A modelling framework for projections of equity portfolio returns under climate transition scenarios

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Agenda

- Introduction
- Literature review
- The Modelling Framework Proposal
- Methodology
- Empirical Results
- An Exercise of Portfolio Projections
- A Summary of Key Takeaways

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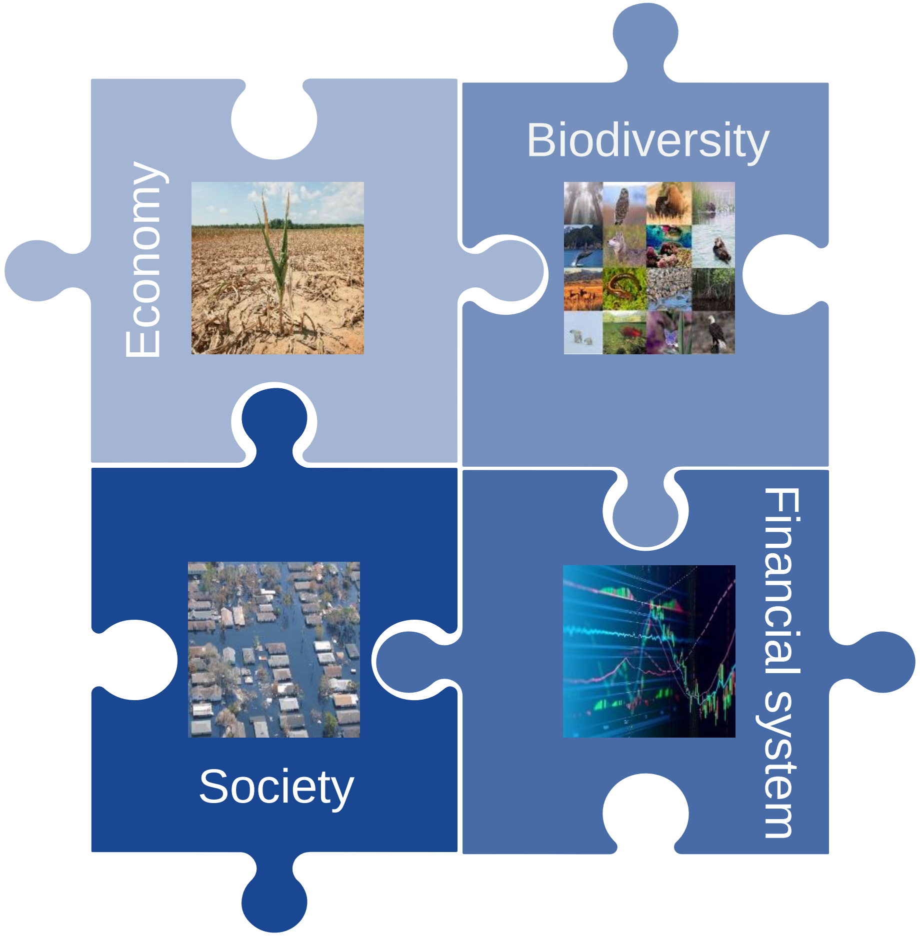
Introduction

Climate change due to anthropogenic emissions is affecting



The increase in damages from extreme weather events registered over recent years is an **alarm bell for policymakers and society** about the **urgent need to accelerate the aims of the Paris Agreement** and strengthen collaboration between governments, businesses and civil society.

The transition to a low-carbon economy is among the most important **challenges of our century** and presents an opportunity to build a **new economic model** based on sustainability

The **transition to a net-zero** economy requires: climate policy that **incentivises**

- **DIVESTMENT** from fossil fuels
- **INVESTMENTS** in clean energy, a shift in consumer preferences to low-carbon behaviour, investment in new technologies, and more sustainable business models

Introduction

Europe is at the **forefront of regulating the transition to a low-carbon economy**, with regulations documented in the Sustainable Finance Action Plan (March 2018), the European Green Deal (December 2019), and the EU Taxonomy (July 2020)

What Climate Risks?

New risks for the financial system

Transition risks:
- **Policy and law** (e.g., carbon price)
- **Technology and market** (e.g., renewable energies)
- **Reputation and behaviour** (e.g., consumer and investor preferences; controversies)

Physical risks:
- **acute** (e.g., flooding, drought)
- **chronic** (e.g., sea-level rise)

Our Focus

Carbon price is considered one of the **most effective systemic policies to reduce emissions**. The cost of a higher carbon price simultaneously **shifts the choices of businesses** (especially for the most heavily polluting ones), **investors and consumers** in the transition to a green economy (van den Bergh and Botzen, 2020). Climate policies can condition in the long-run the physical risk outcomes (e.g. Drouet et al., 2021; Gambhir et al., 2022)

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Literature Review

An emerging literature is exploring if investors are pricing climate transition risks in financial market. Focusing on stock market, some studies…

… focused on **the impact of CO_2 emissions on stock returns** (*e.g., Trinks et al., 2018; Bolton and Kacperczyk, 2021*).

… proposed to **proxy transition risks through green/carbon factors to incorporate in asset pricing models** (*e.g., Jin, 2018; Henriksson et al., 2019; Bonagura et al., 2020; Gorgen et al., 2020; Hübel and Scholz, 2020; Pástor, 2020; Bernardini et al., 2021; Fang et al., 2021; Maiti, 2021, Pastor et al., 2021*)

These studies mainly focus on a historical analysis

Scenario Analysis

The literature on **scenario analysis** of climate policies on capital markets **is still in its infancy**

- Macro level (e.g., Battiston et al., 2017, 2021; Semieniuk et al., 2021)
- Firm-level/portfolio (e.g., Alessi et al., 2021; Benedetti et al., 2021).

