Dynamic ESG Equilibrium

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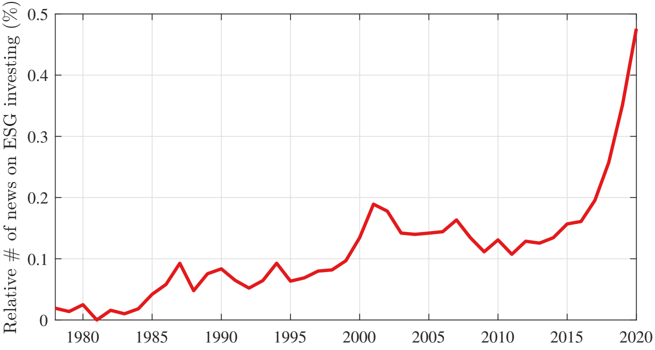
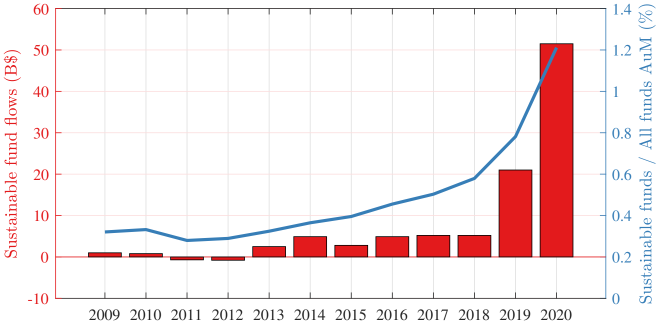
Background: surge in press attention for ESG investing



- Number of newspaper articles in Factiva including keywords on sustainable investing, relative to number of articles on investing

Background: U.S. sustainable fund flows



- Money flows into U.S. sustainable funds from 2009 to 2020
- Fraction of AuM of U.S. sustainable funds relative to entire U.S. mutual fund industry

Background: ESG-return relation

Existing asset pricing models with preferences for ESG (e.g., Heinkel, 2001; Pastor et al., 2021; Pedersen et al., 2021) based on **one period**

- Green assets provide **nonpecuniary benefits**
- In a static equilibrium, **negative ESG-return relation**

Empirical evidence on ESG-return relation is mixed

- **ESG uncertainty** (e.g., Avramov et al., 2021; Gibson et al., 2021; Berg et al., 2022)
- Tastes for ESG are dynamically **time varying**
  - Pastor et al. (2022): increasing climate concerns drive positive contemporaneous returns of green-minus-brown portfolio

This paper: dynamic ESG demand and supply

Model

- Equilibrium model with long-run risk (Bansal and Yaron, 2004)
- Agent's utility from consumption and portfolio ESG profile
- Time-varying preferences for ESG (ESG demand)
- Time-varying assets and market ESG scores (ESG supply)

Implications

- Convenience yield varying with ESG score and ESG demand
  - Green assets deliver **negative convenience yield premium**
- Shocks to ESG demand/scores drive contemporaneous returns
  - Green returns **positively correlated** with **ESG demand** shocks
- ESG demand is a novel risk source
  - Positive market price of risk (diminishing marginal utility)
  - Green assets deliver **positive ESG demand risk premium**

Representative agent's optimization problem

$$U_t = \max_{C_t, \boldsymbol{\omega}_t} \left((1-\beta) A_t^{1-\frac{1}{\psi}} + \beta \mathrm{E}_t \left[U_{t+1}^{1-\gamma} \right]^{\frac{1}{\theta}} \right)^{\frac{1}{1-\frac{1}{\psi}}} \quad \text{(utility)}$$

$$A_t = \underbrace{C_t}_{\substack{\text{physical}\\ \text{consumption}}} + \underbrace{\delta_t}_{\substack{\text{ESG}\\ \text{demand}}} \underbrace{G_{W,t}}_{\substack{\text{ESG}\\ \text{supply}}} \underbrace{(W_t - C_t)}_{\substack{\text{investable}\\ \text{wealth}}} \quad \text{(consumption bundle)}$$

$$G_{W,t} = \sum_{n=1}^{N} \underbrace{\omega_{n,t}}_{\substack{\text{portfolio}\\ \text{weight}}} \underbrace{G_{n,t}}_{\substack{\text{ESG score}\\ >0 \text{ (green)}\\ <0 \text{ (brown)}}} \quad \text{(aggregate ESG supply)}$$

$$W_{t+1} = (W_t - C_t) \left(R_{f,t+1} + \sum_{n=1}^{N} \omega_{n,t} \left(R_{n,t+1} - R_{f,t+1} \right) \right) \quad \text{(wealth)}$$

