Stochastic Modelling in Climate Risk: Financial Mathematics and Economics

ISM-UCL-UCSB-MQ WS

Mechanisms to incentivise fossil fuel divestment and implications for investors risk and return

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Research was funded by Accounting & Finance Association of Australia and New Zealand (AFAANZ), and Royal Thai Government Scholarship

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Paper available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4131449

Software Paper available at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4357488

Software available on https://github.com/QuantFILab/Divfolio

Sidles and Materials available on https://github.com/QuantFILab/ISM-UCL-UCSB-MQ-WS

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Fossil Fuel Divestment Strategies?

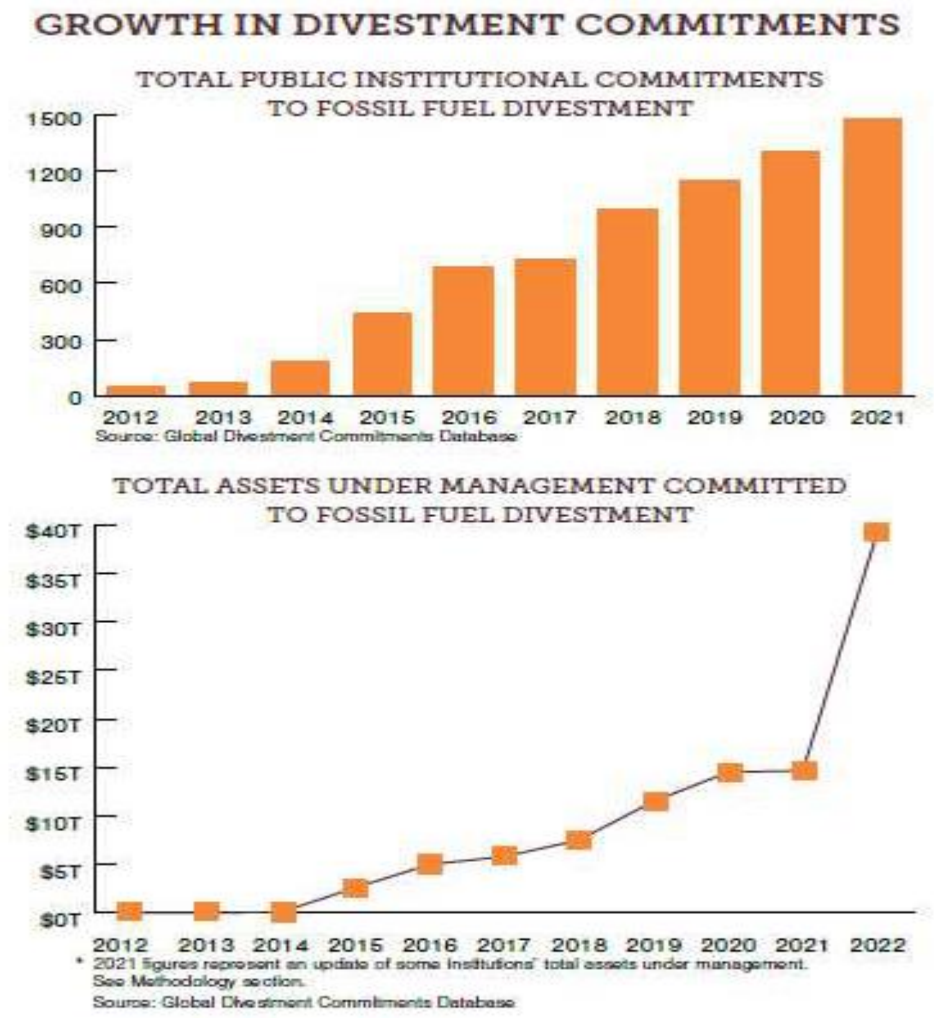
Fossil Fuel Divestment Strategies?

UN Website

Toronto350.org

- Global Environmental Challenge
- Divestment Campaigns
- Paris Agreement/COP26
- SDGs
  - Climate Action (13)
- Principal of Sustainable Finance
  - Environment

Fossil Fuel Divestment Strategies?



- **Investors total committed funds US$40.43 trillion (AUM) –**
- **Public institutions >1500**
  - Global Fossil Fuel Commitment Database (https://divestmentdatabase.org/)
- **Not only institutions and assets under management continuously increasing but accelerating.**
  - pension funds
  - Endowments
  - COP26/World Economic Forum

Literature Review

- Fossil fuel divestment and portfolio performance (Trinks et al, 2018).

  "Divested (fossil-free) portfolios would not have significantly underperformed the unconstrained market portfolio over a comprehensive time frame."

- The financial impact of fossil fuel divestment (Plantinga & Scholtens, 2021)

  "Divestment from fossil fuel companies does not influence total financial risk for the investor"

- Fossil fuel divestments on mutual funds performance (Guo et al, 2022)

  "Investors can select low-carbon firms without jeopardizing their investment objectives or financial performance"

All references can be found in the Paper available at:
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4131449 and
https://papers.ssrn.com/sol3/papers.cfm?abstract_id=4357488

Open problems addressed by our case studies

- What effects do varying divestment rates have?
- What is the strategy for redeploying divested capital?
- How does divestment impact diversified versus concentrated portfolios?
- How can we quantify the carbon footprint of divested and non-divested portfolios?
- Does divestment disproportionately affect certain demographic profiles among investors?
- How does divestment affect the robust covariance structure and diversification of a portfolio?
- What influence does divestment have on the mean and variance profiles of mixed pension funds?

Multi-period Approach to Divestment and Reinvestment

Multi-period Portfolio Optimization Approach to Divestment

h-period optimization

$$w^* = \underset{w_{t+1}, w_{t+2}, \ldots, w_{t+h}}{\operatorname{argmax}} \quad \mathbb{E}[U(r_{t+1}w_{t+1}, r_{t+2}w_{t+2}, \ldots, r_{t+h}w_{t+h}|\mathcal{F}_t)]$$

$$\text{s.t.} \quad \sum_{i=1}^{N_I} w_{i,t+k} + \sum_{j=1}^{N_J} w_{j,t+k} = 1 \quad \text{Full investment}$$

$$\sum_{i=1}^{N_I} |w_{i,t+k}| + \sum_{i=1}^{N_J} |w_{j,t+k}| \leq 1.3 \quad \text{Leverage constraint}$$

$$\sum_{j=1}^{N_J} w_{j,t+k} \leq D_{t+k} \quad \text{Divestment constraint}$$

$$\text{where } k = t+1, t+2, \ldots, t+h$$

- r_t is the return at time t
- w_t is the investment weight at time t
- I is the set of investable assets
- J is the set of divestable assets
- N_I is the number of investable assets
- N_J is the number of divestable assets
- D_t is the limit of the divestable weight
- $\mathcal{F}$ is the information filtrations at time t

Multi-period Portfolio Optimization Approach to Divestment

Challenges

- Complicated to solve analytically in the closed form
- Computationally expensive to compute in large portfolio over many time steps
- Path-dependent optimization in both backward and forward solving
- Leverage and divestment constraints to be considered

Approximation

- Local linearising the utility function to be additive, leading to simplifying the problem to solving sequential local single portfolio optimization
- Approximating constrained optimization using rounding approximation

Approximation of Multi-period Portfolio Optimization

Objectives Function: Local linearising the utility function to be additive, leading to simplifying the problem to solving sequential local single portfolio optimization

$$\begin{aligned}
w^* &= \underset{w_{t+1}, w_{t+2}, \ldots, w_{t+h}}{\operatorname{argmax}} \; \mathbb{E}[U(r_{t+1}w_{t+1}, r_{t+2}w_{t+2}, \ldots, r_{t+h}w_{t+h} | \mathcal{F}_t)] \\
&\approx \underset{w_{t+1}, w_{t+2}, \ldots, w_{t+h}}{\operatorname{argmax}} \; \mathbb{E}[U(r_{t+1}w_{t+1}) + U(r_{t+2}w_{t+2}) + \cdots + U(r_{t+h}w_{t+h}) | \mathcal{F}_t)] \\
&\approx \underset{w_{t+1}, w_{t+2}, \ldots, w_{t+h}}{\operatorname{argmax}} \; \mathbb{E}[U(r_{t+1}w_{t+1}) | \mathcal{F}_t)] + \mathbb{E}[U(r_{t+2}w_{t+2}) | \mathcal{F}_{t+1})] + \cdots + \mathbb{E}[U(r_{t+h}w_{t+h}) | \mathcal{F}_{t+h-1})]
\end{aligned}$$

Feasibility Refinement for Multi-period Portfolio Optimization

Constraints: for every time rebalancing of the unconstrained single-period optimization

1. Rounding leverage constraint

$$w^s_{box} = \begin{cases} 0.3 \times (w^s / \sum_{s \in S} w^s), & \sum_s w^s > 0.3, \\ w^s, & \sum_s w^s \leq 0.3, \end{cases}$$

$$w^l_{box} = \begin{cases} 1.3 \times (w^l / \sum_{l \in L} w^l), & \sum_l w^l > 1.3, \\ w^l, & \sum_l w^l \leq 1.3, \end{cases}$$

- L is the set of long position assets
- S is the set of short position assets

2. Rounding divestment constraint

$$\widetilde{w}^{l,div} = D(t) \times \frac{w^{l,div}_{box}}{\sum_{l \in L} w^{l,div}_{box}} \quad \text{or/and} \quad \widetilde{w}^{s,div} = -D(t) \times \frac{w^{s,div}_{box}}{\sum_{s \in S} w^{s,div}_{box}}.$$

Feasibility Refinement for Multi-period Portfolio Optimization

3. Rounding reinvestment constraint

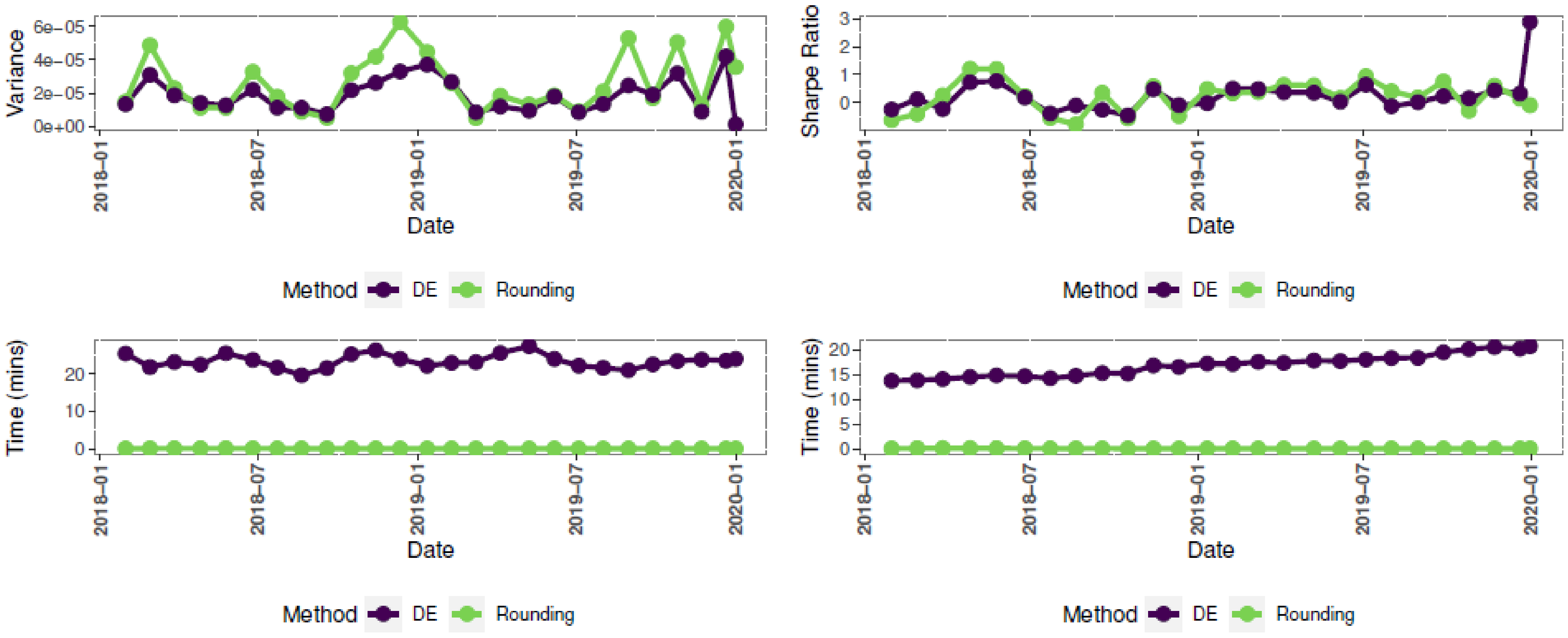
$$w_{ex} = \begin{cases} \sum_{l \in L} \widetilde{w}_{box}^{l,div} - D(t), & \text{if } \sum_{l \in L} w_{box}^{l,d} \geq D(t) \\ \sum_{s \in S} w_{box}^{s,div} + D(t), & \text{if } \sum_{s \in S} w_{box}^{s,div} \leq -D(t) \\ \sum_{l \in L} w_{box}^{l,div} + \sum_{s \in S} w_{box}^{s,div}, & \text{if } \sum_{l \in L} w_{box}^{l,div} \geq D(t) \text{ and } \sum_{s \in S} w_{box}^{s,div} \leq -D(t) \\ 0, & \text{otherwise.} \end{cases}$$

$$\widetilde{w}^{inv} = w^{inv} + \frac{w^{inv}}{\sum_{l \in L} w^{inv}} \times w_{ex}.$$

It is not difficult to verify that $\widetilde{w}^{l,div}1 + \widetilde{w}^{s,div}1 + \widetilde{w}^{inv}1 = 1.$

Approximation of Multi-period Portfolio Optimization

Rounding approximation compares to Differential Evolution



Divestment and reinvestment framework

Select Assets
- CU200/ Energy and Utility Sectors S&P/Global ETF/FTSE 100

Core Portfolios
- Build 5 core portfolios (AEW, PEW, GMV, MS, PP)

Rebalancing
- Apply 130-30 box constraint to rebalance core portfolios.