→ Alessi et al., 2021 assess the impacts of a stressed scenario on a green factor to estimate direct losses for global institutional sectors, including European large banks, if investors do not price climate policy risks.

→ Benedetti et al. (2021) evaluate the impact of carbon prices on stocks of fossil fuel firms. They provide evidence on how investors can reduce the risk by lowering the weight of firm's fossil-fuel in favor of those environmental-friendly and energy efficient.

However, both studies did not consider carbon price pathways from NGFS, which are representing a point of reference for several financial institutions worldwide

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The Modelling Framework Proposal

We propose a methodological framework and an empirical analysis **to project equity portfolio returns under different carbon price policies according to NGFS scenarios**.

Green Factor

To estimate the firms' exposure to climate policies, we constructed a proxy variable - the **Green Factor** - constructed on a market-weighted portfolio, with **long positions in firms** labelled as **green** and **short positions** in firms **labelled as brown**

Extended CAPM

We estimate an **extended Capital Asset Pricing Model** (market + green factor) using the classic OLS and robust MM-estimator. The model is estimated at firm-level

LBVAR Model

To evaluate the **transmission channel from carbon price to the stock market**, we propose estimating a **large Bayesian vector autoregression** (LBVAR) model. This model estimates the relationship between carbon price and factor returns (i.e., the market and the green factor) included in the extended CAPM and other macro-financial variables

Projections

We project the **impact of the climate policy scenarios on stock returns** for each firm in the portfolio. The time horizon for projections is 2030

NGFS scenarios:

- Current policies
- Nationally Determined Contributions

} HHW

- Below 2°C
- Net zero 2050

} Orderly

- Divergent net zero
- Delayed transition (stress)

} Disorderly

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Methodology – Green Factor

We propose a **New Green Factor** as a proxy to capture the exposure of stocks to climate policy risks:

How we identify **Brown** and **Green** firms using the following criteria:

Brown:
- Firms of **Climate Policy Relevant Sectors** (CPRS) classification developed in Battiston et al. (2017) and subsequent refinements. The CPRS is a classification of economic activities exposed to transition risk, and it is compatible with the EU Taxonomy.
- Firms must have a **carbon intensity value above 50** tonnes/mln $

Green:
- Firms **not classified as brown**
- an **environmental pillar score >= 75** (Best in class)
- a **carbon intensity** value **below or equal to 50** tonnes/mln $
- **absence of environmental controversies** to consider if the firm is violating the "do no significant harm (DNSH)" principle included in article 17 of the EU Taxonomy

We sort stocks into six portfolios based on market capitalization:

Green Factor

- **Small-medium (S) & Green (G)**
- **Small-medium (S) & Brown (B)**
- Small-medium (S) & Neutral (N)
- **Medium-large (L) & Green (G)**
- **Medium-large (L) & Brown (B)**
- Medium-large (L) & Neutral (N)

GMB = 0.5*(SG + LG) – 0.5*(SB + LB)

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Methodology – Extended CAPM

We consider the classic capital asset pricing model (CAPM) introduced by Sharpe (1964) and defined as

$$R_{it} - Rf_t = \alpha_i + \beta_i^{MKT}(MKT_t - Rf_t) + \epsilon_{it}. \qquad (1)$$

R_{it} - Rf_t is the excess return of stock *i* at time *t*, while the factor $MKT_t - Rf_t$ is the excess return of the market.

To estimate the pricing of climate-related (transition) risks in stock returns, we need to investigate whether investors include such risks in asset pricing. We aim to capture this risk through the proposed green factor

$$R_{it} - Rf_t = \alpha_i + \beta_i^{MKT}(MKT_t - Rf_t) + \beta_i^{GMB} GMB_t + \epsilon_{it} \qquad (2)$$

where $\beta_{GMB\,i}$ is the green factor parameter to be estimated and represents the exposure of firm *i* to climate policy risks.

$\widehat{\beta}_i^{GMB}$		**Estimated exposure**
	Statistically significant and positive sign	**Green**
	Statistically significant and negative sign	**Brown**
	Not statistically significant	**Climate risk neutral**

The model is estimated using both an OLS estimator and a robust-MM estimator (Bailer, 2005)

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Methodology – The Large Bayesian VAR (LBVAR) model 1/3

We propose a **macro-financial model** to perform scenario analysis on the CAPM's risk factors, **focusing on the transition risk stemming from the introduction of carbon pricing in the economy** and consistent with NGFS scenarios

Let $X_t = (x_{1,t}, x_{2,t} \ldots x_{n,t})'$ be the vector including the n variables in the system that follow a VAR(p) model:

$$X_t = c + B_1 X_{t-1} + \ldots + B_p X_{t-p} + u_t \qquad (3)$$

where p is the order of lags, t is the time dimension, X is an $n \times 1$ vector of variables, $B_1, \ldots, B_p$ are $n \times n$ matrices of coefficients to be estimated, $c = (c_1, \ldots, c_n)'$ is a vector of constants and u_t is normally distributed multivariate white noise with covariance matrix Σ.

