Time-varying Environmental Betas and Latent Green Factors

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Research question

Do environmental and ESG characteristics *really* matter to explain the cross section of US stock returns?

If so, which characteristics matter more? And how do they affect returns?

Motivations

Do ESG and environmental metrics affect returns?

- Characteristics that proxy companies' environmental footprint may be used to build long-short portfolios: see e.g. Pastor et al. (2022), Hsu et al. (2022), Alessi et al. (2020), In et al. (2019), Cheema-Fox et al. (2021)
- or as explanatory variables for returns: see e.g. Bolton and Kacperczyk (2022) and Bolton and Kacperczyk (2021)

By choosing different "E" measures, the literature gets different results: sign and significance of the "greenium" is not clear, when controlling for other "standard" characteristics

Main idea of the paper (1)

- We use a model that allows to extract factors from a potentially large set of characteristics -> as IPCA
- and that allows to easily **interpret** these factors -> **new constrained IPCA**
- Our new specification allows:
  - to identify and estimate an environmental risk factor f_{t+1} and its loadings $\beta_{i,t}$ by starting from a large set of observable instruments $z_{i,t}^G$ commonly used to proxy the greenness of companies
  - while controlling for a large set of standard "financial metrics" $z_{i,t}^F$
- Our conditional model will speak out about the role of $z_{i,t}^G$ in explaining equity returns

Main idea of the paper (2)

- Lindsey, Pruitt, and Shiller (2022) use a similar methodology alongside ESG data. There are three main differences between our work and theirs, as we:
  - **extend IPCA to clearly separate the factors associated to environmental characteristics** and financial characteristics
  - perform also sectoral analysis

Preview of main findings

Do environmental and ESG characteristics *really* matter to explain the cross section of US stock returns?

- Yes, but...
- ...only as a factor which explains the returns of a few sectors: Oil and Utilities

Which characteristics matter?

- Emissions-based characteristics are the most important

Introduction - IPCA

The original IPCA model specification in Kelly, Pruit, and Su (JFE 2019) is:

$$r_{i,t+1} = \alpha_{i,t} + \beta_{i,t} f_{t+1} + \varepsilon_{i,t+1}$$

- $r_{i,t+1}$ = excess return of the stock i
- f_{t+1} = vector of the K latent risk factors

Loadings are defined as a linear combination of a set of characteristics

$$\beta_{i,t} = z'_{i,t}\Gamma_\beta + \nu_{\beta,i,t} \; ; \qquad \alpha_{i,t} = z'_{i,t}\Gamma_\alpha + \nu_{\alpha,i,t}$$

- $z'_{i,t}$ = $(1 \times L)$ vector of observable firm-level characteristics of company i
- Γ_β = $(L \times K)$ matrix mapping the L characteristics to the K latent risk factors with $L \geq K$
- Γ_α = $(L \times 1)$ vector mapping the L characteristics to the $\alpha_{i,t}$

In a more compact form:

$$r_{t+1} = Z_t\Gamma_\alpha + Z_t\Gamma_\beta f_{t+1} + \varepsilon^*_{t+1}$$

Model specification

- We allow for the presence of two sets of factors: **"financial"** and **environmental** factors
- Loadings of **financial** (**environmental**) factors depend only on **financial** (**environmental**) characteristics:

$$r_{t+1} = \boldsymbol{Z}_t^{\boldsymbol{F}} \Gamma_{\alpha}^{\boldsymbol{F}} + \boldsymbol{Z}_t^{\boldsymbol{F}} \Gamma_{\beta}^{\boldsymbol{F}} \boldsymbol{f}_{t+1}^{\boldsymbol{F}} + \boldsymbol{Z}_t^{\boldsymbol{G}} \Gamma_{\alpha}^{\boldsymbol{G}} + \boldsymbol{Z}_t^{\boldsymbol{G}} \Gamma_{\beta}^{\boldsymbol{G}} \boldsymbol{f}_{t+1}^{\boldsymbol{G}} + \varepsilon_{t+1}^{**} \qquad (1)$$