Divestment
- Apply proposed divestment schedule on divestible assets in core portfolios.

Reinvestment
- Allocate excess weights from divestment assets to investible assets.

Assess Performance, Stability, Efficiency
- Assess stability of risk profiles of divested portfolios, Measure Carbon Reduction Ratio (CDR) and Investment/Reinvestment Ratio. Assess impact on Investor Demographics

Experiments

Experimental Design on Four Case Studies

- S&P 500, with the divested funds (CU200, energy and utilities) reinvested in other sectors.

We study the impact and stability on the portfolio's risk and return behaviour by divesting from fossil-fuel intensive sectors and reinvesting this capital in other sectors as well as allowing divestment by using leveraged positions.

- ETFs, with the divested carbon intensive assets

We study the impact on key investors demographics: management fees, ESG score and carbon footprint change, and the dividend yields attributed to divestment practices.

- FTSE 100, with the divested high ESG risk assets

We study the impact on portfolio diversification and robust covariance structure.

- Mixed Pension Funds of the US and the UK, with the divested high environmental risk assets

We study the impact on the performance of the mean and variance of the mixed pension funds.

Selecting divestment and reinvestment sets

- Asset universe
  - S&P 500, Global iShares ETFs, FTSE 100.

- Divestment Assets Sets
  - Carbon Underground 200 (CU200) Assets (Coal, Oil and Gas)
  - Energy and Utility Sector Assets

  Global Industry Classification Standard (GICS) sector identification code
  - High Sustainability Risks: E, S and G

Table 1: Average environmental scores and amount of carbon emission of the some companies in S&P 500 separated by GICS sector ranked by direct CO_2 emissions where n_{co2} is the number of the assets available for calculating the amount of carbon emission and N_{co2} is the number of the whole assets in the sector.

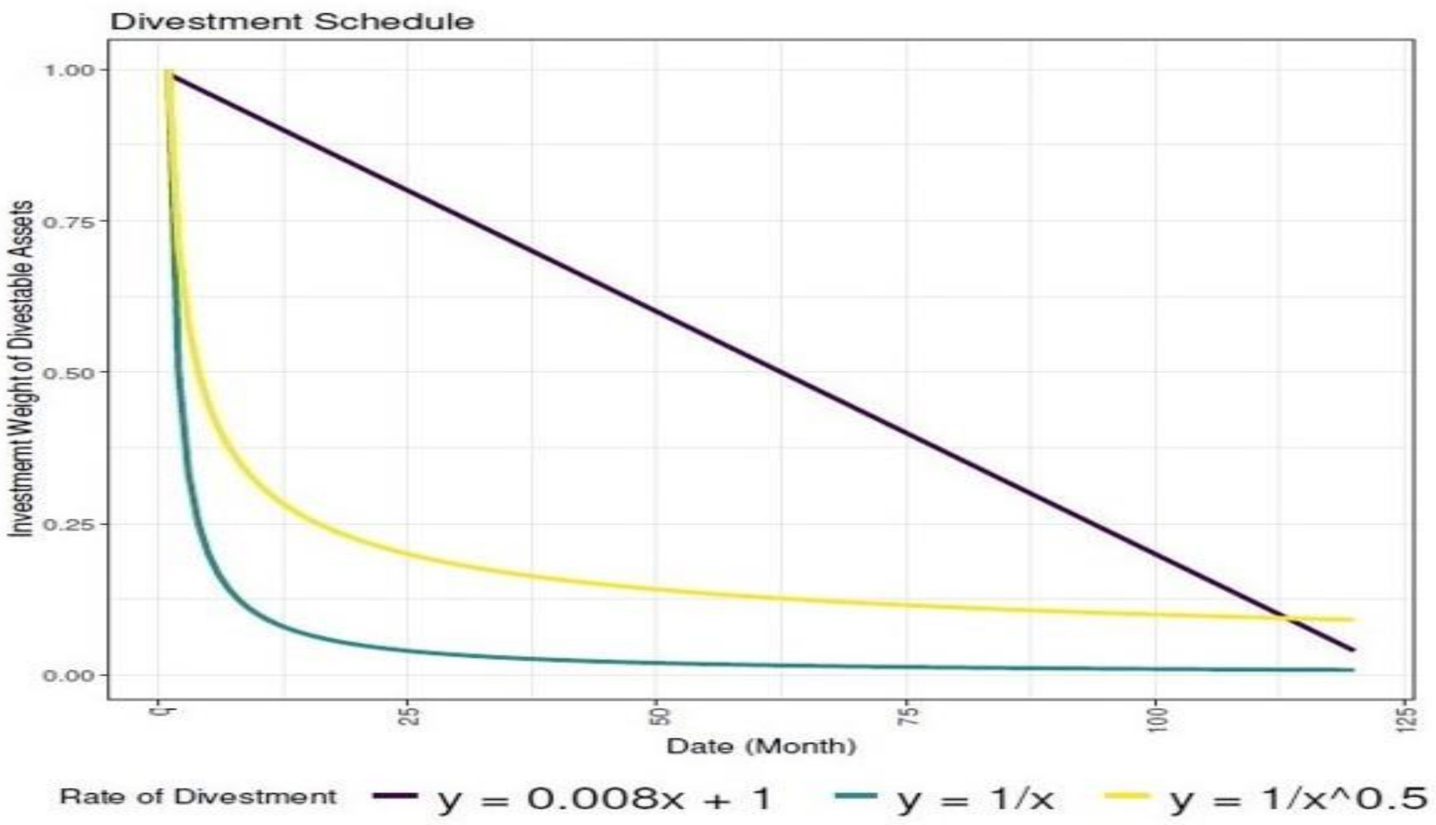
Rank	GICS.Sector	E score	CO_2 Emissions (Ton)	CO_2 Emissions (%)	n_{co2}	N_{co2}
1	Utilities	14.90	29,884,383.57	46.06	21	28
2	Energy	15.64	16,488,511.67	25.41	15	21
3	Materials	13.08	6,951,694.12	10.71	24	28
4	Industrials	7.38	3,572,568.61	5.51	45	74
5	Communication Services	1.19	2,566,298.00	3.96	13	24
6	Consumer Staples	7.42	2,539,331.17	3.91	24	30
7	Consumer Discretionary	4.00	1,384,162.29	2.13	41	63
8	Information Technology	3.45	618,047.76	0.95	48	73
9	Real Estate	3.55	390,973.88	0.60	24	29
10	Health Care	1.49	337,598.75	0.52	39	64
11	Financials	1.56	147,601.10	0.23	38	64

Note: We cannot obtain amount of carbon emission from all companies in S&P500. The coverage ratio can be calculated by n_{co2}/N_{co2}.

Rebalancing portfolio

- Portfolio strategies:
  - passive equal-weighted (PEW), active equal-weighted (AEW) portfolios, global minimum variance (GMV) portfolio, maximum Sharpe (MS) portfolio, and `principal (PC) portfolio' constructed from orthogonal risk drivers to construct the portfolio weights.
- Rebalance portfolios:
  - 100 day sliding window, monthly rebalancing.
  - standard formula in the core portfolios (box constraints of 130-30).

Divestment



Divestment Schedule
1.00
0.75
0.50
0.25
0.00
Investment Weight of Divestable Assets
25
50
75
100
125
Date (Month)
Rate of Divestment
y = 0.008x + 1
y = 1/x
y = 1/x^0.5

Reinvestment

Assessment Tools

Assessment I: Risk Profiles

- Expected return; the cumulative expected return; the standard deviation; Sharpe ratio;
- Sortino ratio (SR); Value-at-Risk (VaR);

$$\mathrm{SR} = \frac{E(R - R_f)}{\sqrt{\frac{1}{T}\sum_{t=1}^{T}\min(0, R_t - R_f)^2}},$$

$$\mathrm{VaR}(\alpha) = F_R^{-1}(\alpha)$$

- Maximum Draw-Down (MDD);

$$\mathrm{MDD} = \min\{R_{t-N}, R_{t-N+1}, \ldots, R\} - \max\{R_{t-N}, R_{t-N+1}, \ldots, R_t\}$$

- Beta; Treynor ratio; Omega ratio;

$$\beta = \frac{cov(R, R^{\mathrm{S\&P500}})}{Var(R^{\mathrm{S\&P500}})},$$

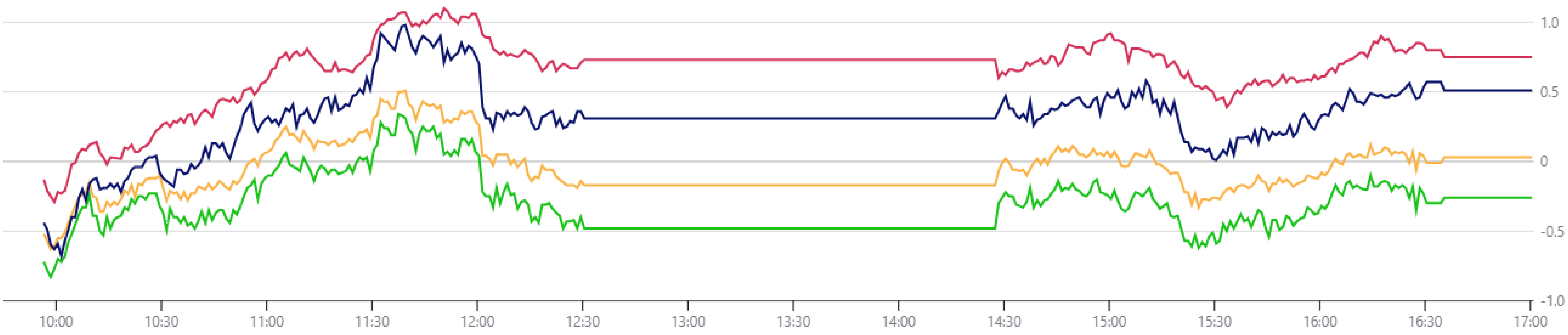
$$\mathrm{TR} = \frac{E(R - R_f)}{\beta}.$$

$$\Omega(0) = \frac{\int_0^\infty (1 - F_R(r))\,dr}{\int_{-\infty}^0 F_R(r)dr},$$

Assessment II: Stability profiles

Does relative behaviour of the portfolio change?

- Stability:
  - Clustering Large Applications (CLARA) algorithm to the time series of the risk profiles (Kaufman and Rousseeuw (1986)).



Assessment III: Average reinvestment and divestment weights

How much capital weight is reallocated across industry sectors in the portfolio?

- Asset average reinvestment/divestment weights $\overline{\Delta_j}$:

$$\overline{\Delta_j} = \frac{1}{|T|} \sum_{t \in T} \left(w_{j,t}^{p} - \widetilde{w}_{j,t}^{p} \right), \qquad j \in \{1, \ldots \ldots, 469\},$$

  – Where $w_{j,t}^{p}$ portfolio weight of the benchmark portfolio of type p, with no divestment at time t, $\widetilde{w}_{j,t}^{p}$ is a portfolio weight of asset j in the divested portfolio of type p, $\overline{\Delta_j}$ indicates a change of portfolio weight after divestment of the asset j.