We estimate the model **including data on daily frequency**:
- MKT and GMB factor returns;
- Carbon price;
- Short-term and long-term rates (one-month Euribor rate and 10-year Bund, respectively);
- Inflation swap at a two-year horizon;
- Oil price (Brent).

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Methodology – The Large Bayesian VAR (LBVAR) model 2/3

We estimate the model within an LBVAR framework (Banbura et al., 2010). In contrast to classic structural models, **LBVAR is very flexible in capturing complex data relationships**.

For scenario analysis, **we need to identify structural shocks in our system of equations**. In particular, our aim is to **derive the pathways** of the variables consistent **with an increase in carbon price that is driven by a climate policy shock**.

Let us define the structural VAR as follows

$$\mathcal{A}_0 X_t = \chi + \mathcal{A}_1 X_{t-1} + \cdots + \mathcal{A}_p X_{t-p} + \epsilon_t, \qquad (4)$$

where ϵ_t is a vector of independent white noise processes with unit-diagonal variance covariance matrix. Solving the system of equations for $\mathcal{A}_0$, leads to the original VAR in reduced form (3).

Let us define $\Gamma = \mathcal{A}_0^\top$, structural identification consists in deriving Γ s.t.

$$u_t = \Gamma \epsilon_t, \qquad (5)$$

The Γ matrix is a **fundamental ingredient** for our conditional scenario analysis. **We perform structural identification using the sign restrictions method** (e.g., Faust, 1998; Canova and De Nicolo, 2002; Uhlig 2005).

Methodology – The Large Bayesian VAR (LBVAR) model 3/3

As is standard practice in VAR literature**, we impose the sign to be satisfied at time t_0**, while the **system's dynamic response is entirely data-driven**.

Variables	Monetary policy shock	Aggregate demand shock	Aggregate supply shock	Climate policy shock
Cumulative return GMB			-	+
Cumulative return MKT	-	+	-	-
Risk-free rate	+	+	+	
Carbon price (euro/tonne)				+
Two-years inflation swap	-	+	+	+
Brent (euro/barrel)				
Bund ten years				

Identification assumptions through sign restrictions on impact

We implement the impulse-response analysis by sampling alternative structural identifications, as suggested by Uhlig (2005). To **perform scenario analysis** we need to pick a single candidate Γ. We adopt **the median target approach proposed by Fry and Pagan** (2005, 2011).

The structural scenario is derived following an approach similar to Antolin-Diaz et al. (2021).

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Empirical Results – Data

We pilot our analysis on a **portfolio of about 2,000 shares listed in Europe over the 2016–2021 period**, offering a comprehensive overview of the European stock market.

As drivers of models, we consider **firm-level non-financial variables** (such as carbon intensity and environmental controversies), **firm-level financial variables** (such as stock price and market capitalisation) and **financial macro-variables** (such as future on carbon price (EU) and the one-month Euribor rate).

Variables	Source	Frequency	Period	Metric/Model
CPRS classification	Battiston et al. (2017)	-	2008-2020	Green factor
Carbon intensity	Refinitiv	Yearly	2008-2020	Green factor
Environmental pillar score	Refinitiv	Yearly	2008-2020	Green factor
No. of environmental controversies	Refinitiv	Yearly	2008-2020	Green factor
Firm's market capitalisation (euro)	Refinitiv	Daily	2009-July 2021	Green factor
Firm's stock price (euro)	Refinitiv	Daily	2009-July 2021	Green factor + CAPM
One-month Euribor rate (or risk-free)	Refinitiv	Daily	2009-July 2021	CAPM + LBVAR
Risk factors: MKT, SMB, CMA, HML, RMW, WML	Fama and French webpage	Daily	2009-July 2021	CAPM + LBVAR (MKT)
Carbon price (euro/tonne)	EUA/Refinitiv	Daily	2009-July 2021	LBVAR
Two-years inflation swap	Refinitiv	Daily	2009-July 2021	LBVAR
Brent (euro/barrel)	Refinitiv	Daily	2009-July 2021	LBVAR
The ten-year constant maturity German Government Bond Yield (or Bund)	Refinitiv	Daily	2009-July 2021	LBVAR

The risk factors sourced from Fama & French were retrieved from: http://mba.tuck.dartmouth.edu/pages/faculty/ken.french/index.html. As we consider the perspective of a European investor, we convert the factors to euro returns using the approach described in Gluck et al. (2020).