Euler equation for risky asset return

$$\mathrm{E}_t \left[\underbrace{M_{t+1}}_{\text{SDF}} R_{n,t+1} \right] = 1 - \underbrace{\delta_t G_{n,t}}_{\text{convenience yield}}$$

$$M_{t+1} = \beta^{\theta} \left(\frac{C_{t+1}}{C_t} \right)^{-\frac{\theta}{\psi}} \tilde{R}_{W,t+1}^{\theta-1} \left(\frac{1 + \delta_{t+1} G_{W,t+1} \frac{W_{t+1} - C_{t+1}}{C_{t+1}}}{1 + \delta_t G_{W,t} \frac{W_t - C_t}{C_t}} \right)^{-\frac{\theta}{\psi}}$$

3 factors:

- Consumption growth, $\frac{C_{t+1}}{C_t}$
- ESG-adjusted return on aggregate wealth, $\tilde{R}_{W,t+1} = \frac{R_{W,t+1}}{1 - \delta_t G_{W,t}}$
- Growth consumption bundle/physical consumption, $\frac{A_{t+1}/C_{t+1}}{A_t/C_t}$

Stochastic discount factor (SDF)

To solve for the SDF, the following dynamics are specified:

$$
\begin{aligned}
\Delta c_{t+1} &= \mu_c + x_t + \sigma_c \varepsilon_{c,t+1} \quad \text{(consumption growth)} \\
x_{t+1} &= \rho_x x_t + \sigma_x \varepsilon_{x,t+1} \quad \text{(expected consumption growth)} \\
G_{W,t+1} &= \mu_G + \rho_G G_{W,t} + \sigma_G \varepsilon_{G,t+1} \quad \text{(aggregate ESG supply)} \\
\delta_{t+1} &= \mu_\delta + \rho_\delta \delta_t + \sigma_\delta \varepsilon_{\delta,t+1} \quad \text{(aggregate ESG demand)}
\end{aligned}
$$

- Systematic risks: $\varepsilon_{c,t+1}, \varepsilon_{G,t+1}, \varepsilon_{\delta,t+1}, \varepsilon_{x,t+1} \sim \mathcal{N}(0,1)$ i.i.d.

Assume $\psi > 1$, $\bar{G}_W > 0$, and $\bar{\delta} > 0$, equilibrium SDF:

$$
\begin{aligned}
m_{t+1} = m_0 &+ \underbrace{m_G}_{>0} G_{W,t} + \underbrace{m_\delta}_{>0} \delta_t + \underbrace{m_x}_{<0} x_t \\
&- \underbrace{\lambda_c}_{>0} \varepsilon_{c,t+1} - \underbrace{\lambda_G}_{>0} \varepsilon_{G,t+1} - \underbrace{\lambda_\delta}_{>0} \varepsilon_{\delta,t+1} - \underbrace{\lambda_x}_{>0} \varepsilon_{x,t+1} \quad \text{(SDF)}
\end{aligned}
$$

Risky asset ESG score and dividend growth dynamics

Asset-n ESG score dynamics:

$$G_{n,t+1} = \mu_{Gn} + \rho_{Gn} G_{n,t} + \sigma_{Gn,G} \varepsilon_{G,t+1} + \sigma_{Gn} \varepsilon_{Gn,t+1}$$

Asset-n dividend growth:

$$\Delta d_{n,t+1} = \mu_{dn} + \rho_{dn,x} x_t + \sigma_{dn,c} \varepsilon_{c,t+1} + \sigma_{dn,dM} \varepsilon_{dM,t+1} + \sigma_{dn} \varepsilon_{dn,t+1}$$

Risky asset price-to-dividend ratio and return

Assume $\psi > 1$, $\bar{G}_W > 0$, and $\bar{\delta} > 0$, in equilibrium:

$$pd_{n,t} = A_{n,0} + \underbrace{A_{n,G}}_{>0} G_{W,t} + \underbrace{A_{n,\delta}}_{\substack{>0 \text{ if } \bar{G}_n > 0 \\ \text{increasing in } \bar{G}_n}} \delta_t + A_{n,x} x_t + \underbrace{A_{n,Gn}}_{>0} G_{n,t}$$