- Sector $i's$ average reinvestment/divestment weight :

$$\overline{w}_{i}^{h,p} = \sum_{j \in K_i \cap J} \overline{\Delta}_{j}^{h,p}, \qquad h \in H, \qquad p \in P, \qquad k \in K.$$

  – $H = \{long, short\},\ P = \{divested\ portfolios\},\ K = \{GICS\ Sector\ Assets\},\ J = \{S\&P\ 500\ Assets\}$

Assessment IV: Carbon footprint reduction efficiency

Does divestment lead to a reduction in the carbon footprint of a portfolio?

- **CDR Ratio:**

$$CDR^{h,p} = \left| \frac{\sum_{k \in K_{inv}} C_k \overline{w}_k^{h,p}}{\sum_{k \in K_{div}} C_k \overline{w}_k^{h,p}} \right| \quad for\ h \in H, p \in P,$$

  - C_k ~ amount of carbon emitted by sector K, assume is constant over time.
  - K_{inv} ~ reinvested sectors (except the divested sector)
  - K_{div} ~ divested sectors

Assessment V: Impact of divestment on investor demographics

Does divestment have an effect on investor demographics?

$$NER = \beta_0^{NER} + \beta_1^{NER} RCF + \beta_2^{NER} NA + \beta_3^{NER} ESG + \beta_4^{NER} YTDR + \beta_5^{NER} TY + \beta_6^{NER} I_{MAR} + \varepsilon^{NER}$$

$$TY = \beta_0^{TY} + \beta_1^{TY} RCF + \beta_2^{TY} NA + \beta_3^{TY} ESG + \beta_4^{TY} YTDR + \beta_5^{TY} NER + \beta_6^{TY} I_{MAR} + \varepsilon^{TY}$$

- Where NER ~ net expense ratio, RCF ~relative carbon footprint, ESG~ esg quality score, YTDR ~ yield to date return, TY~ 12month trailing yield, I_{MAR}~ market index, ε_{NER} and ε_{TY} denote the i.i.d. Gaussian errors from the regressions respectively.

- $ESG\left(RCF_i(t)\right) = \min(6.813 - 0.001 RCF_i(t), 10)$ for i ∈ $\{inst, fast, slow\}$,
  - $RCF_{inst}(t) = 0, divesting\ all\ carbon\ assets\ at\ beginning$
  - $RCF_{slow}(t) = 427.27 - 35t, divesting\ all\ carbon\ footprint\ by\ linear\ function\ of\ time$
  - $RCF_{fast}(t) = \frac{427.27}{t^{1.5}},\ reducing\ carbon\ footprint\ by\ hyperbolic\ function\ of\ time$
  - NA =$18.4 billion constant, I_{MAR}= 1, 427.27 =Initial RCF.

Assessment VI: Robust Covariance Structure

Does divestment disrupt the correlation structure among assets within a portfolio?

- Graphical Least Absolute Shrinkage and Selection Operator (glasso) is a method for eliminating a weak/non robust correlation from a group of random variables.

- The network of the sufficiently strong correlations can be constructed by the estimate sparse covariance matrix.

- The optimization of the glasso involves the sparse Gaussian graphical model with the following minimization problem:

$$\hat{G} = \underset{G \in CG}{\operatorname{argmin}} \frac{1}{2} \operatorname{Tr}(G^T S G) - \operatorname{Tr}(G^T S) + \lambda \|G\|_1,$$

where $CG = \{G \in \mathbb{R}^{N \times N} | G_{i,i} = 0 \;\; \text{for } i = 1, \ldots, N\}$ is a set of estimate sparse covariance matrix.

Assessment VII: Portfolio Diversification Ratio

How does divestment affect portfolio diversification?

$$
\begin{aligned}
PDR &= \frac{\operatorname{Var}\left(\sum_{j=1}^{N} w_j R_j\right)}{\sum_{j=1}^{N} \operatorname{Var}\left(w_j R_j\right)} = \frac{\operatorname{Var}\left(\sum_{k=1}^{N_K} w_k R_k + \sum_{k'=1}^{N_{K'}} w_{k'} R_{k'}\right)}{\sum_{j=1}^{N} \operatorname{Var}\left(w_j R_j\right)} \\
&= \underbrace{\frac{\operatorname{Var}\left(\sum_{k=1}^{K} w_k R_k\right)}{\sum_{j=1}^{N} \operatorname{Var}\left(w_j R_j\right)}}_{\text{SVCR}} + \underbrace{\frac{\operatorname{Var}\left(\sum_{k'=1}^{K'} w_{k'} R_{k'}\right)}{\sum_{j=1}^{N} \operatorname{Var}\left(w_j R_j\right)}}_{\text{SEVR}} + \underbrace{\frac{\sum_{k=1}^{K} \sum_{k'=1}^{K'} \operatorname{Cov}\left(w_k R_k, w_{k'} R_{k'}\right)}{\sum_{j=1}^{N} \operatorname{Var}\left(w_j R_j\right)}}_{\text{SEC}},
\end{aligned}
$$

- SVCR (Sector Variance Contribution Ratio): Indicates the proportion of variance from a specific sector in comparison to a perfectly diversified portfolio. A high SVCR doesn't necessarily lead to an increase in the portfolio's variance

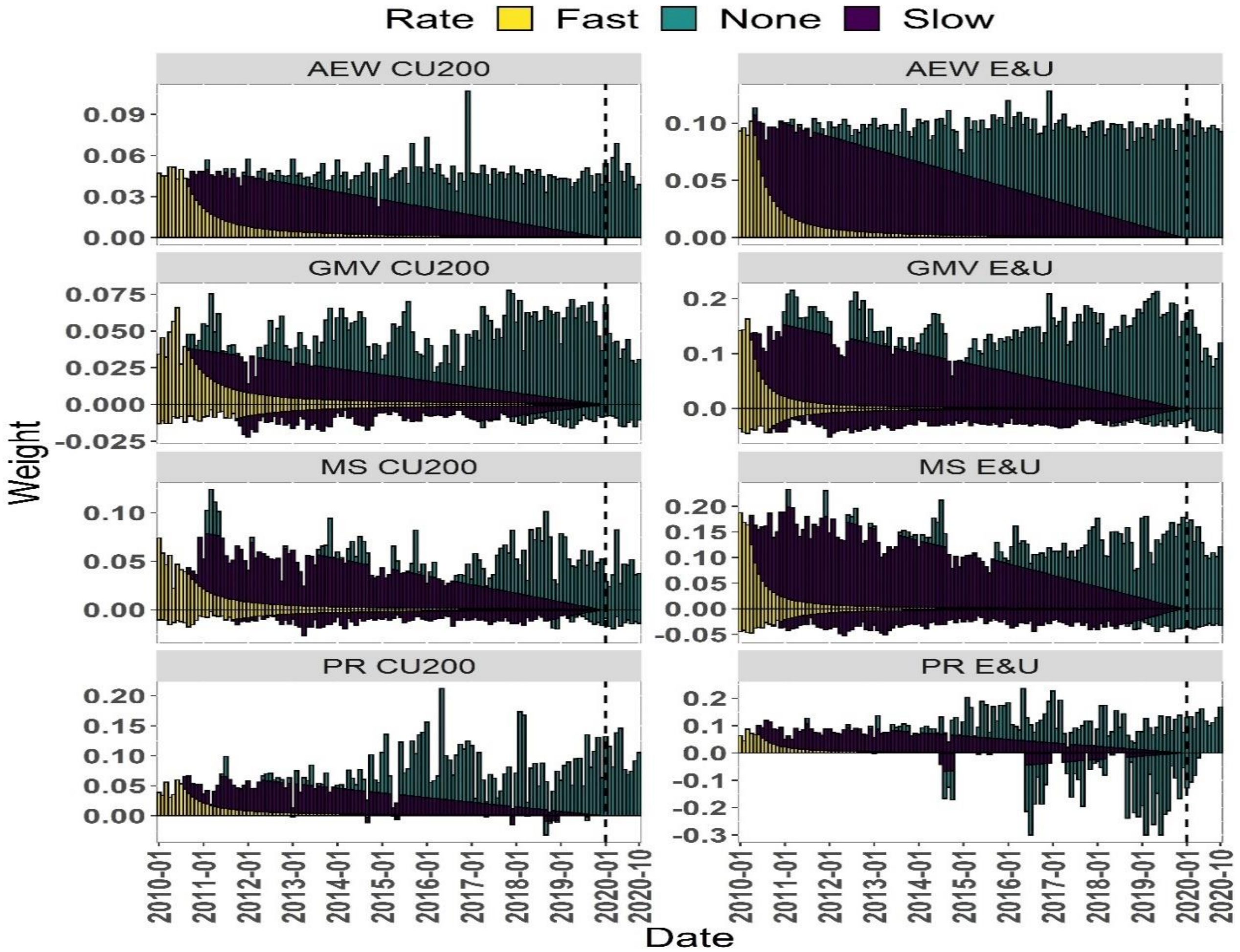
- SEVR (Sector-Excluded Variance Ratio): Represents the variance of a portfolio absent assets from a particular sector. A heightened SEVR means the sector in question decreases portfolio variance

- SEC (Sector-Excluded Correlation): Evaluates the correlation between the portfolio without a specific sector and that sector itself. A negative SEC implies the sector's covariance reduces the portfolio's overall variance.

Case Study I: S&P 500, with the divested funds (CU200, energy and utilities) reinvested in other sectors.

- Divestments do not produce statistically significant monthly average returns.
- Rate of divestment makes an impact on the stability of the risk-return profile
- Slow divestment offers the best tracking error performance compared to fast divestment
- Reinvestment strategies can inadvertently increase carbon intensity into the portfolios
- Industrials, Information Technology, Financial are the sectors who benefit the most

Portfolio Weights under Varying Divestment Schedules



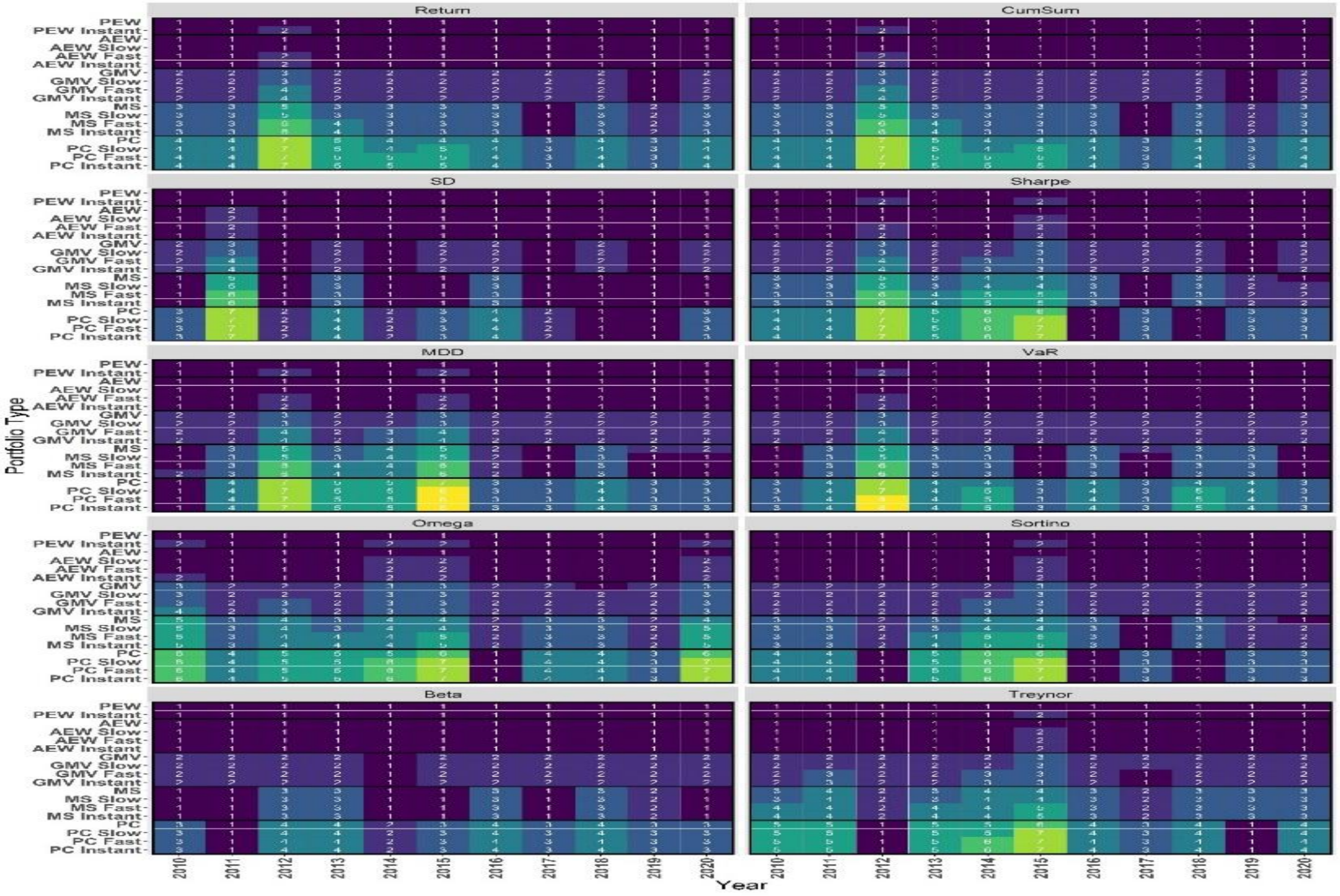
Left Panel: Energy Assets. **Right Panel: Energy and Utility Assets**

AEW = Active equal weights, GMV = Global minimum variance, MS = Maximum Sharpe, PR = Principal components PEW = Passive Equal Weights, The dashed vertical line in each plot is the terminal time when the weight of the assets to divest hits zero.