- $\boldsymbol{Z}_t^{\boldsymbol{F}}$ ($\boldsymbol{Z}_t^{\boldsymbol{G}}$) = $\boldsymbol{N} \times \boldsymbol{L_F}$ ($\boldsymbol{N} \times \boldsymbol{L_G}$) matrix of **financial** (**environmental**) characteristics for all companies at a given time t
- $\Gamma_{\beta}^{\boldsymbol{F}}$ ($\Gamma_{\beta}^{\boldsymbol{G}}$) = $\boldsymbol{L_F} \times \boldsymbol{K_F}$ ($\boldsymbol{L_G} \times \boldsymbol{K_G}$) matrix mapping the $\boldsymbol{L_F}$ **financial** ($\boldsymbol{L_G}$ **environmental**) characteristics in the $\boldsymbol{K_F}$ **financial** ($\boldsymbol{K_G}$ **environmental**) factors
- $\Gamma_{\alpha}^{\boldsymbol{F}}$ ($\Gamma_{\alpha}^{\boldsymbol{G}}$) = $\boldsymbol{L_F} \times 1$ ($\boldsymbol{L_G} \times 1$) vector mapping the $\boldsymbol{L_F}$ **financial** ($\boldsymbol{L_G}$ **environmental**) characteristics in the alpha
- $\boldsymbol{f}_{t+1}^{\boldsymbol{F}}$ ($\boldsymbol{f}_{t+1}^{\boldsymbol{G}}$) = $\boldsymbol{K_F} \times 1$ ($\boldsymbol{K_G} \times 1$) vector of **financial** (**environmental**) factor returns at a given time $t+1$

Intuition: a constrained IPCA model

- Equation (1) can be written as the original IPCA specification with a constrained Γ_β that we call $\tilde{\Gamma}_\beta$:

$$r_{t+1} = Z_t \Gamma_\alpha + Z_t \tilde{\Gamma}_\beta f_{t+1} + \varepsilon_{t+1}$$

$$r_{t+1} = \underbrace{\begin{bmatrix} Z_t^F & Z_t^G \end{bmatrix}}_{=Z_t} \underbrace{\begin{bmatrix} \Gamma_\alpha^F \\ \Gamma_\alpha^G \end{bmatrix}}_{=\Gamma_\alpha} + \underbrace{\begin{bmatrix} Z_t^F & Z_t^G \end{bmatrix}}_{=Z_t} \underbrace{\begin{bmatrix} \Gamma_\beta^F & 0_{L^F \times K^G} \\ 0_{L^G \times K^F} & \Gamma_\beta^G \end{bmatrix}}_{=\tilde{\Gamma}_\beta} \underbrace{\begin{bmatrix} f_{t+1}^F \\ f_{t+1}^G \end{bmatrix}}_{=f_{t+1}} + \varepsilon_{t+1}$$

Model assumptions

As in the original IPCA by Kelly et al. (2019), we impose the identification assumptions:

- $\tilde{\Gamma}'_{\beta}\tilde{\Gamma}_{\beta} = \mathbb{I}_{K_F+K_G}$
- the time-series average of each factor is non-negative
- the orthogonality within financial factors and **within** environmental factors:

$$\sum_{t=1}^{T} f_t^F f_t^{F\prime} = diagonal_{K^F}, \qquad \sum_{t=1}^{T} f_t^G f_t^{G\prime} = diagonal_{K^G}$$

For better factor interpretability, we also impose orthogonality **between** environmental and financial factors as constraint:

$$\sum_{t=1}^{T} f_t^F f_t^{G\prime} = 0_{K^F \times K^G}$$

Estimation I

- Let us define $f = [f_1, f_2, ..., f_T]$ containing the time series of the factors
- Our estimation objective is to minimize the sum squared model errors:

$$h(\Gamma_\beta^F, \Gamma_\beta^G, f) \equiv \sum_{t=0}^{T-1} (r_{t+1} - Z_t \tilde{\Gamma}_\beta f_{t+1})'(r_{t+1} - Z_t \tilde{\Gamma}_\beta f_{t+1}) \qquad (2)$$