$$\begin{aligned} r_{n,t+1} = {} & r_{n,0} \underbrace{-m_G}_{<0} G_{W,t} + \underbrace{(\kappa_{n,\delta} - m_\delta)}_{<0 \text{ if } \bar{G}_n > 0} \delta_t \underbrace{-m_x}_{>0} x_t + \underbrace{\kappa_{n,Gn}}_{<0} G_{n,t} \\ & + \sigma_{dn,c} \varepsilon_{c,t+1} + \underbrace{\kappa_{rn,pd} A_{n,G} \sigma_G}_{>0} \varepsilon_{G,t+1} \\ & + \underbrace{\kappa_{rn,pd} A_{n,\delta} \sigma_\delta}_{>0 \text{ if } \bar{G}_n > 0} \varepsilon_{\delta,t+1} + \kappa_{rn,pd} A_{n,x} \sigma_x \varepsilon_{x,t+1} \\ & + \underbrace{\kappa_{rn,pd} A_{n,Gn} \sigma_{Gn}}_{>0} \varepsilon_{Gn,t+1} + \sigma_{dn,dM} \varepsilon_{dM,t+1} + \sigma_{dn} \varepsilon_{dn,t+1} \end{aligned}$$

Risky asset expected excess return

$$\mathsf{E}_t\left[r_{n,t+1} - r_{f,t+1}\right] + \frac{1}{2}\mathsf{Var}_t\left[r_{n,t+1}\right] =$$

$$\underbrace{\sigma_{dn,c}}_{\mathsf{Cov}_t[r_{n,t+1},\varepsilon_{c,t+1}]} \lambda_c + \underbrace{\kappa_{rn,pd}\left(A_{n,G}\sigma_G + A_{n,Gn}\sigma_{Gn,G}\right)}_{\mathsf{Cov}_t\left[r_{n,t+1},\varepsilon_{G,t+1}\right]}\lambda_G$$

$$+ \underbrace{\kappa_{rn,pd}A_{n,\delta}\sigma_\delta}_{\mathsf{Cov}_t\left[r_{n,t+1},\varepsilon_{\delta,t+1}\right] > 0 \text{ if } \bar{G}_n > 0} \lambda_\delta + \underbrace{\kappa_{rn,pd}A_{n,x}\sigma_x}_{\mathsf{Cov}_t[r_{n,t+1},\varepsilon_{x,t+1}]} \lambda_x$$

$$+ \underbrace{\log\left(1 - \bar{\delta}\bar{G}_n\right) - \frac{\bar{G}_n\left(\delta_t - \bar{\delta}\right)}{1 - \bar{\delta}\bar{G}_n} - \frac{\bar{\delta}\left(G_{n,t} - \bar{G}_n\right)}{1 - \bar{\delta}\bar{G}_n}}_{-y_{n,t} \text{ (convenience yield premium)}}$$

Expected return contributions of ESG

- ESG supply risk premium
- ESG demand risk premium > 0 for green assets (< 0 brown)
- Convenience yield premium < 0 for green assets (> 0 brown)

Data and estimation

Monthly asset-level ESG scores observing ratings from MSCI KLD (1991-2015), MSCI IVA (2007-2019), Refinitiv Asset4 (2002-2019)

- Normalize between -0.5 and 0.5 within each vendor's universe
- U.S. stocks with returns available on CRSP are retained
- On each date, ESG score averaged across available vendors
- Value-weighted market portfolio
- Brown/neutral/green (30/40/30) value-weighted portfolios

Estimation of the log-linearized model

- VAR(1) obtained stacking state variables and portfolio returns
- Unobservable long-run risk and ESG demand: Kalman filter

Parameter estimates

Economy-wide parameters (Θ_E) and market prices of risk									
γ	μ_c	σ_c	x_0	μ_G	ρ_G	σ_G	δ_0	$\bar{\delta}$	σ_δ
12.11057	0.00141	0.00925	0.00118	0.00030	0.99337	0.01064	0.00033	0.00035	0.00005
(1.11048)	(0.00059)	(0.00036)	(0.00210)	(0.00029)	(0.00641)	(0.00040)	(0.00015)	(0.00013)	(0.00000)
λ_c	λ_G	λ_δ	λ_x						
0.11199	0.00607	0.01267	0.17005						
(0.01099)	(0.00204)	(0.00154)	(0.01644)						

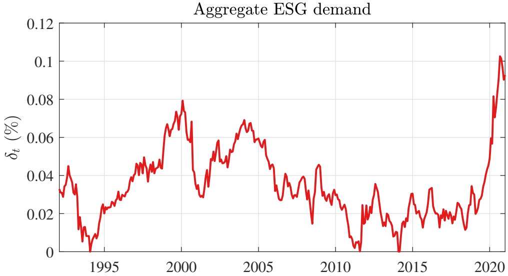
Market portfolio parameters (Θ_M)			
μ_{dM}	$\rho_{dM,x}$	$\sigma_{dM,c}$	σ_{dM}
0.00637	3.35832	0.00144	0.01267
(0.00084)	(0.26521)	(0.00222)	(0.00798)