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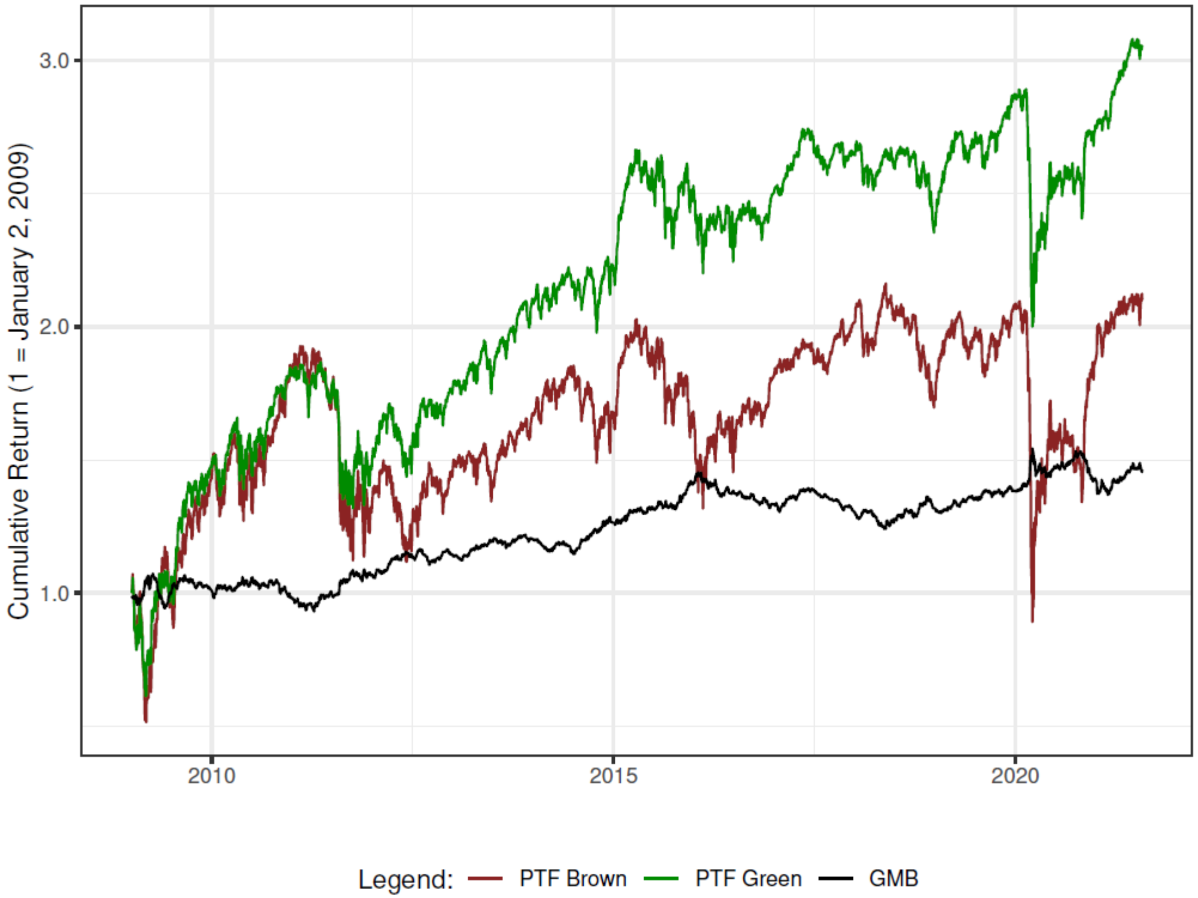
Empirical Results – Green Factor

Time series of the cumulative returns of green and brown portfolios and the GMB factor



- We observe that a positive difference between the performance of green and brown portfolios emerges from 2013 and **furtherly enlarges starting from 2015, after the Paris Agreement**.
- The recent **COVID-19 pandemic (Black Swan event)** has highlighted how **green are more resilient than brown firms during turbulent market periods**. Several studies in the literature confirmed this evidence (e.g., Albuquerque et al., 2020; Bonagura et al., 2020; Jacob and Nerlinger, 2021; Yousaf et al., 2022).

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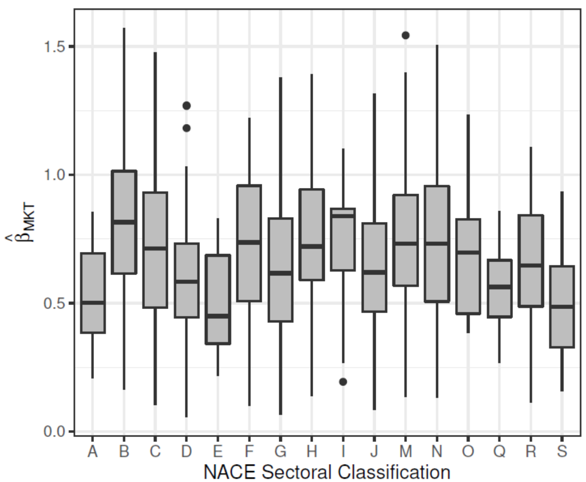
Empirical Results – Extended CAPM

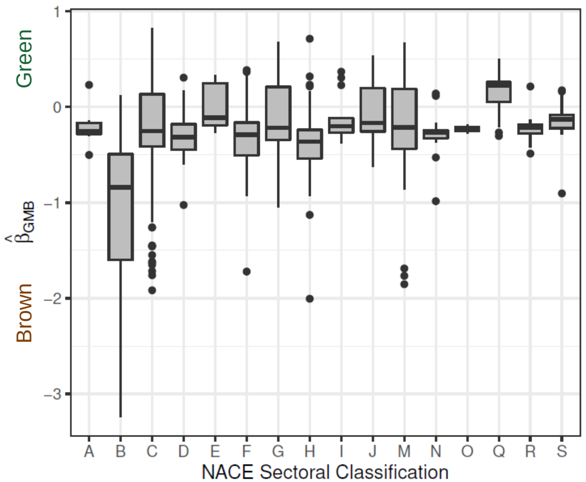
We focus on **firms listed from January 2016 to July 2021**. The final sample includes 1,982 firms and 1,417 daily observations for each stock. We restrict the estimation of the CAPM to recent years to capture **the most recent investor perceptions regarding the exposure of a firm to climate-related transition risks and systemic risk**.