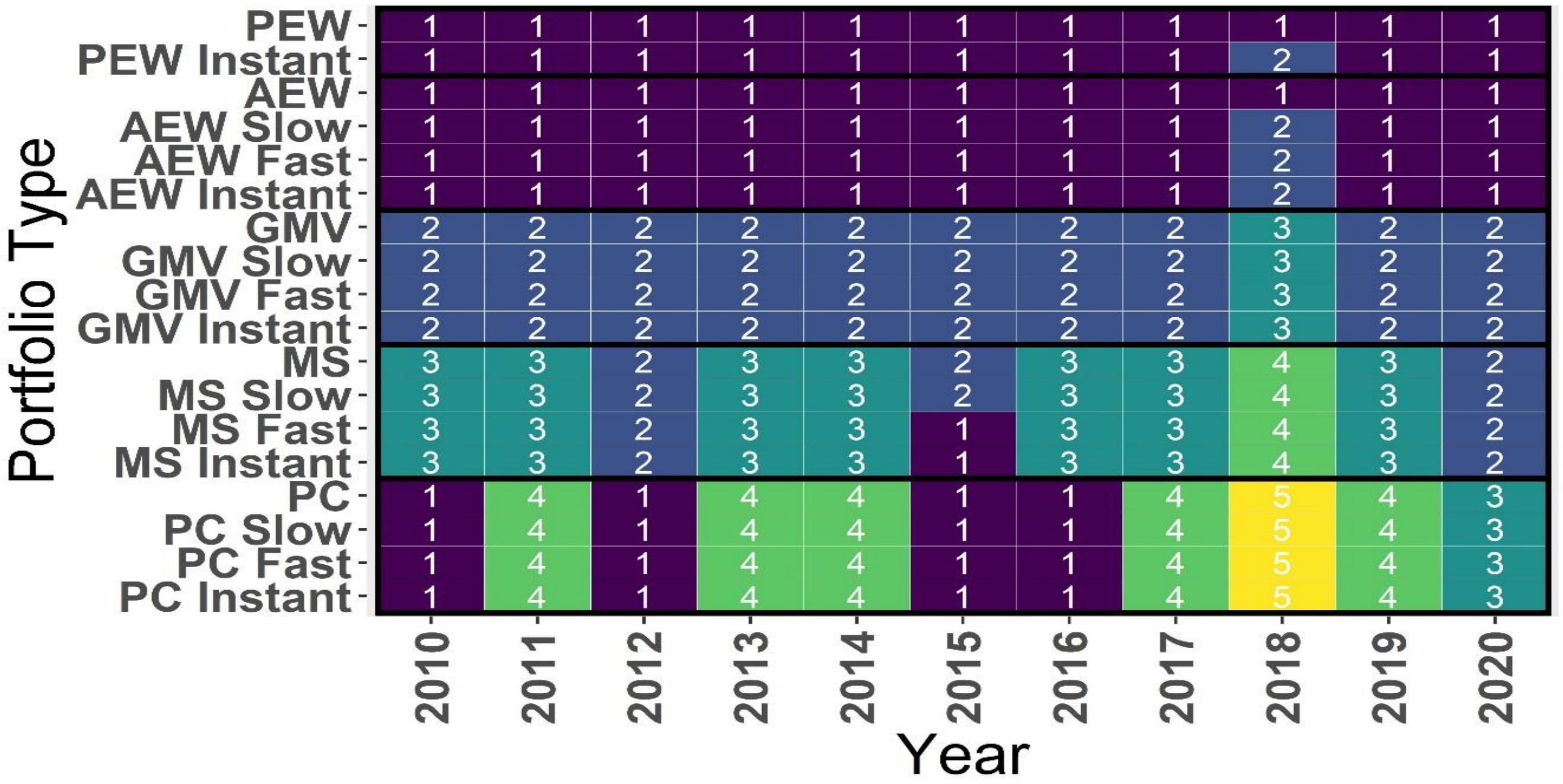
Risk profile of S&P500 Portfolios with divestment of energy + utilities under different schedules

Portfolio	Divestment Rate	Return (%)	Cumulative Return (%)	Standard Deviation (%)	Sharpe Ratio	Max Draw-down	VaR (%)	Omega	Sortino	Beta	Treynor (%)
PEW	None	0.060	1.248	0.919	0.124	-2.051	-1.322	1.683	0.188	0.961	0.072
		(±0.196)	(±4.094)	(±0.683)	(±0.218)	(±0.501)	(±1.157)	(±1.117)	(±0.329)	(±0.109)	(±0.214)
	Δ Instant	0.059*	0.058*	0.017*	0.030	0.000	0.016*	0.029	0.033	−0.028*	0.091*
		(±0.199)	(±4.138)	(±0.676)	(±0.224)	(±0.513)	(±1.152)	(±1.271)	(±0.340)	(±0.110)	(±0.220)
AEW	None	0.059	1.223	0.916	0.123	-2.058	-1.319	1.670	0.186	0.962	0.069
		(±0.197)	(±4.115)	(±0.680)	(±0.218)	(±0.508)	(±1.153)	(±1.100)	(±0.328)	(±0.108)	(±0.213)
	Δ Slow	0.037	0.037	0.008*	0.019	-0.000	0.006	0.015	0.020	−0.013*	0.049
		(±0.195)	(±4.066)	(±0.670)	(±0.220)	(±0.511)	(±1.145)	(±1.162)	(±0.333)	(±0.108)	(±0.211)
	Δ Fast	0.055	0.055	0.016*	0.029	0.000	0.014*	0.026	0.028	−0.025*	0.085*
		(±0.197)	(±4.105)	(±0.671)	(±0.223)	(±0.515)	(±1.145)	(±1.230)	(±0.337)	(±0.110)	(±0.215)
	Δ Instant	0.061	0.060	0.017*	0.031	-0.000	0.016*	0.028	0.030	-0.027	0.093*
		(±0.198)	(±4.116)	(±0.671)	(±0.223)	(±0.516)	(±1.146)	(±1.235)	(±0.338)	(±0.109)	(±0.216)
GMV	None	0.055	1.158	0.739	0.133	-2.112	-1.064	1.735	0.198	1.156	0.052
		(±0.159)	(±3.285)	(±0.573)	(±0.227)	(±0.607)	(±0.983)	(±1.319)	(±0.335)	(±0.143)	(±0.141)
	Δ Slow	0.038	0.037	0.015*	0.017	0.001	0.022*	0.010	0.018	−0.018*	0.062*
		(±0.160)	(±3.322)	(±0.562)	(±0.229)	(±0.583)	(±0.985)	(±1.345)	(±0.339)	(±0.144)	(±0.144)
	Δ Fast	0.064	0.061	0.025*	0.035	0.001	0.031*	0.035	0.040	−0.032*	0.129*
		(±0.163)	(±3.372)	(±0.563)	(±0.234)	(±0.588)	(±0.989)	(±1.508)	(±0.349)	(±0.151)	(±0.150)
	Δ Instant	0.072*	0.069	0.026*	0.037	0.000	0.031*	0.034	0.042	−0.033*	0.140*
		(±0.163)	(±3.371)	(±0.563)	(±0.233)	(±0.586)	(±0.989)	(±1.500)	(±0.348)	(±0.152)	(±0.150)
MS	None	0.064	1.332	0.901	0.123	-2.069	-1.290	1.651	0.184	0.949	0.074
		(±0.183)	(±3.809)	(±0.665)	(±0.212)	(±0.555)	(±1.111)	(±1.072)	(±0.316)	(±0.111)	(±0.200)
	Δ Slow	0.011	0.011	0.012*	-0.004	-0.003	0.016*	-0.002	-0.003	−0.016*	0.028
		(±0.183)	(±3.802)	(±0.659)	(±0.212)	(±0.525)	(±1.104)	(±1.067)	(±0.317)	(±0.111)	(±0.200)
	Δ Fast	0.034	0.034	0.027*	0.010	0.001	0.028*	0.014	0.014	−0.034*	0.072*
		(±0.186)	(±3.878)	(±0.662)	(±0.216)	(±0.531)	(±1.107)	(±1.135)	(±0.325)	(±0.112)	(±0.207)
	Δ Instant	0.035	0.035	0.028	0.009	0.002	0.029*	0.014	0.014	-0.034	0.075*
		(±0.187)	(±3.885)	(±0.663)	(±0.216)	(±0.533)	(±1.108)	(±1.138)	(±0.325)	(±0.112)	(±0.207)
PC	None	0.071	1.479	1.171	0.114	-2.050	-1.668	1.614	0.172	0.747	0.146
		(±0.253)	(±5.293)	(±0.827)	(±0.214)	(±0.496)	(±1.363)	(±1.040)	(±0.319)	(±0.202)	(±0.471)
	Δ Slow	0.050	0.052	−0.032*	0.053*	-0.005	−0.036*	0.029	0.060*	0.034*	-0.002
		(±0.234)	(±4.875)	(±0.807)	(±0.217)	(±0.499)	(±1.319)	(±1.110)	(±0.328)	(±0.188)	(±0.459)
	Δ Fast	0.067	0.069	−0.032*	0.062	-0.003	−0.037*	0.036	0.069	0.029*	0.019
		(±0.235)	(±4.899)	(±0.807)	(±0.219)	(±0.506)	(±1.320)	(±1.136)	(±0.331)	(±0.186)	(±0.460)
	Δ Instant	0.072	0.074	−0.030*	0.064	-0.003	−0.035*	0.039	0.071	0.027*	0.024
		(±0.236)	(±4.913)	(±0.808)	(±0.219)	(±0.507)	(±1.322)	(±1.146)	(±0.331)	(±0.185)	(±0.461)

Stability of Risk Profiles over time



Aggregate risk-reward portfolio profiles



Portfolio Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
PEW	1	1	1	1	1	1	1	1	1	1	1
PEW Instant	1	1	1	1	1	1	1	1	2	1	1
AEW	1	1	1	1	1	1	1	1	1	1	1
AEW Slow	1	1	1	1	1	1	1	1	2	1	1
AEW Fast	1	1	1	1	1	1	1	1	2	1	1
AEW Instant	1	1	1	1	1	1	1	1	2	1	1
GMV	2	2	2	2	2	2	2	2	3	2	2
GMV Slow	2	2	2	2	2	2	2	2	3	2	2
GMV Fast	2	2	2	2	2	2	2	2	3	2	2
GMV Instant	2	2	2	2	2	2	2	2	3	2	2
MS	3	3	2	3	3	2	3	3	4	3	2
MS Slow	3	3	2	3	3	2	3	3	4	3	2
MS Fast	3	3	2	3	3	1	3	3	4	3	2
MS Instant	3	3	2	3	3	1	3	3	4	3	2
PC	1	4	1	4	4	1	1	4	5	4	3
PC Slow	1	4	1	4	4	1	1	4	5	4	3
PC Fast	1	4	1	4	4	1	1	4	5	4	3
PC Instant	1	4	1	4	4	1	1	4	5	4	3

Which sectors benefit from divestment?