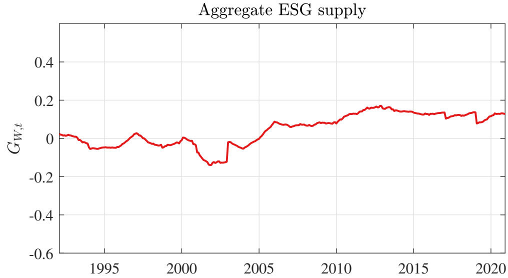
Brown portfolio parameters (Θ_{br})								
μ_{dbr}	$\rho_{dbr,x}$	$\sigma_{dbr,c}$	$\sigma_{dbr,dM}$	σ_{dbr}	μ_{Gbr}	ρ_{Gbr}	σ_{GbrG}	σ_{Gbr}
0.00714	3.58388	0.00383	0.00728	0.00181	-0.00369	0.98863	-0.00840	0.01683
(0.00076)	(0.22522)	(0.00243)	(0.00821)	(0.00229)	(0.00331)	(0.01020)	(0.00099)	(0.00065)

Neutral portfolio parameters (Θ_{neu})								
μ_{dneu}	$\rho_{dneu,x}$	$\sigma_{dneu,c}$	$\sigma_{dneu,dM}$	σ_{dneu}	μ_{Gneu}	ρ_{Gneu}	σ_{GneuG}	σ_{Gneu}
0.00632	3.34334	0.00061	0.02067	0.00455	-0.00033	0.96928	-0.00076	0.00730
(0.00113)	(0.37589)	(0.00241)	(0.01089)	(0.00220)	(0.00015)	(0.01414)	(0.00039)	(0.00028)

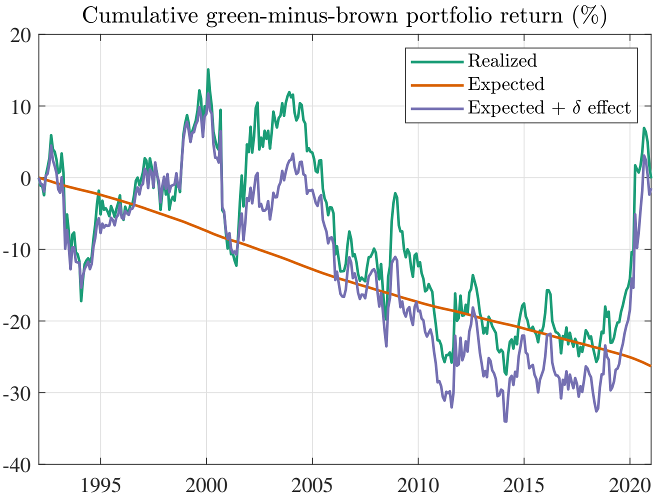
Green portfolio parameters (Θ_{gr})								
μ_{dgr}	$\rho_{dgr,x}$	$\sigma_{dgr,c}$	$\sigma_{dgr,dM}$	σ_{dgr}	μ_{Ggr}	ρ_{Ggr}	σ_{GgrG}	σ_{Ggr}
0.00633	3.33846	0.00123	0.00859	0.00725	0.00183	0.99434	0.01062	0.01440
(0.00076)	(0.22033)	(0.00222)	(0.00741)	(0.00055)	(0.00231)	(0.00717)	(0.00084)	(0.00054)