- For each stock *i* in the portfolio, we estimate the extended CAPM using OLS and a robust MM estimator.
- MM-estimator tends to outperform OLS estimator in terms of Mean Absolute Error

Distributions of the estimated exposure to sistemic risk



Distributions of the estimated exposure to climate policy risk



Sector	No. of equities	Linear Model (4) $\hat{\beta}^{MKT}$	Linear Model (4) $\hat{\beta}^{GMB}$	Robust Linear Model (4) $\hat{\beta}^{MKT}$	Robust Linear Model (4) $\hat{\beta}^{GMB}$
A	16	100.0	62.5	100.0	43.8
B	96	99.0	88.5	97.9	92.7
C	917	98.0	51.1	99.3	61.1
D	69	100.0	58.0	100.0	63.8
E	15	100.0	46.7	100.0	73.3
F	73	98.6	43.8	100.0	56.2
G	157	98.7	41.4	99.4	51.6
H	89	100.0	53.9	100.0	64.0
I	25	100.0	40.0	100.0	52.0
J	246	100.0	36.2	100.0	46.3
M	118	100.0	44.1	100.0	56.8
N	52	100.0	36.5	100.0	38.5
O	6	100.0	33.3	100.0	50.0
Q	25	92.0	32.0	100.0	48.0
R	30	96.7	36.7	100.0	40.0
S	48	100.0	27.1	100.0	35.4
Total	1,982	98.7	48.4	99.5	57.9

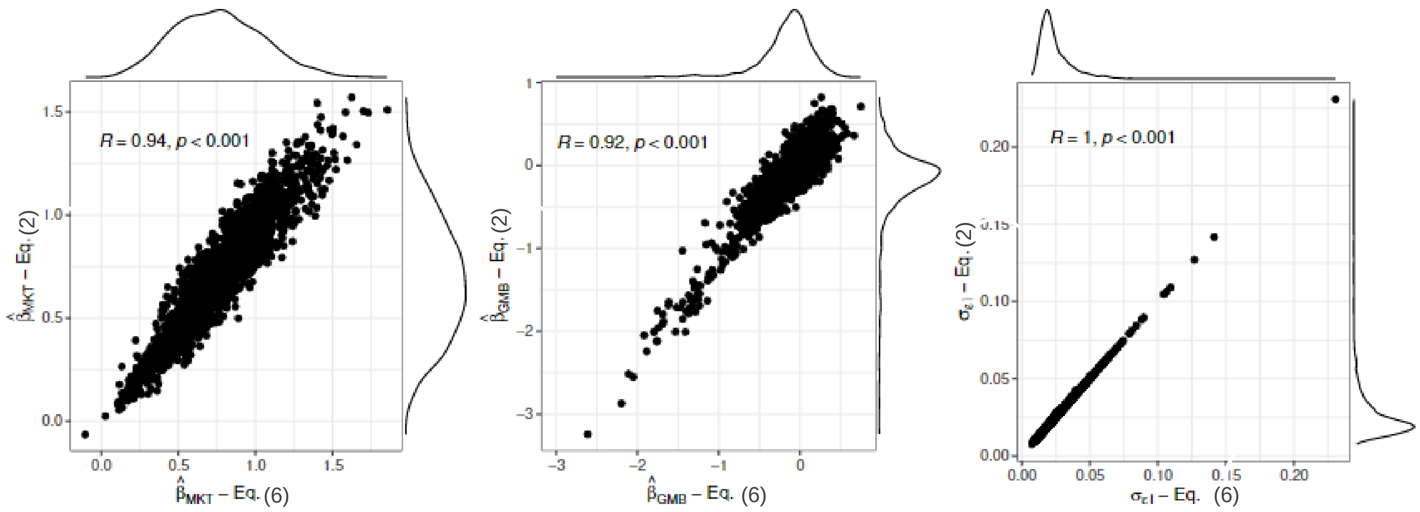
(A) Agriculture, Forestry and Fishing; **B Mining and Quarrying**; **(C) Manufacturing**; **(D) Electricity, Gas, Steam and Air Conditioning Supply**; (E) Water Supply, Sewerage, Waste Management and Remediation Activities; **(F) Construction**; (G) Wholesale and Retail Trade; **(H) Transporting and Storage**; (I) Accommodation and Food Service Activities; (J) Information and Communication; (L) Real Estate Activities; (M) Professional, Scientific and Technical Activities; (N) Administrative and Support Service Activities; (O) Public Administration and Defense, Compulsory Social Security; (P) Education; (Q) Human Health and Social Work Activities; (R) Arts, Entertainment and Recreation; (S) Other Service Activities; (T) Activities of Households as Employers; (U) Activities of Extraterritorial Organisations and Bodies

Empirical Results – A robustness analysis on CAPM 2/2

We carried out a robustness analysis to shed additional light on the extended CAPM. Specifically, we explore if there are important differences in estimates when extending the model (2) by including Fama and French (2015) factors augmented by the momentum factor (Carhart, 1997).

$$R_{it} - Rf_t = \alpha_i + \beta_i^{MKT}(MKT_t - Rf_t) + \beta_i^{GMB} GMB_t + \epsilon_{it} \qquad (2)$$

$$R_{it} - Rf_t = \alpha_i + \beta_i^{MKT} MKT_t - Rf_t + \beta_i^{SMB} SMB_t + \beta_i^{CMA} CMA_t + \beta_i^{RMW} RMW_t + \beta_i^{WML} WML_t + \beta_i^{GMB} GMB_t + \epsilon_{it} \qquad (6)$$



R is the Pearson correlation, while p is the p-value.