Assessment of divestment efficiency - Carbon Divestment and Reinvestment Ratio (CDR Ratio)

	PEW		AEW			GMV			MS			PC	
	Inst	Slow	Fast	Inst	Slow	Fast	Inst	Slow	Fast	Inst	Slow	Fast	Inst
(Long) E	0.117	0.119	0.119	0.119	0.229	0.262	0.274	0.195	0.234	0.259	0.152	0.146	0.142
(Short) E	-	-	-	-	0.917	0.339	0.260	0.800	0.407	0.309	-	33.333	25.000
(Long) E&U	0.070	0.070	0.070	0.070	0.089	0.098	0.100	0.093	0.101	0.103	0.144	0.119	0.115
(Short) E&U	-	-	-	-	0.300	0.125	0.109	0.185	0.113	0.102	0.014	0.013	0.013

Case Study II: Global ETFs, with the divested carbon intensive assets

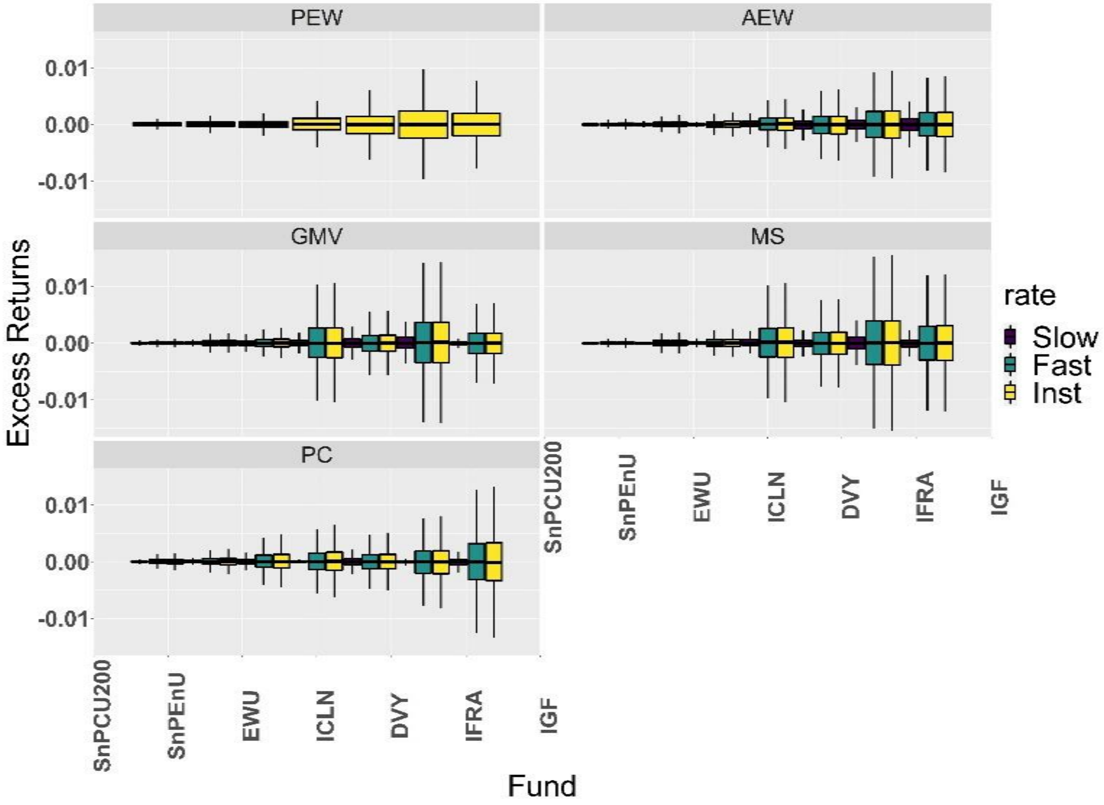
- Carbon divestment in ETF portfolios tend to relate to lower dividend yields and net expense
- No statistically significant impact of divestment strategies on returns, irrespective of the portfolio type and divestment schedules.
- Rate of divestment and the concentration of divestable assets have a substantial impact on the risk profiles and their stability over time and at the expense of higher tracking errors.

Analysis of Performance Tracking of Core Portfolios types to the real ETFs

Table 2: Average percentage of the excess return between the ETF's real returns and core portfolio types

	PEW	AEW	GMV	MS	PC
DVY	-0.0061%	-0.0039%	-0.0048%	-0.0039%	-0.0215%
	(±0.2621)	(±0.2781)	(±0.3438)	(±0.3476)	(±0.6252)
EWU	-0.0393%	-0.0504%	-0.0373%	-0.0491%	-0.0249%
	(±0.7075)	(±0.7297)	(±0.8533)	(±0.8379)	(±0.9858)
ICLN	-0.0464%	-0.0528%	-0.0225%	-0.0458%	-0.0724%
	(±1.0195)	(±1.1173)	(±1.3379)	(±1.2233)	(±2.0227)
IFRA	-0.0170%	-0.0115%	-0.0286%	-0.0233%	-0.0580%
	(±0.4703)	(±0.5723)	(±0.5636)	(±0.5726)	(±0.8604)
IGF	-0.0198%	-0.0216%	-0.0190%	-0.0303%	-0.0615%
	(±0.6018)	(±0.6409)	(±0.8235)	(±0.7003)	(±1.0612)

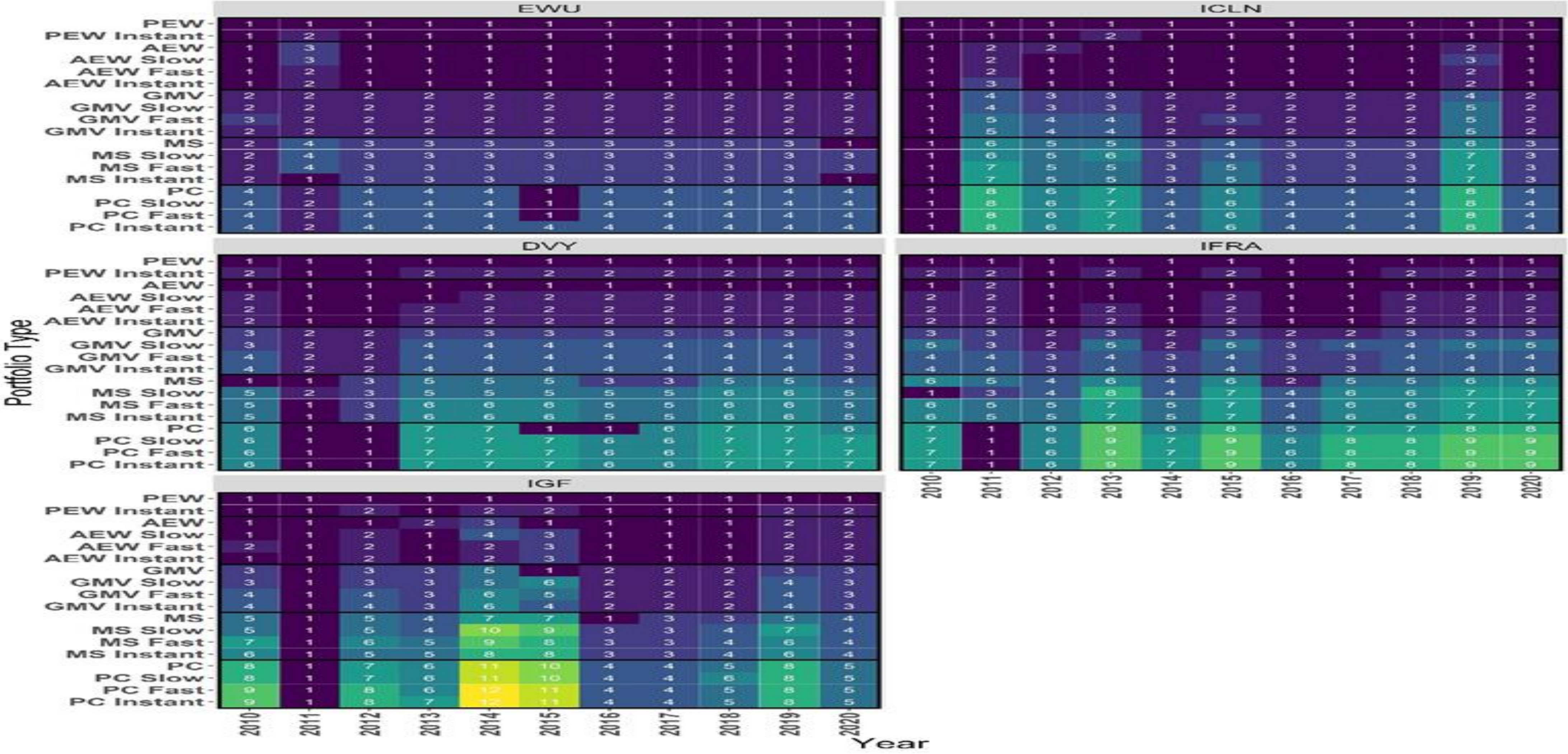
The number in the parenthesis is the tracking error - a standard deviation of the excess return, and the highlighted cells are the nearest portfolios to the selected ETFs according to both excess return and tracking error.



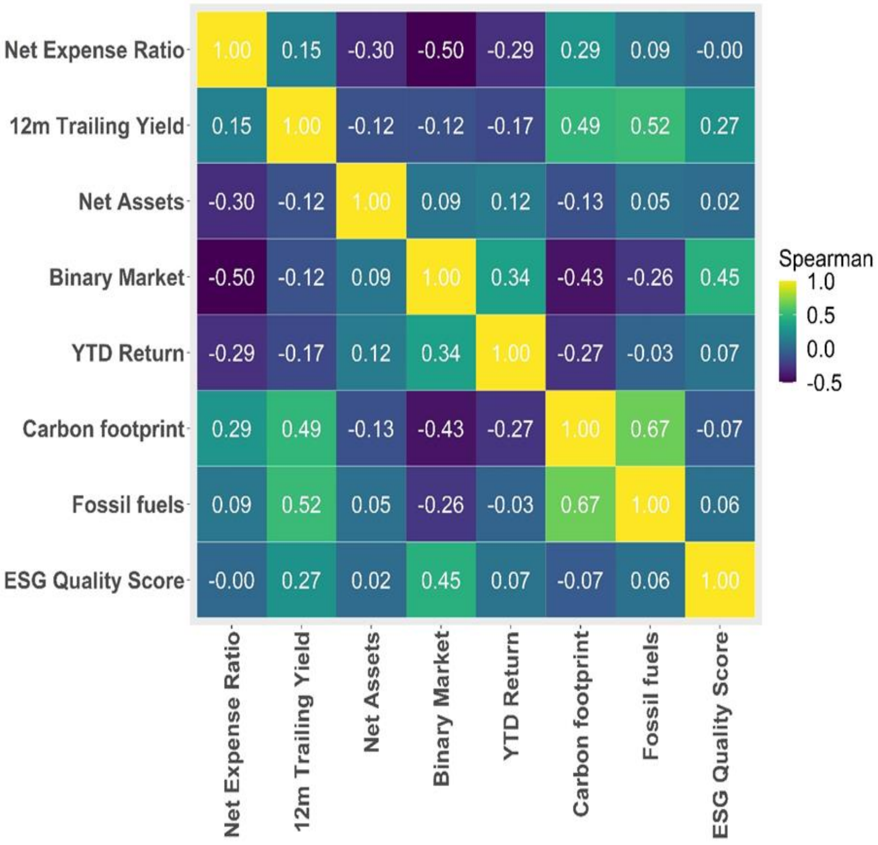
Analysis of Performance ETF (IGF)