- subject to the constraint:

$$g(f) \equiv \sum_{t=0}^{T-1} f_{t+1}^F f_{t+1}^G = \mathbf{0}_{K^F \times 1}$$

- The Lagrangian is

$$\mathscr{L}(\Gamma_\beta^F, \Gamma_\beta^G f, \lambda) = h(\Gamma_\beta^F, \Gamma_\beta^G f) - \lambda' g(f)$$

where $\tilde{\Gamma}_\beta$ contains Γ_β^F and Γ_β^G.

Estimation II

- the FOCs are:

$$\hat{f}_{t+1} = (\widehat{\tilde{\Gamma}'}_{\beta} Z_t' Z_t \widehat{\tilde{\Gamma}}_{\beta} - \Lambda)^{-1} \widehat{\tilde{\Gamma}'}_{\beta} Z_t' r_{t+1}, \ \forall t$$

$$\sum_{t=1}^{T-1} f_{t+1}^{F} f_{t+1}^{G\prime} = \mathbf{0}_{K^F \times 1}$$

$$\text{vec}(\hat{\Gamma}_{\beta}^{F\prime}) = \left(\sum_{t=1}^{T-1} {Z^{F}}'_t Z_t^F \otimes \hat{f}_{t+1}^{F} \hat{f}_{t+1}^{F\prime} \right)^{-1} \left(\sum_{t=1}^{T-1} \left[Z_t^F \otimes \hat{f}_{t+1}^{F\prime} \right]' \left(r_{t+1} - Z_t^G \hat{\Gamma}_{\beta}^{G} \hat{f}_{t+1}^{G} \right) \right)$$

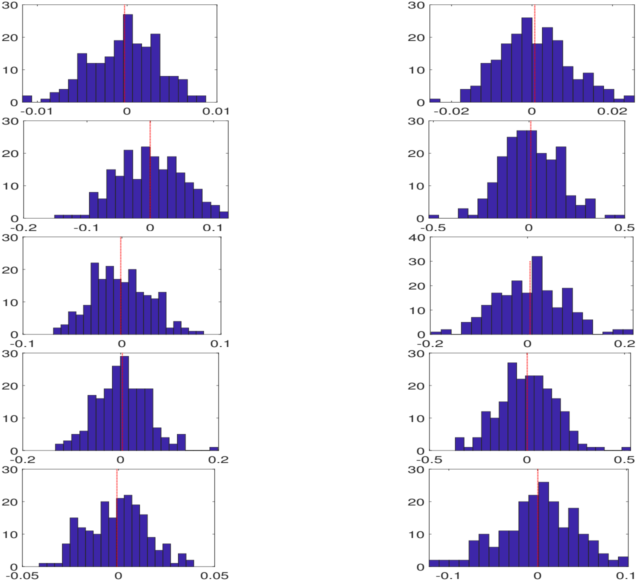
$$\text{vec}(\hat{\Gamma}_{\beta}^{G\prime}) = \left(\sum_{t=1}^{T-1} {Z^{G}}'_t Z_t^G \otimes \hat{f}_{t+1}^{G} \hat{f}_{t+1}^{G\prime} \right)^{-1} \left(\sum_{t=1}^{T-1} \left[Z_t^G \otimes \hat{f}_{t+1}^{G\prime} \right]' \left(r_{t+1} - Z_t^F \hat{\Gamma}_{\beta}^{F} \hat{f}_{t+1}^{F} \right) \right)$$

- We estimate the model by using alternating least squares

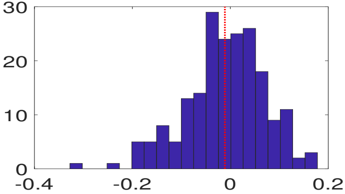
Finite sample properties

- Following Kelly et al. (2020), we examines the finite sample properties of our constrained IPCA estimation with Monte Carlo simulations
- We use a specification with $L^F = 5$, $L^G = 2$, $L = L^G + L^F$ $K^F = 2$, $K^G = 1$, $K = K^G + K^F$, $N = 260$, and $T = 162$
- We represent the estimation error distribution for each element of Γ_β^F and Γ_β^G