Aggregate ESG demand and supply

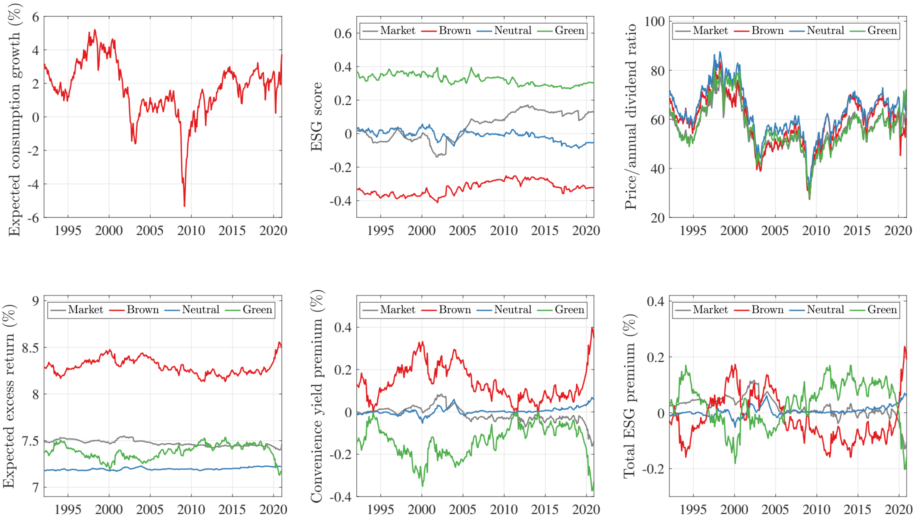




Returns of green-minus-brown portfolio



Estimated time series



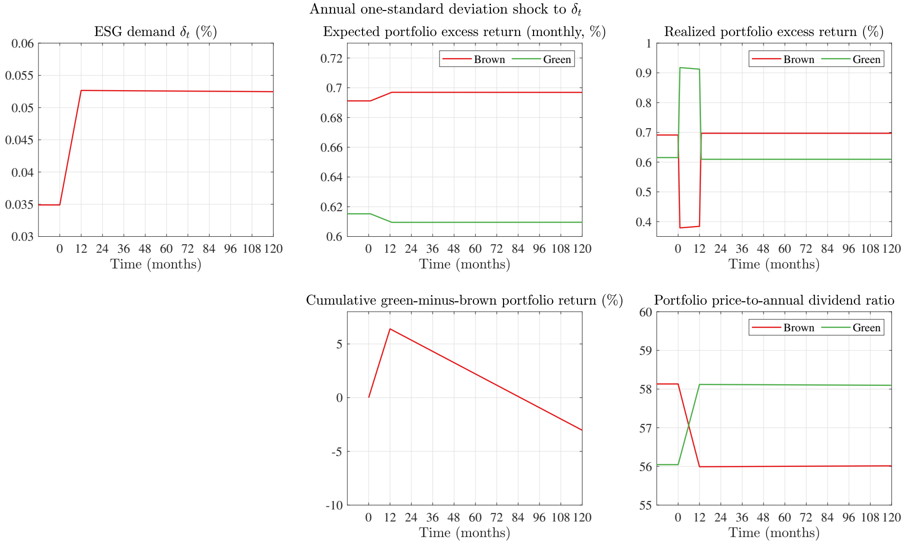
Estimated moments (full sample — 1992-2020)

Portfolio	Market	Brown	Green	Green-Brown
Data				
Avg. excess return	8.05%	8.26%	8.26%	-0.00%
Excess return volatility	14.82%	16.14%	15.04%	8.06%
Model				
Short-run consumption risk premium	0.19%	0.51%	0.17%	-0.35%
	(0.31%)	(0.33%)	(0.31%)	(0.17%)
Long-run consumption risk premium	8.38%	9.11%	8.33%	-0.79%
	(0.94%)	(0.82%)	(0.80%)	(0.15%)
ESG supply risk premium	0.01%	0.01%	0.01%	0.01%
	(0.01%)	(0.01%)	(0.01%)	(0.00%)
ESG demand risk premium	0.02%	-0.16%	0.16%	0.32%
	(0.00%)	(0.02%)	(0.02%)	(0.04%)
Avg. convenience yield premium	-0.01%	0.14%	-0.14%	-0.28%
	(0.01%)	(0.05%)	(0.05%)	(0.10%)
Avg. exp. excess return	7.48%	8.30%	7.38%	-0.92%
	(0.91%)	(0.79%)	(0.79%)	(0.22%)
Avg. exp. excess return + δ-induced return	7.51%	7.83%	7.78%	-0.05%
	(0.91%)	(0.78%)	(0.81%)	(0.33%)
Excess return volatility	14.91%	16.18%	15.12%	8.00%
	(0.24%)	(0.17%)	(0.21%)	(0.14%)