Portfolio	Divestment Rate	Return (%)	Cumulative Return (%)	Standard Deviation (%)	Sharpe Ratio	Max Draw-down	VaR (%)	Omega	Sortino	Beta	Treynor (%)
PEW	None	0.000	0.007	0.007	0.097	-2.093	-0.009	1.669	0.142	0.962	0.001
		(±0.002)	(±0.041)	(±0.005)	(±0.260)	(±0.574)	(±0.009)	(±1.599)	(±0.380)	(±0.378)	(±0.002)
	Δ Instant	-0.029	-0.015	0.034	0.039	0.002	0.036	0.018	0.035	−0.263*	0.686
		(±0.002)	(±0.045)	(±0.004)	(±0.277)	(±0.519)	(±0.009)	(±1.591)	(±0.394)	(±0.355)	(±0.004)
AEW	None	0.000	0.008	0.007	0.096	-2.123	-0.010	1.655	0.142	0.893	0.001
		(±0.002)	(±0.043)	(±0.005)	(±0.261)	(±0.686)	(±0.010)	(±1.400)	(±0.379)	(±0.393)	(±0.006)
	Δ Slow	-0.056	-0.047	-0.010	0.035	-0.020	-0.008	0.032	0.041	−0.103*	-0.398
		(±0.002)	(±0.043)	(±0.004)	(±0.274)	(±0.533)	(±0.008)	(±1.633)	(±0.397)	(±0.400)	(±0.004)
	Δ Fast	-0.111	-0.093	0.019	-0.005	-0.012	0.033	0.029	-0.009	−0.246*	2.524
		(±0.002)	(±0.045)	(±0.004)	(±0.281)	(±0.557)	(±0.008)	(±1.673)	(±0.401)	(±0.374)	(±0.033)
	Δ Instant	-0.111	-0.094	0.024	-0.007	-0.013	0.044	0.029	-0.011	-0.261	8.621
		(±0.002)	(±0.045)	(±0.004)	(±0.280)	(±0.553)	(±0.009)	(±1.675)	(±0.400)	(±0.363)	(±0.105)
GMV	None	0.000	0.007	0.005	0.096	-2.058	-0.007	1.685	0.148	0.914	-0.002
		(±0.001)	(±0.029)	(±0.005)	(±0.261)	(±0.694)	(±0.008)	(±1.897)	(±0.395)	(±0.567)	(±0.015)
	Δ Slow	0.000	-0.001	-0.004	-0.030	0.011	-0.016	-0.039	-0.042	−0.097*	-0.697
		(±0.001)	(±0.029)	(±0.004)	(±0.257)	(±0.766)	(±0.007)	(±1.386)	(±0.376)	(±0.563)	(±0.009)
	Δ Fast	0.094	0.096	0.073*	0.015	0.028	0.045	-0.047	-0.022	−0.325*	-1.324
		(±0.001)	(±0.031)	(±0.005)	(±0.254)	(±0.750)	(±0.007)	(±1.208)	(±0.365)	(±0.504)	(±0.008)
	Δ Instant	0.125	0.120	0.073*	0.032	0.025	0.047	-0.047	-0.007	−0.327*	-1.411
		(±0.001)	(±0.031)	(±0.005)	(±0.252)	(±0.750)	(±0.007)	(±1.201)	(±0.361)	(±0.501)	(±0.008)
MS	None	0.000	0.009	0.007	0.088	-2.060	-0.010	1.550	0.125	0.795	0.005
		(±0.002)	(±0.044)	(±0.005)	(±0.253)	(±0.528)	(±0.008)	(±1.077)	(±0.364)	(±0.410)	(±0.062)
	Δ Slow	-0.116	-0.127	0.044*	-0.085	-0.032	0.058*	-0.012	-0.078	−0.099*	-1.247
		(±0.002)	(±0.047)	(±0.004)	(±0.252)	(±0.413)	(±0.009)	(±1.092)	(±0.370)	(±0.407)	(±0.028)
	Δ Fast	0.186	0.184	0.156*	-0.002	-0.020	0.154*	0.005	0.030	−0.363*	-35.543
		(±0.002)	(±0.049)	(±0.004)	(±0.251)	(±0.464)	(±0.009)	(±1.123)	(±0.364)	(±0.365)	(±1.746)
	Δ Instant	0.186	0.184	0.160*	0.001	-0.021	0.161*	0.005	0.032	-0.372	-8.061
		(±0.002)	(±0.049)	(±0.004)	(±0.250)	(±0.463)	(±0.009)	(±1.123)	(±0.363)	(±0.363)	(±0.286)
PC	None	0.001	0.017	0.012	0.093	-2.006	-0.017	1.924	0.146	0.447	0.013
		(±0.003)	(±0.070)	(±0.007)	(±0.275)	(±0.472)	(±0.014)	(±3.535)	(±0.426)	(±0.302)	(±0.086)
	Δ Slow	0.090	0.102	0.060*	-0.030	-0.006	0.051	-0.114	-0.027	−0.106*	1.159
		(±0.004)	(±0.079)	(±0.007)	(±0.274)	(±0.494)	(±0.013)	(±1.549)	(±0.413)	(±0.288)	(±0.171)
	Δ Fast	-0.077	-0.042	0.106*	-0.166	-0.004	0.112*	-0.147	-0.165	−0.266*	-0.827
		(±0.004)	(±0.084)	(±0.008)	(±0.273)	(±0.479)	(±0.013)	(±1.439)	(±0.409)	(±0.276)	(±0.085)
	Δ Instant	-0.090	-0.057	0.109*	-0.184	-0.004	0.120*	-0.150	-0.179	−0.285*	-0.717
		(±0.004)	(±0.084)	(±0.008)	(±0.274)	(±0.477)	(±0.013)	(±1.437)	(±0.410)	(±0.269)	(±0.079)

Consistency of Aggregate Risk Profiles over time for ETF Portfolio – Energy +Utility Companies Divested



Impact of fossil fuel divestment on investor demographics



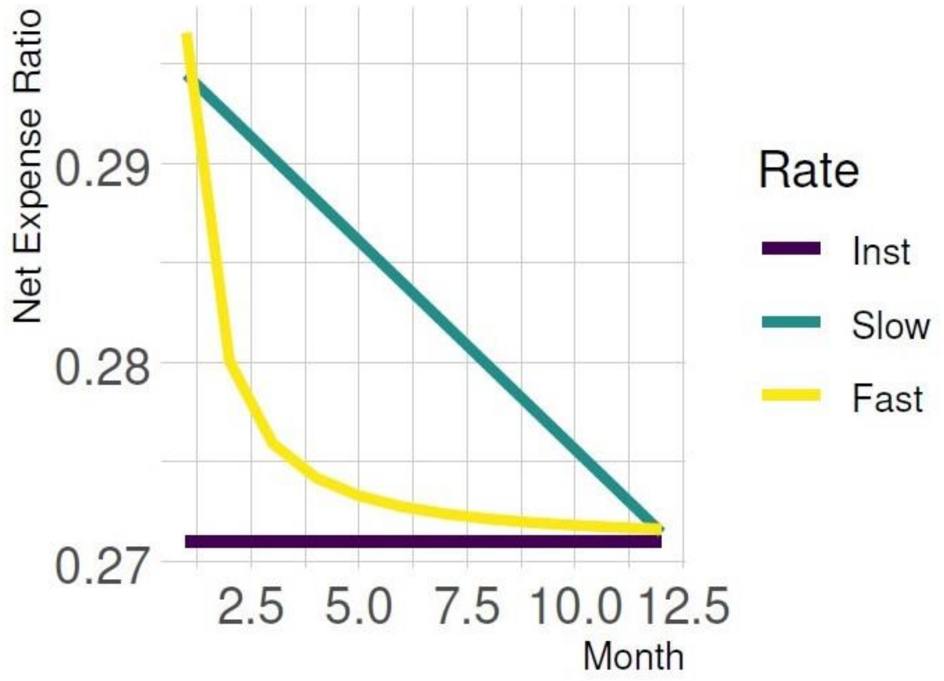
Parameter Estimates – OLS Regression

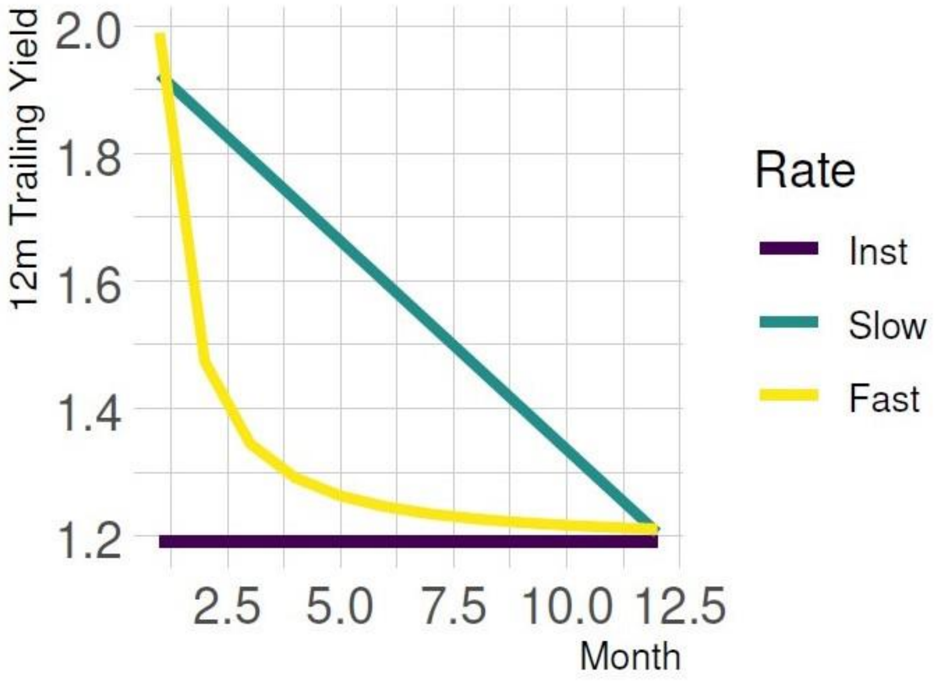
	Net Expense Ratio	12-month Trailing Yield
12m Trailing Yield	-0.019	
	(0.062)	
Net Expense Ratio		-0.021
		(0.070)
Net Assets	-0.234***	0.000
	(0.053)	(0.059)
ESG Quality Score	0.216***	0.286***
	(0.063)	(0.066)
Binary Market	-0.534***	-0.129
	(0.069)	(0.081)
YTD Return	-0.045	-0.032
	(0.057)	(0.060)
Carbon Footprint	0.110	0.469***
	(0.064)	(0.061)
Intercept	0.000	0.000
	(0.053)	(0.056)
R2	0.361	0.314
Degrees of freedom	229	229
F-statistics	(18.84, 7)	(15, 7)
Residual Std. error	0.149	0.84

Notes: ***Significant at the 1 percent level.

Impact of fossil fuel divestment on investor demographics

Prediction of the net expense ratio (left) and the trailing yield 12m (right) from the regressions with declining carbon footprint across the time in one year (12 months)





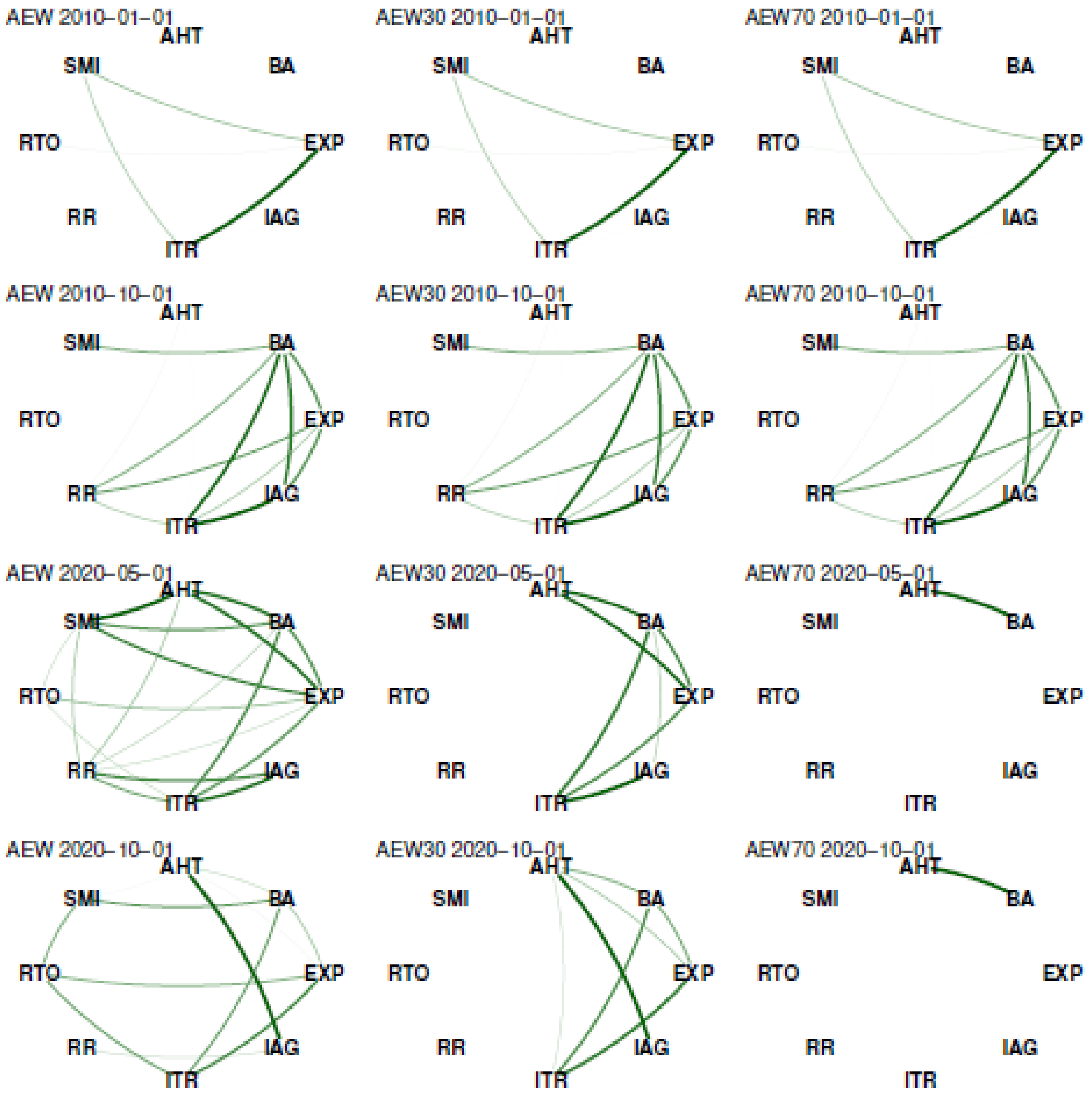
Case Study III: FTSE 100, with the divested high ESG risk assets