Simulated estimation errors - Γ_{β}^{F}



Simulated estimation errors - Γ_{β}^{G}



Data (1)

- Large unbalanced panel of 155,234 monthly observations **from Jul-2008 to Dec-2021** of **2463** US companies
- A stock is included in our dataset if, for at least one period we observe all its financial and environmental characteristics (available at monthly or annual frequency)
- **12 financial characteristics from Jensen et al. (2022)**: Total Asset, Book to market, Beta, E2P, Free CF, Idiosyncratic volatility, Investment, size, Turnover, Leverage, Profitability, ROE, rel2high, bid-ask spread, momentum, ST reversal, LT reversal, and a constant

Data (2)

- We use ESG and environmental characteristics from 2 providers: MSCI ESG IVA and Eikon-Datastream:
  - The characteristics are: ESG score, “E” score, and emissions score, from both MSCI and Eikon,
  - Environmental weight from MSCI
  - Sectoral Carbon Intensity, Adjusted Carbon Intensity, and Adjusted Carbon Emissions form Eikon
- Eikon’s methodology accounts for the differences among sectors in each score, so Eikon’s ratings are sectoral neutral
- MSCI’s methodology accounts for the differences among sectors only in the final ESG score

Data (3)

- *Carbon Intensity*, *Carbon Emissions* and *MSCI Environmental weight* highly depend on sectors, therefore we decompose them as in Heston and Rouwenhorst (1994) and Langlois (2021)
- For each characteristic at each t, we run the following cross-sectional regression:

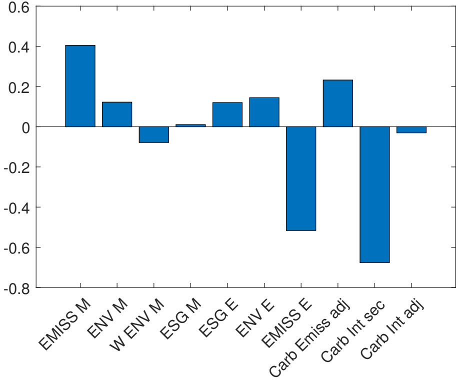
$$\text{chr}_{i,t} = \kappa + \sum_{ind=1}^{N_{ind,t}-1} I_{ind,t}\mathbb{I}_{i \in ind} + v_{i,t}$$

- Sectoral components are highly correlated and therefore we drop sectoral emissions and sectoral MSCI Environmental weight

Data (4)

- We heave some characteristics that are sectoral neutral:
  - MSCI's and Eikon's ESG scores, Eikon's "E" and emissions scores, adjusted carbon intensity, and adjusted carbon emissions, and environmental weight
- and others that depend on sectors:
  - MSCI's "E" and emissions score, and sectoral Carbon Intensity
- **Green characteristics** are orthogonalized with respect to financial characteristics:
  see e.g. Bolton and Kacperczyk (2021) vs Aswani et al. (2022)
- Number of factors $K^F = 5$ (as in Kelly et al. (2019)) and $K^G = 1$

Green Factor Exposure



	Γ_β^G	$p-$value	
EMISS M	0.41	0.262	
ENV M	0.12	0.365	
W ENV M	-0.08	0.437	
ESG M	0.01	0.839	
ESG E	0.12	0.418	
ENV E	0.14	0.41	
EMISS E	-0.52	0.045	**
Carb Emiss adj	0.23	0.18	
Carb Int sec	-0.68	0	***
Carb Int adj	-0.03	0.763	

Since by construction, the risk premia of the factor is positive, and characteristics are standardized, we can interpret the sign and the magnitude of the values in Γ_β^G