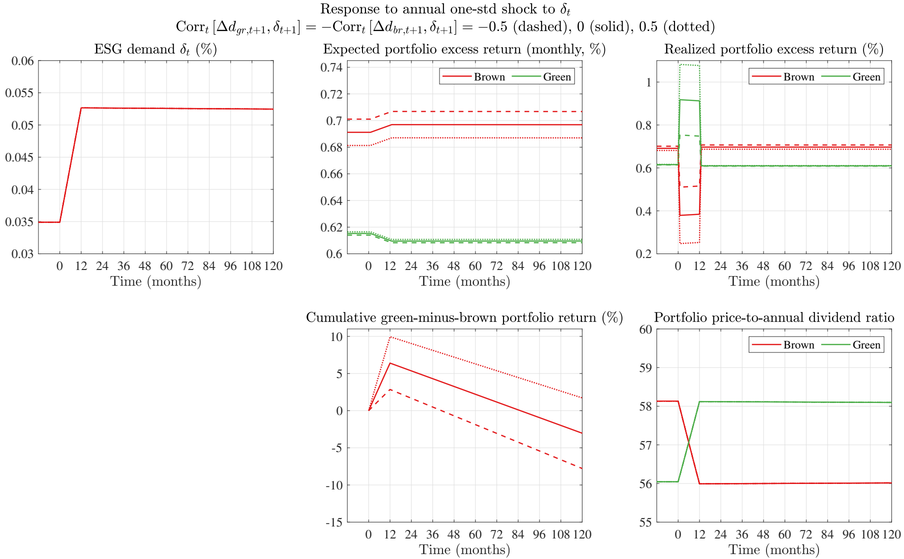
Estimated moments (subsample — 2018-2020)

Portfolio	Market	Brown	Green	Green-Brown
Data				
Avg. excess return	12.27%	7.01%	14.21%	7.19%
Model				
Short-run consumption risk premium	0.19%	0.51%	0.17%	-0.35%
	(0.31%)	(0.33%)	(0.31%)	(0.17%)
Long-run consumption risk premium	8.38%	9.11%	8.33%	-0.79%
	(0.94%)	(0.82%)	(0.80%)	(0.15%)
ESG supply risk premium	0.01%	0.01%	0.01%	0.01%
	(0.01%)	(0.01%)	(0.01%)	(0.00%)
ESG demand risk premium	0.02%	-0.16%	0.16%	0.32%
	(0.00%)	(0.02%)	(0.02%)	(0.04%)
Avg. convenience yield premium	-0.06%	0.17%	-0.16%	-0.33%
	(0.03%)	(0.08%)	(0.07%)	(0.15%)
Avg. exp. excess return	7.43%	8.33%	7.36%	-0.97%
	(0.91%)	(0.80%)	(0.78%)	(0.27%)
Avg. exp. excess return + δ-induced return	8.08%	3.58%	11.96%	8.39%
	(0.92%)	(0.96%)	(0.98%)	(1.16%)