- The portfolios' robust covariance structure remained consistent despite increasing divestment proportions, until specific assets were entirely divested

- Divestment strategies based on environmental risk improve portfolio diversification

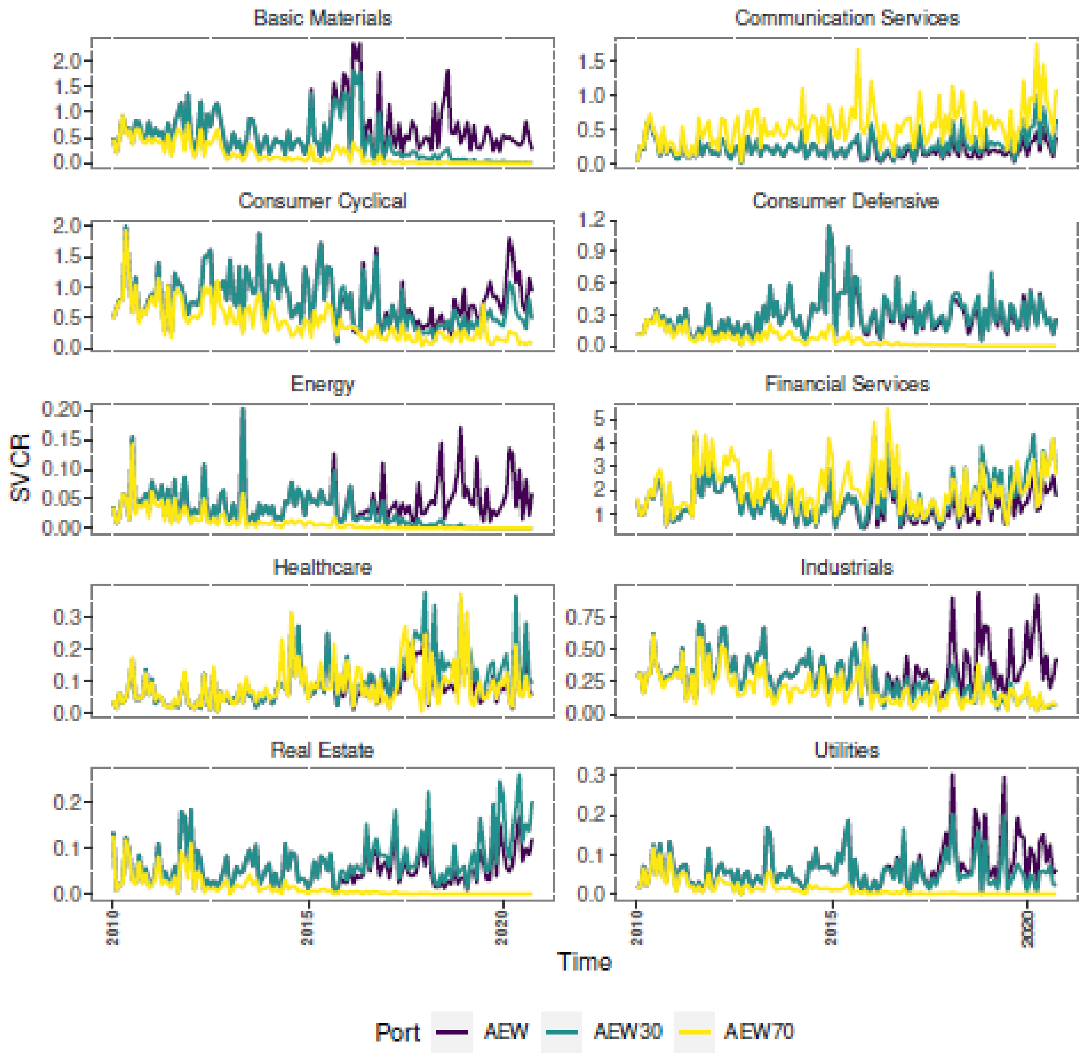
Impact of fossil fuel divestment on Robust Covariance Structure

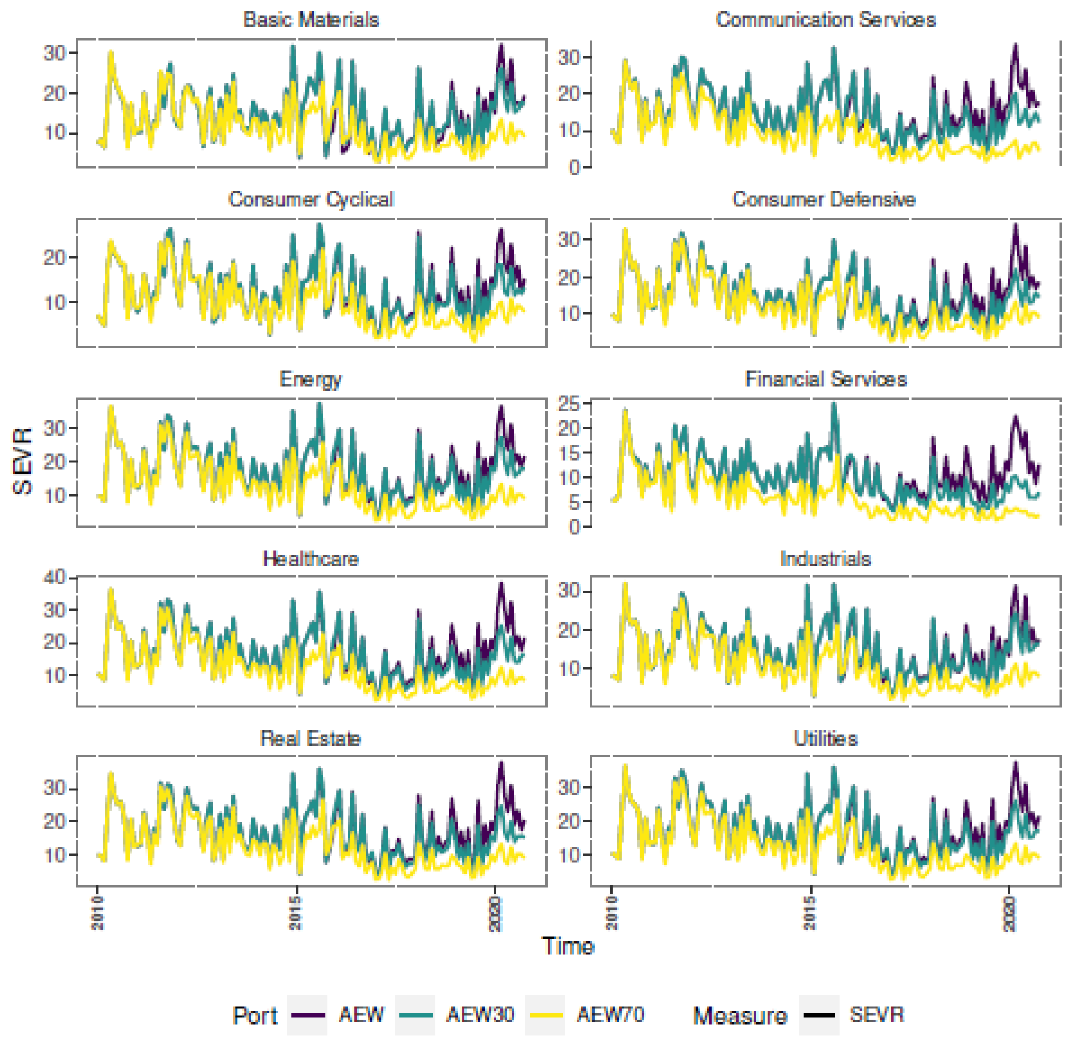
- Active Equal Weight Portfolios with Environmental Risk Scanning at 30% and 70% Levels.
- Visualizing a Single Sector of the FTSE 100 in a Robust Covariance Network.
- The Robust Covariance Structure Remains Unchanged Until a Certain Level of Divestment is Completed.