Interpretation of Γ_β^G

- Characteristics related to emissions seem to be the most important: indeed sectoral carbon intensity, the two emission scores and adjusted carbon emissions have the grater absolute values
- Among these, sectoral characteristics (sectoral carbon intensity and MSCI's emissions score) show that returns of companies within polluting sectors are negatively correlated with this factor
- On the other hand, sectoral neutral characteristics (adjusted carbon emissions and Eikon's emissions score) show that returns of companies which pollute more compared their peers, are positively correlated with this factor
- however, only Eikon's emissions score and sectoral carbon intensity are statistically significant

Estimated Latent Green Factor

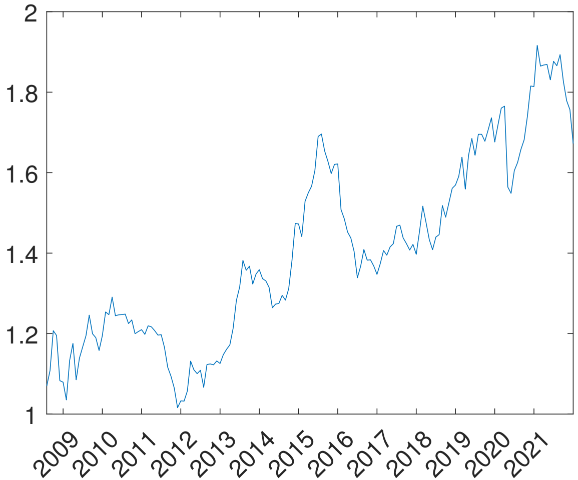


Figure: Cumulative returns of the environmental factor. The average excess annual return is 4.4%, st. dev. 11%, and Sharpe Ratio 0.40

Performance measures: R^2s

- We use the performance measures, as in Kelly et al. (2021), to assess the model's ability in explaining excess returns:
  - The Total R^2 is the fraction of variance in the whole panel of assets that is explained by the model
  - The Cross section R^2, that is the R^2 from Fama-MacBeth cross-sectional regressions of test asset returns at time $t+1$ on (conditional) betas as of time t
  - The Time Series R^2, that is the average time series R^2 among test assets

Environmental factor contribution

- We start by computing the R^2s including only the first financial factor, then we add to the model the second financial factor and compute the new $R^2 s$
- We keep adding factors until we include all the financial ($K^F = 5$) factors
- Last, we add the **environmental factor**. In the last column we display the R^2 of the complete model, which includes both the environmental and financial factors

Factor interpretation: In-sample R^2

	R^2	F1	F1:F2	F1:F3	F1:F4	F1:F5	F1:F5 $+\alpha^F$	F1:F5 $+\alpha$	F1:F5+G1 $+\alpha$
All stocks	Total	28.19	29.78	30.84	33.12	35.41	35.50	35.50	35.93
	Time Series	16.46	17.88	16.71	21.38	24.56	24.71	24.75	**26.24**
	Cross Section	17.54	19.43	20.71	23.78	26.42	26.55	26.55	27.08
Oil	Total	41.58	41.19	43.91	44.90	45.18	45.28	45.29	**47.73**
	Time Series	45.48	45.06	47.34	48.52	49.44	49.56	49.57	**51.97**
	Cross Section	15.38	16.83	19.58	20.63	20.86	21.34	21.34	**24.01**
Util	Total	8.65	8.74	10.74	14.17	27.74	27.73	27.84	**30.12**
	Time Series	−3.49	−3.91	−3.66	1.38	24.35	24.22	24.36	**26.48**
	Cross Section	−5.35	−3.98	−2.29	1.83	12.67	12.79	12.88	**16.61**

Table: Cumulative contribution of the financial factors and the environmental factor for all the asset universe and the sectors Energy and Utilities