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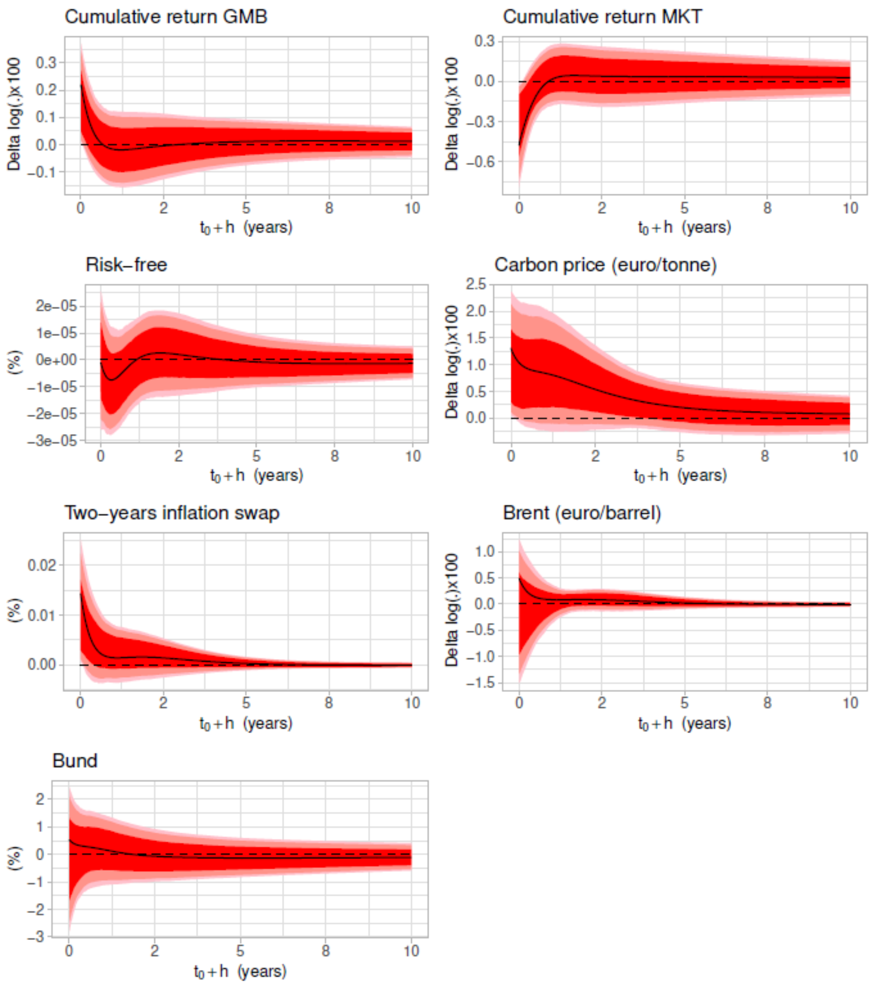
Empirical Results – Impulse-Response from LBVAR Model



Impulse-response from a Climate Policy shock exercise. We report the accepted draws and median target response (black line). The three areas in the plot correspond to 50%, 80% and 95% of all responses that satisfy sign restrictions

The sign restriction is imposed only at time t_0. This means that from t_{0+h}, the data entirely drive the dynamic response of the variables to this shock. Each response can be interpreted as the difference between the path of the variable *n* in the system when the CP shock occurs at time t_0 and the path of the same variable in the absence of any shock.

Highlights:

- We note that the **reaction** of the variables in the system to the **Climate Policy shock is only temporary**.
- Specifically, we find that the response reverts to the zero line in less than two years, except for the carbon price, for which the shock is more persistent over time.
- We find that the **adverse reaction of the stock market index becomes slightly positive after one year from the shock**. This evidence suggests that a transition policy to a low-carbon economy **has only short-run adverse effects on the stock market**.