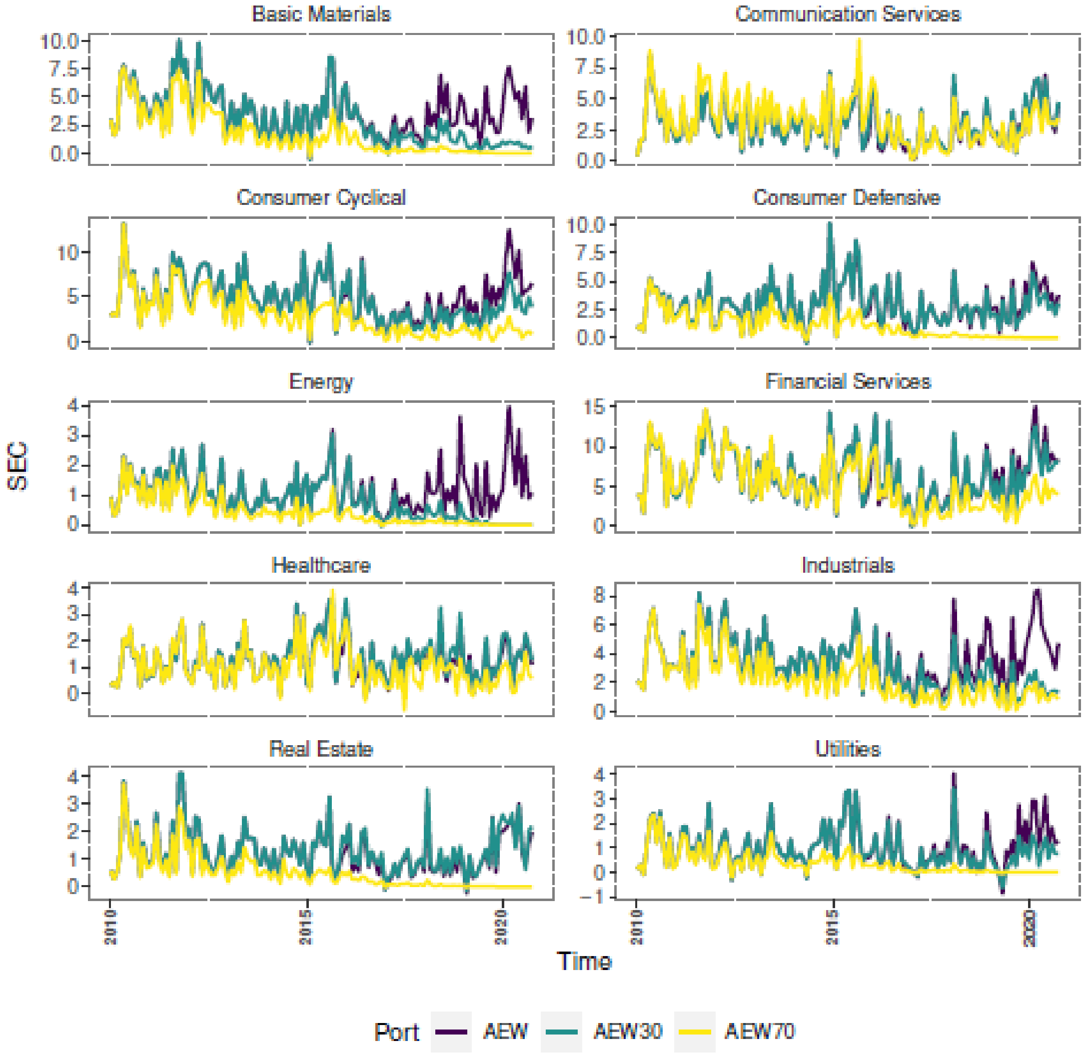
Pasin Marupanthorn, htt

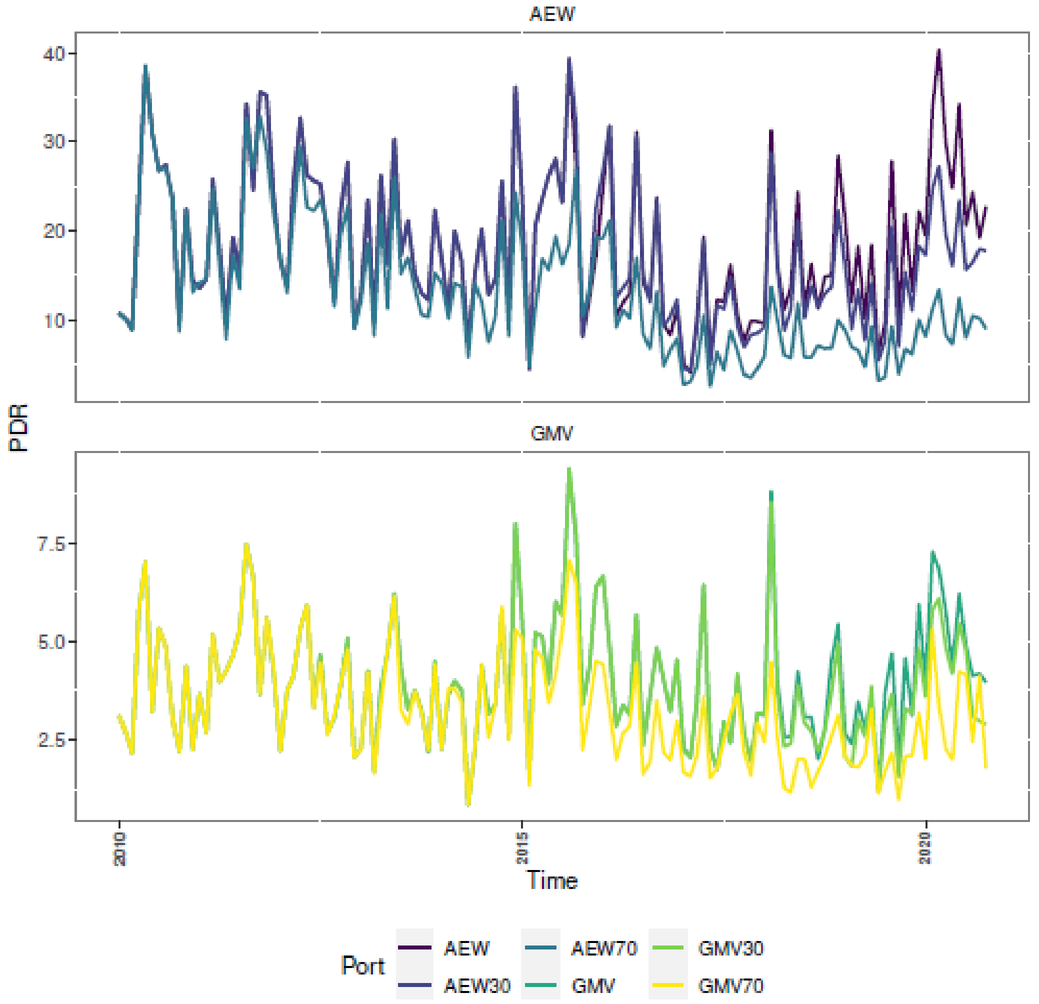
Impact of fossil fuel divestment on Portfolio Diversification





Impact of fossil fuel divestment on Portfolio Diversification





Case Study VI: Mixed Pension Funds of the US and the UK, with the divested high environmental risk assets

- Divestment does not yield statistically significant variations in returns and volatilities. This underscores the inherent value of environment-centric divestment strategies in pension fund management.

Mixed Pension Fund

- Utilizing mean-variance methodology to align both funds can optimize the balance between risk and return, highlighting the benefits of integrating funded pensions with their unfunded counterparts (J. Dutta, and el., 2000).

- Let *r* be the return of the funded pension portfolio, *g* be the return of the unfunded pension portfolio, and w^f be the portfolio weight, the return of the mixed pension fund portfolio is,

$$P = w^f r + (1 - w^f)g.$$

- According to the mean-variance portfolio farmwork, the optimal portfolio weight is calculated by

$$w_*^f = \underset{w^f}{\operatorname{argmax}} \quad \mathbb{E}(P) - \frac{\gamma}{2}\mathrm{Var}(P)$$

$$w_*^f = \frac{\mu_r - \mu_g + \gamma(\sigma_g^2 - \sigma_{rg})}{\gamma(\sigma_r^2 + \sigma_g^2 - 2\sigma_{rg})}$$

- γ is the risk aversion parameter, μ is the expected return, and σ is the volatility of the portfolio

High Environmental Risk Assets Divesting

- Replicating the funded portfolios of the US and the UK by the passive equal weight portfolios of the assets in S&P 500 and FTSE 100

- Replicating the unfunded portfolios of the US and the UK by the national GDP growths

- Annually Rebalancing from 2013 to 2023

- Scanning the divestable assets by ranking in the uppermost 50% based on environmental risk scores

- Divestment on the funded portfolio

$$P_t^{\mathrm{div}} = w_*^{f,\mathrm{div}} r_t^{\mathrm{div}} + (1 - w_*^{f,\mathrm{div}}) g_t,$$

Implication on the Mean and Variance of Mixed Pension Funds

GDP growth rates and total equity return comparisons: non-divested vs. divested portfolios (2013-2023)

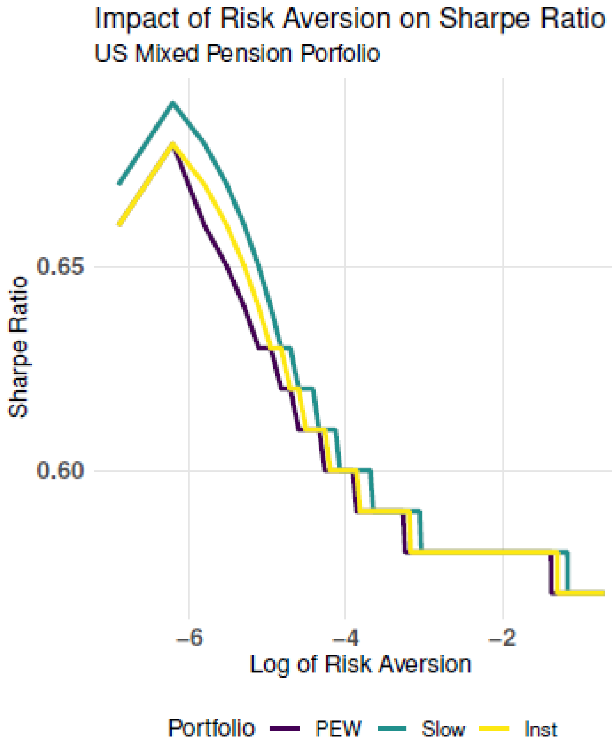
Country	Port	GDP growth (%)		Return on equity		Covariance	Correlation
		Mean	Variance	Mean	Variance		
US	PEW	1.21	4.47	3.79	37.76	7.18	0.55
	Slow			3.81	39.07	6.78	0.51
	Instant			3.94	39.62	6.63	0.50
UK	PEW	1.05	10.68	2.44	35.96	8.87	0.45
	Slow			2.40	34.61	8.92	0.46
	Instant			2.53	35.49	8.92	0.46

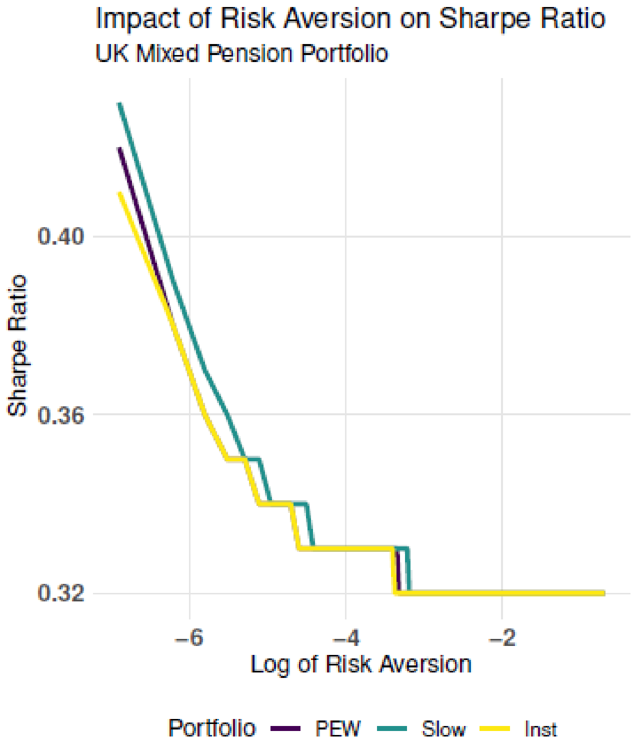
- Divestment based on scanning the E score does not statistically affect the mean, variance, and covariance.

Effect of Risk Aversion Parameter

Country	Port	$\gamma = 0.001$				$\gamma = 0.002$				$\gamma = 0.004$			
		w_*^f	Mean	Var	Sharpe	w_*^f	Mean	Var	Sharpe	w_*^f	Mean	Var	Sharpe
US	PEW	54.06	2.60	15.55	0.66	27.03	1.91	7.97	0.68	13.52	1.56	5.71	0.65
	Slow	57.34	2.78	17.08	0.67	28.67	1.99	8.24	0.69	14.33	1.60	5.72	0.67
	Instant	54.60	2.63	15.93	0.66	27.30	1.92	7.97	0.68	13.65	1.57	5.66	0.66
UK	PEW	29.24	1.46	12.10	0.42	14.62	1.25	10.77	0.38	7.31	1.15	10.57	0.35
	Slow	31.20	1.51	12.34	0.43	15.60	1.28	10.82	0.39	7.80	1.17	10.58	0.36
	Instant	28.28	1.43	11.88	0.41	14.14	1.24	10.73	0.38	7.07	1.14	10.57	0.35

Funding weight (%), expected return (%), variance, and Sharpe ration of the mixed pension portfolios with varying risk aversion parameters





DivFolio: A Shiny Application for Portfolio Divestment in Green Finance Wealth Management

Guideline of using divestment software

- Full guideline available on https://github.com/QuantFILab/Divfolio
- Example CSV Files available on https://github.com/QuantFILab/ISM-UCL-UCSB-MQ-WS
- Web application available on https://quantfilab.shinyapps.io/divfolioserveri/

Introduction to DivFolio

- R Shiny Application
- Functions for portfolio divestment
- Three Accessing Options
  - Web application
  - Desktop application
  - Local R script

  https://github.com/QuantFILab/Divfolio

Features comparison of available open portfolio analytics software. The available features were observed on 25/09/2022. Additional features may be developed after that date.

Features	DivFolio	Portfolio Visualizer	Personal Capital Finance	Yahoo! Finance	Google Finance	3D Portfolio Optimiser
Single-period Portfolio Backtest	✓	✓	✓	✗	✓	✗
Multi-period Portfolio Backtest	✓	✓	✓	✗	✗	✗
Portfolio Analytics	✓	✓	✓	✗	✓	✓
Asset Analytics	✓	✓	✓	✓	✓	✓
Portfolio Optimization	✓	✓	✓	✗	✗	✓
Personal Investment Planning Robo Advisor	✗	✗	✓	✗	✗	✗
Brokerage Integration	✗	✗	✓	✓	✗	✗
Portfolios and Benchmark Comparison	✓	✓	✓	✗	✗	✓
Illustrating ESG Scores	✓	✗	✓	✓	✗	✓
Divestment Planning Simulation	✓	✗	✗	✗	✗	✗
Portfolio's ESG Score Comparison	✓	✗	✓	✗	✗	✓
Customize Portfolio's Attribute Comparison	✓	✓	✓	✗	✗	✗
Risk Profiles Stability Analysis and Comparison	✓	✗	✗	✗	✗	✗
Graph Correlation Structure Analysis and Comparison	✓	✗	✗	✗	✗	✗

Divestment Example by replicating the constitutes in Goldman Sachs Japan Equity Portfolio

1. Sony Group Corp (6758.T)
2. Toyota Motor Corp (7203.T)
3. Mitsubishi UFJ Financial Group Inc. (8306.T)
4. ORIX Corp (8591.T)
5. Recruit Holdings Co Ltd (6098.T)
6. Keyence Crop (6861.T)
7. ITOCHU Corp (8001.T)
8. Hitachi Ltd (6501.T)
9. Fast Retailing Co Ltd (9983.T)
10. Shin-Etsu Chemical Co Ltd (4063.T)

We appreciate your attention. Please feel free to ask any questions.

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