right] - 0.5 \sum_{t=1}^{T} \eta'_{t|t-1} f^{-1}_{t|t-1} \eta_{t|t-1} \tag{6}$$

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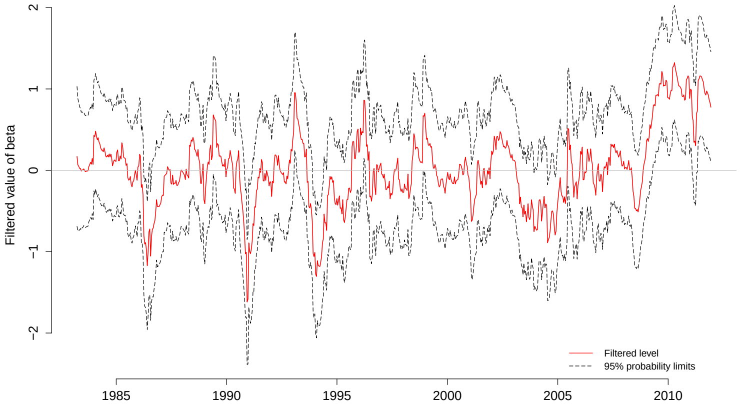
$$\beta_t = \beta_{t-1} + \upsilon_t$$



PV of Total Energy Savings[a] and the Equivalent Discount Rate (%)

	Oil Price Follows VAR(1) 5 Years	25 Years	50 Years	100 Years	Oil Price Follows Random Walk with no Drift 5 Years	25 Years	50 Years	100 Years
Beta follows AR(1) & Others VAR(1) w/ no trend	3.32E+02 (18.78)	1.27E+03 (6.33)	2.33E+03 (3.62)	4.06E+03 (2.20)	5.89E+02 (-6.28)	5.39E+03 (-5.38)	2.40E+04 (-5.07)	3.96E+05 (-5.21)
Beta follows RW & Others VAR(1) w/ no trend	3.60E+02 (14.63)	5.30E+04 (-16.80)	4.82E+17 (-51.50)	1.87E+42 (-60.96)	6.38E+02 (-9.04)	1.30E+06 (-28.58)	8.83E+17 (-52.12)	1.34E+43 (-61.76)
Beta follows AR(1) & Others VAR(1) w/ linear trend	6.31E+02 (-8.71)	1.65E+04 (-11.50)	1.48E+06 (-14.35)	1.73E+12 (-19.82)	6.43E+02 (-9.34)	1.23E+04 (-10.00)	5.23E+05 (-12.24)	2.28E+11 (-18.09)
Beta follows RW & Others VAR(1) w/ linear trend	6.14E+02 (-7.75)	2.48E+05 (-22.85)	4.93E+14 (-43.91)	4.13E+68 (-79.42)	6.24E+02 (-8.30)	1.08E+05 (-19.69)	2.50E+15 (-45.80)	6.04E+66 (-78.47)
Beta follows AR(1) & Others VAR(1) w/ price*trend	5.61E+02 (-4.57)	9.23E+03 (-8.50)	4.34E+05 (-11.85)	1.47E+12 (-19.69)	6.39E+02 (-9.09)	1.43E+04 (-10.79)	8.29E+05 (-13.18)	7.52E+12 (-21.05)
Beta follows RW & Others VAR(1) w/ price*trend	5.52E+02 (-3.98)	2.11E+06 (-30.15)	2.72E+28 (-71.28)	3.37E+80 (-84.66)	6.23E+02 (-8.28)	3.04E+06 (-31.30)	6.40E+28 (-71.80)	5.32E+80 (-84.74)
Beta follows AR(1) & Others VAR(1) w/ quadratic trend	1.14E+03 (-25.67)	2.07E+06 (-30.09)	1.44E+14 (-42.43)	2.32E+46 (-64.63)	6.36E+02 (-8.97)	1.46E+04 (-10.89)	3.53E+07 (-20.24)	2.87E+28 (-45.64)
Beta follows RW & Others VAR(1) w/ quadratic trend	1.53E+03 (-32.27)	6.13E+22 (-86.64)	2.24E+101 (-99.36)	Inf (NA)	8.26E+02 (-17.09)	5.03E+19 (-81.75)	3.57E+94 (-99.07)	Inf (NA)

Notes: Total Savings calculated by summing up average per period savings over years of interest, assuming 1 barrel of oil per year consumption.

$$TotalSaving = \sum_{\mathcal{T}=1}^{T}\left(\frac{1}{N}\sum_{n=1}^{N} P_{n,\mathcal{T}}\, exp\left(-\sum_{t=1}^{\mathcal{T}} \delta_{n,t}\right)\right)$$

Equivalent Discount Rate by Project Life