Factor interpretation: Out-of-sample R^2

	R^2	F1	F1:F2	F1:F3	F1:F4	F1:F5	F1:F5 $+\alpha^F$	F1:F5 $+\alpha$	F1:F5+G1 $+\alpha$
All stocks	Total	25.66	28.36	30.05	30.92	33.17	33.17	33.16	33.55
	Time Series	19.84	16.61	19.74	20.72	26.41	26.51	26.54	27.37
	Cross Section	10.81	13.54	15.27	16.05	18.07	18.08	18.07	18.47
Oil	Total	36.98	40.67	42.47	42.90	43.60	43.50	43.51	**45.96**
	Time Series	42.89	46.04	47.43	48.15	49.01	48.91	48.92	**51.50**
	Cross Section	12.92	14.20	15.00	15.38	16.28	16.12	16.13	**18.57**
Util	Total	8.62	11.26	13.12	12.68	23.92	24.10	24.05	**25.82**
	Time Series	-1.85	-0.21	0.70	0.00	18.33	19.37	19.24	20.02
	Cross Section	0.33	2.03	2.89	3.40	9.11	9.16	9.12	**11.59**

Table: Cumulative contribution of the financial factors and the environmental factor for all the asset universe and the sectors Energy and Utilities

Robustness Checks

- Use the original IPCA to assess if our constrained-extension alters substantially the explanatory power of the model
- Use the original IPCA by using only financial characteristics to assess if our environmental factor can be explained by a generic sixth financial factor
- Estimate the model without orthogonalizing environmental factors with respect to financial factors
- Estimate the model without orthogonalizing environmental characteristics with respect to financial characteristics
- Use sectoral emissions instead of sectoral carbon intensity, and the two factors from the two models have a correlation of 95%

Conclusions

- We propose a new constrained-IPCA model to augment the interpretability of the factors
- We use it to understand whether environmental characteristics matter to explain excess stock returns
- Environmental characteristics matter to explain both cross section and time variation of return for Oil and Utilities companies

Thank You!

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Bibliography I

ALESSI, L., E. OSSOLA, AND R. PANZICA (2020): "What greenium matters in the stock market? The role of greenhouse gas emissions and environmental disclosures," Working paper.

ASWANI, J., A. RAGHUNANDAN, AND S. RAJGOPAL (2022): "Are Carbon Emissions Associated with Stock Returns?" Working Ppaer.

BOLTON, P. AND M. T. KACPERCZYK (2021): "Do Investors Care about Carbon Risk?" Journal of Financial Economics.

——— (2022): "Global Pricing of Carbon-Transition Risk," Journal of Finance (forthcoming).

CHEEMA-FOX, A., B. R. LAPERLA, G. SERAFEIM, D. TURKINGTON, AND H. WANG (2021): "Decarbonization Factors," The Journal of Impact and ESG Investing, 2, 47–73.

HESTON, S. L. AND K. ROUWENHORST (1994): "Does industrial structure explain the benefits of international diversification?" Journal of Financial Economics, 36, 3–27.

HSU, P.-H., K. LI, AND C.-Y. TSOU (2022): "The Pollution Premium," Journal of Finance (forthcoming).

Bibliography II

IN, S. Y., K. Y. PARK, AND A. H. B. MONK (2019): “Is ’Being Green’ Rewarded in the Market?: An Empirical Investigation of Decarbonization and Stock Returns,” Working Paper.

JENSEN, T. I., B. T. KELLY, AND L. H. PEDERSEN (2022): “Is There A Replication Crisis In Finance?” Journal of Finance (forthcoming).

KELLY, B. T., D. PALHARES, AND S. PRUITT (2021): “Modeling Corporate Bond Returns,” Journal of Finance.

KELLY, B. T., S. PRUITT, AND Y. SU (2019): “Characteristics are covariances: A unified model of risk and return,” Journal of Financial Economics, 134, 501–524.

——— (2020): “Instrumented Principal Component Analysis,” Working Paper.

LANGLOIS, H. (2021): “What Matters in a Characteristic?” Working Paper.

PASTOR, L., R. F. STAMBAUGH, AND L. A. TAYLOR (2022): “Dissecting Green Returns,” Journal of Financial Economics, 146, 403–424.