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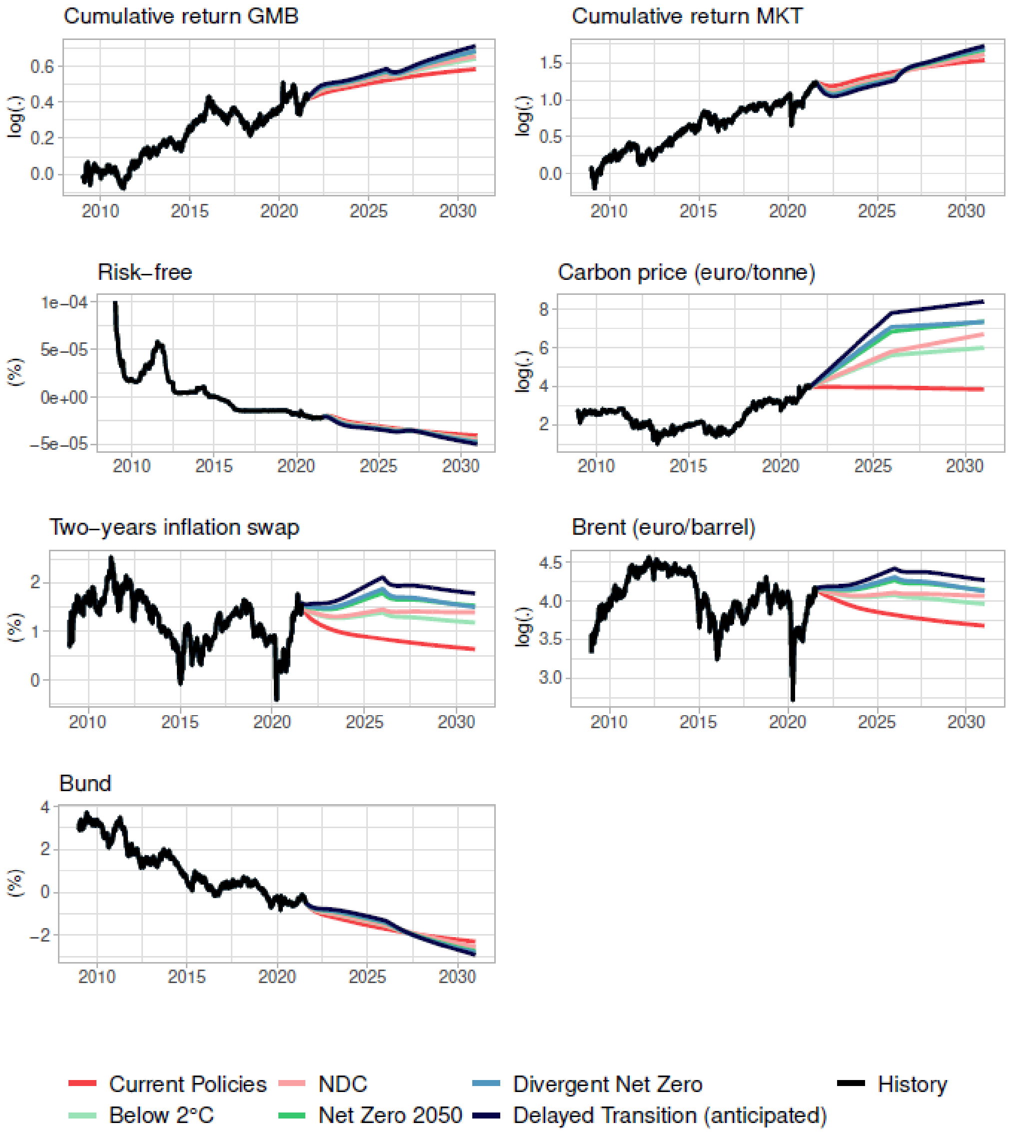
Empirical Results – Scenario Endogenous Variables



We report the pathways of the endogenous variables in the system according to the different carbon pricing scenarios.

- The cumulative returns of the **green factor will be at their highest in scenarios where carbon pricing policy is the most aggressive**. This means that in constructing a portfolio with long green and short brown strategies, we should expect a greater cumulated return in the disorderly transition (anticipated) scenario than the Current Policies scenario.
- In the most aggressive scenario, a sharp contraction in the market excess return is likely to occur. However, **the stock market will absorb the shock gradually by outperforming the Current Policies scenario after three years** from the aggressive Climate Policy scenario.

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An Exercise of Portfolio Projections

- We construct **sectoral portfolios using the NACE one-digit classification** of firms.
- We apply the projections of risk factors (green and market factors) to firm-level estimates obtained from the extended CAPM model

Sectors	Eq. (4) Average values		Hot-house World NDCs		Orderly Below 2°C		Orderly Net Zero 2050		Disorderly Divergent Net Zero		Disorderly - Stress analysis Delayed Transition (anticipated)	
	β^{GMB}	β^{MKT}	2025	2030	2025	2030	2025	2030	2025	2030	2025	2030
A	-0.084	0.518	-3.62	4.97	-3.26	5.19	-5.56	9.63	-6.04	11.24	-7.37	13.62
B	-0.989	0.817	-8.57	-0.68	-7.72	1.25	-13.17	2.89	-14.31	4.65	-17.46	4.53
C	-0.141	0.708	-5.23	7.18	-4.71	7.57	-8.04	14.02	-8.73	16.39	-10.65	19.82
D	-0.208	0.598	-4.60	4.73	-4.15	5.21	-7.08	9.74	-7.69	11.54	-9.39	13.84
E	-0.019	0.506	-3.32	5.52	-2.99	5.62	-5.09	10.37	-5.54	12.00	-6.75	14.62
F	-0.195	0.739	-5.65	7.01	-5.09	7.52	-8.68	13.95	-9.43	16.39	-11.51	19.74
G	-0.079	0.631	-4.44	6.71	-4.00	6.95	-6.82	12.85	-7.41	14.95	-9.04	18.15
H	-0.272	0.762	-6.07	6.42	-5.47	7.09	-9.33	13.21	-10.14	15.65	-12.37	18.73
I	-0.081	0.741	-5.29	8.47	-4.77	8.74	-8.13	16.15	-8.84	18.76	-10.78	22.78
J	-0.039	0.638	-4.36	7.28	-3.93	7.45	-6.69	13.74	-7.27	15.92	-8.87	19.38
M	-0.114	0.749	-5.47	8.20	-4.93	8.54	-8.40	15.79	-9.13	18.40	-11.14	22.30
N	-0.139	0.730	-5.40	7.56	-4.87	7.95	-8.29	14.72	-9.01	17.20	-11.00	20.80
O	-0.122	0.710	-5.18	7.45	-4.67	7.80	-7.96	14.44	-8.65	16.84	-10.56	20.39
Q	0.048	0.560	-3.49	7.09	-3.15	7.07	-5.35	12.99	-5.81	14.92	-7.08	18.28
R	-0.108	0.633	-4.55	6.39	-4.10	6.69	-6.99	12.39	-7.59	14.46	-9.26	17.51
S	-0.060	0.501	-3.42	5.00	-3.08	5.18	-5.25	9.59	-5.71	11.16	-6.96	13.55
All sectors	-0.166	0.691	-5.18	6.59	-4.67	7.02	-7.95	13.04	-8.64	15.29	-10.55	18.45

We report the cumulative returns with respect to the Current Policies scenario. The firms included in each sectoral portfolio are equally weighted. We report the values in 2025 and 2030, with 2020 as the base year (2020=100).