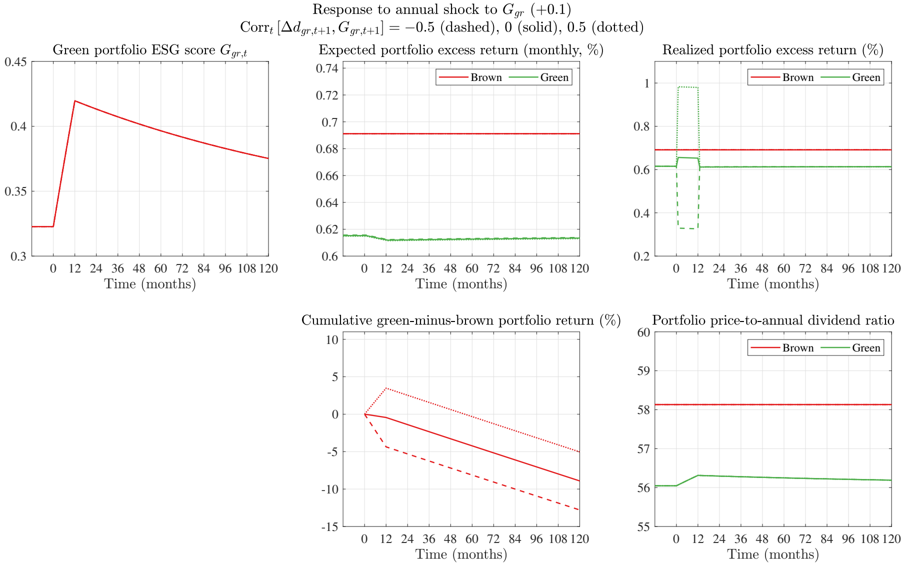
Shock to aggregate ESG demand



Impact of casflows' correlation with ESG demand



Impact of casflows' correlation with ESG score

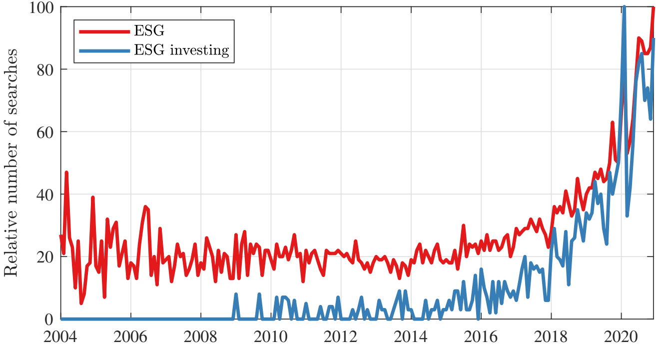


Conclusion

- Filtered ESG demand shows significant time variation
  - Nonpecuniary benefits from ESG investing account for a nontrivial and growing fraction of total consumption
- Expected return of green assets
  - Time-varying negative convenience yield premium
  - Positive ESG demand risk premium
  - ESG-expected return relation can be either positive or negative
- Realized return of green assets
  - Increasing ESG demand drives contemporaneous positive and large return
  - The cumulative effect could last for several years

Additional material

Background: surge in web attention for ESG investing



- Trends in US web searches for "ESG" and "ESG investing"

Expected excess asset return

Compensation for exposure to 3 risk factors and convenience yield

$$\mathrm{E}_t\left[r_{n,t+1} - r_{f,t+1}\right] + \frac{1}{2}\mathrm{Var}_t\left[r_{n,t+1}\right] =$$
$$\frac{\theta}{\psi}\mathrm{Cov}_t\left[\Delta c_{t+1}, r_{n,t+1}\right] + (1-\theta)\,\mathrm{Cov}_t\left[\tilde{r}_{W,t+1}, r_{n,t+1}\right]$$
$$+\frac{\theta}{\psi}\mathrm{Cov}_t\left[\log\left(\frac{1+\delta_{t+1}G_{W,t+1}\frac{W_{t+1}-C_{t+1}}{C_{t+1}}}{1+\delta_t G_{W,t}\frac{W_t - C_t}{C_t}}\right), r_{n,t+1}\right] - y_{n,t}$$

- $\Delta c_{t+1} = \log\frac{C_{t+1}}{C_t}$
- $r_{n,t+1} = \log R_{n,t+1},\ r_{f,t+1} = \log R_{f,t+1},\ \tilde{r}_{W,t+1} = \log \tilde{R}_{W,t+1}$
- Convenience yield: $y_{n,t} = -\log\left(1 - \delta_t G_{n,t}\right)$

Price-to-consumption ratio, return on wealth, SDF

$$
\begin{aligned}
pc_t &= A_{pc,0} + A_{pc,G} G_{W,t} + A_{pc,\delta}\delta_t + A_{pc,x} x_t \quad \text{(price/consumption)} \\
r_{W,t+1} &= r_{W,0} - A_{pc,G}\left(1 - \kappa_{rW,pc}\rho_G\right) G_{W,t} - A_{pc,\delta}\left(1 - \kappa_{rW,pc}\rho_\delta\right)\delta_t \\
&\quad + \left(1 - A_{pc,x}\left(1 - \kappa_{rW,pc}\rho_x\right)\right) x_t \\
&\quad + A_{pc,G}\kappa_{rW,pc}\sigma_G\varepsilon_{G,t+1} + A_{pc,\delta}\kappa_{rW,pc}\sigma_\delta\varepsilon_{\delta,t+1} \\
&\quad + A_{pc,x}\kappa_{rW,pc}\sigma_x\varepsilon_{x,t+1} + \sigma_c\varepsilon_{c,t+1} \quad \text{(return on wealth)} \\
m_{t+1} &= m_0 + m_G G_{W,t} + m_\delta\delta_t + m_x x_t \\
&\quad - \lambda_c\varepsilon_{c,t+1} - \lambda_G\varepsilon_{G,t+1} - \lambda_\delta\varepsilon_{\delta,t+1} - \lambda_x\varepsilon_{x,t+1} \quad \text{(SDF)}
\end{aligned}
$$

where

- $A_{pc,G}, A_{pc,\delta}, A_{pc,x} > 0$ (assuming $\bar{\delta} > 0$ and $\bar{G}_W \geq 0$)
- Four sources of systematic risk: $\varepsilon_{c,t+1}, \varepsilon_{G,t+1}, \varepsilon_{\delta,t+1}, \varepsilon_{x,t+1}$
- Market prices of risk: $\lambda_c, \lambda_G, \lambda_\delta, \lambda_x > 0$

Risk-free rate of return

$$r_{f,t+1} = -m_0 - \frac{\lambda_c^2}{2} - \frac{\lambda_G^2}{2} - \frac{\lambda_\delta^2}{2} - \frac{\lambda_x^2}{2} - \underbrace{m_G}_{>0} G_{W,t} - \underbrace{m_\delta}_{>0} \delta_t - \underbrace{m_x}_{<0} x_t$$

Market price-to-dividend ratio and return

Market ESG score and dividend growth process:

$$G_{M,t} = G_{W,t}$$
$$\Delta d_{M,t+1} = \mu_{dM} + \rho_{dM,x} x_t + \sigma_{dM,c} \varepsilon_{c,t+1} + \sigma_{dM} \varepsilon_{dM,t+1}$$

Assume $\psi > 1$ and $\bar{\delta} > 0$, in equilibrium:

$$pd_{M,t} = A_{M,0} + \underbrace{A_{M,G}}_{>0} G_{W,t} + \underbrace{A_{M,\delta}}_{>0 \text{ if } \bar{G}_W > 0} \delta_t + \underbrace{A_{M,x}}_{>0} x_t$$

$$r_{M,t+1} = r_{M,0} + \underbrace{(\kappa_{W,G} - m_G)}_{<0} G_{W,t} + \underbrace{(\kappa_{W,\delta} - m_\delta)}_{<0 \text{ if } \bar{G}_W > 0} \delta_t \underbrace{- m_x}_{>0} x_t$$
$$+ \underbrace{\kappa_{rM,pd} A_{M,G} \sigma_G}_{>0} \varepsilon_{G,t+1} + \underbrace{\kappa_{rM,pd} A_{M,\delta} \sigma_\delta}_{>0 \text{ if } \bar{G}_W > 0} \varepsilon_{\delta,t+1}$$
$$+ \underbrace{\kappa_{rM,pd} A_{M,x} \sigma_x}_{>0} \varepsilon_{x,t+1} + \underbrace{\sigma_{dM,c}}_{>0} \varepsilon_{c,t+1} + \sigma_{dM} \varepsilon_{dM,t+1}$$

Market expected excess return

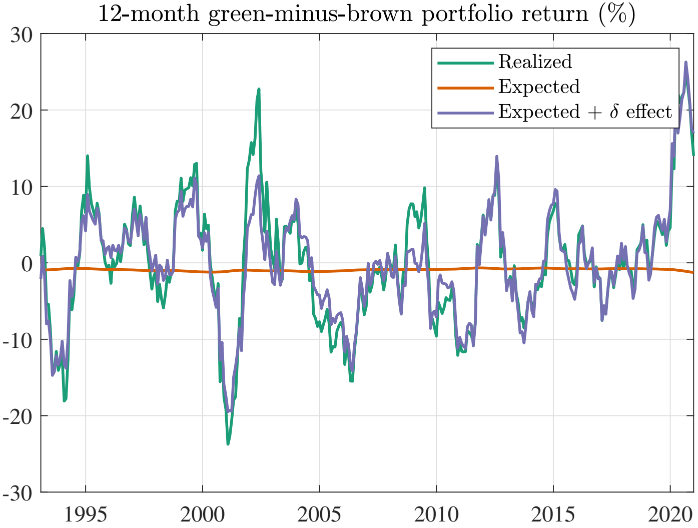
$$\mathrm{E}_t\left[r_{M,t+1}-r_{f,t+1}\right]+\frac{1}{2}\mathrm{Var}_t\left[r_{M,t+1}\right]=$$

$$\underbrace{\sigma_{dM,c}}_{\mathrm{Cov}_t\left[r_{M,t+1},\varepsilon_{c,t+1}\right]>0}\lambda_c+\underbrace{\kappa_{rM,pd}A_{M,G}\sigma_G}_{\mathrm{Cov}_t\left[r_{M,t+1},\varepsilon_{G,t+1}\right]>0}\lambda_G$$

$$+\underbrace{\kappa_{rM,pd}A_{M,\delta}\sigma_\delta}_{\mathrm{Cov}_t\left[r_{M,t+1},\varepsilon_{\delta,t+1}\right]>0\text{ if }\bar{G}_W>0}\lambda_\delta+\underbrace{\kappa_{rM,pd}A_{M,x}\sigma_x}_{\mathrm{Cov}_t\left[r_{M,t+1},\varepsilon_{x,t+1}\right]>0}\lambda_x$$

$$+\underbrace{\log\left(1-\bar{\delta}\bar{G}_W\right)-\frac{\bar{\delta}\left(G_{W,t}-\bar{G}_W\right)}{1-\bar{\delta}\bar{G}_W}-\frac{\bar{G}_W\left(\delta_t-\bar{\delta}\right)}{1-\bar{\delta}\bar{G}_W}}_{-y_{M,t}\text{ (convenience yield premium)}}$$

Returns of green-minus-brown portfolio



Shock to aggregate ESG supply