A Summary of Key Takeaways

- We suggest a **new modelling framework** to project equity portfolio returns under climate transition scenarios.
- We propose a **new green factor** based on a daily spread of portfolios with long positions in green stocks and short positions in brown stocks.
- To evaluate the transmission channel from carbon price to the stock market, we propose **estimating a large Bayesian vector autoregression model**. This model estimates the relationship between carbon price and factor returns (i.e., the market and the green factor) included in the extended CAPM by including macro-financial variables.
- **We project the impact of the climate policy scenarios on stock returns** for each stock in the portfolio. The time horizon for projections is 2030. Given the uncertainty in the timing of the introduction of climate policy, we consider different **scenario analyses coherent with the carbon price pathways suggested by the Network for Greening the Financial System (NGFS)**.
- **Climate transition risks are not confined to fossil fuel firms**, especially under a stressed scenario.
- Our framework may represent adequate **support for investors** to prepare portfolios for such risks **under uncertainty about the timing of carbon policy introduction**.
- Future extensions of the modelling framework may consider the inclusion of direct effects from physical risks and the evaluation of the impact of climate risks on value-at-risk (including Green swans).

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Full Version of the Working Paper

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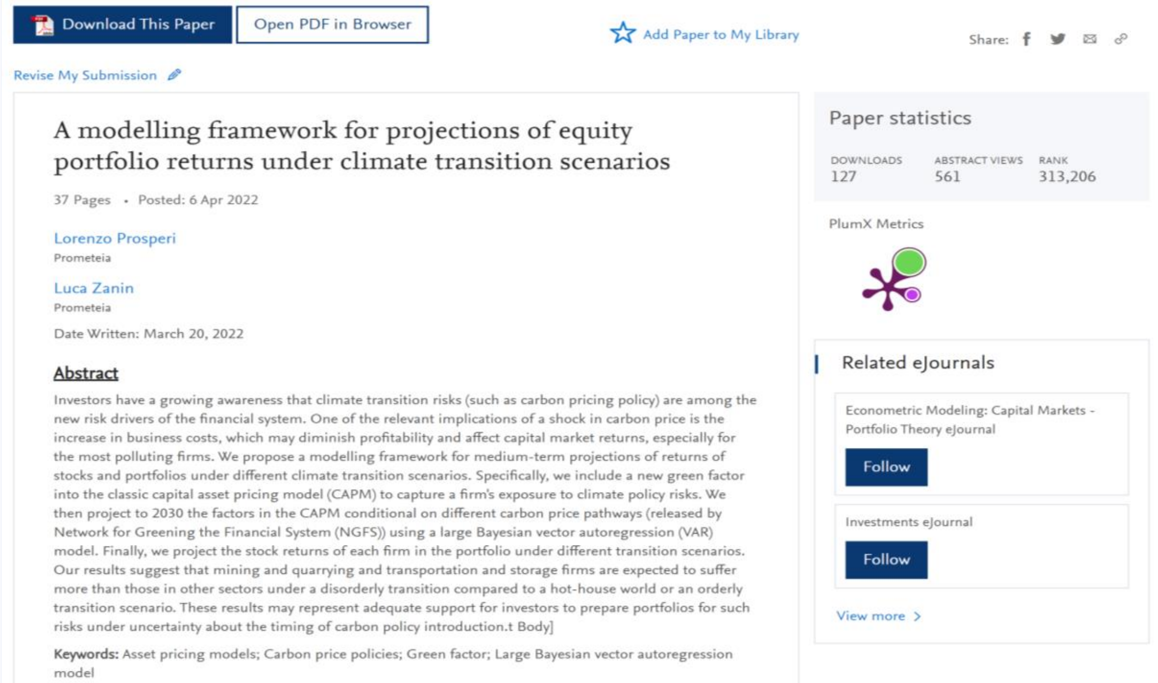

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Abstract

Investors have a growing awareness that climate transition risks (such as carbon pricing policy) are among the new risk drivers of the financial system. One of the relevant implications of a shock in carbon price is the increase in business costs, which may diminish profitability and affect capital market returns, especially for the most polluting firms. We propose a modelling framework for medium-term projections of returns of stocks and portfolios under different climate transition scenarios. Specifically, we include a new green factor into the classic capital asset pricing model (CAPM) to capture a firm's exposure to climate policy risks. We then project to 2030 the factors in the CAPM conditional on different carbon price pathways (released by Network for Greening the Financial System (NGFS)) using a large Bayesian vector autoregression (VAR) model. Finally, we project the stock returns of each firm in the portfolio under different transition scenarios. Our results suggest that mining and quarrying and transportation and storage firms are expected to suffer more than those in other sectors under a disorderly transition compared to a hot-house world or an orderly transition scenario. These results may represent adequate support for investors to prepare portfolios for such risks under uncertainty about the timing of carbon policy introduction.t Body]

Keywords: Asset pricing models; Carbon price policies; Green factor; Large Bayesian vector autoregression model

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