Green Bonds for the Transition to a Low Carbon Economy

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Structure

(1) Introduction

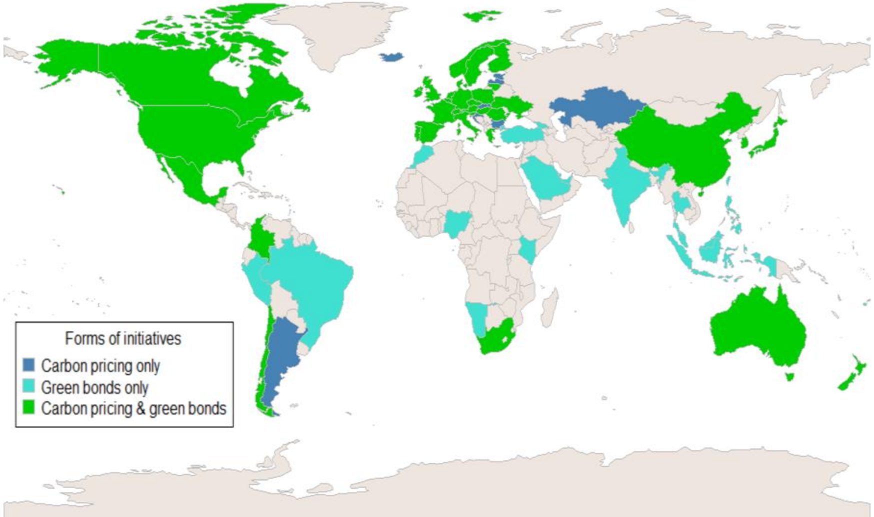
(2) A dynamic portfolio model for green investment

(3) Empirical study: green versus conventional bonds performance

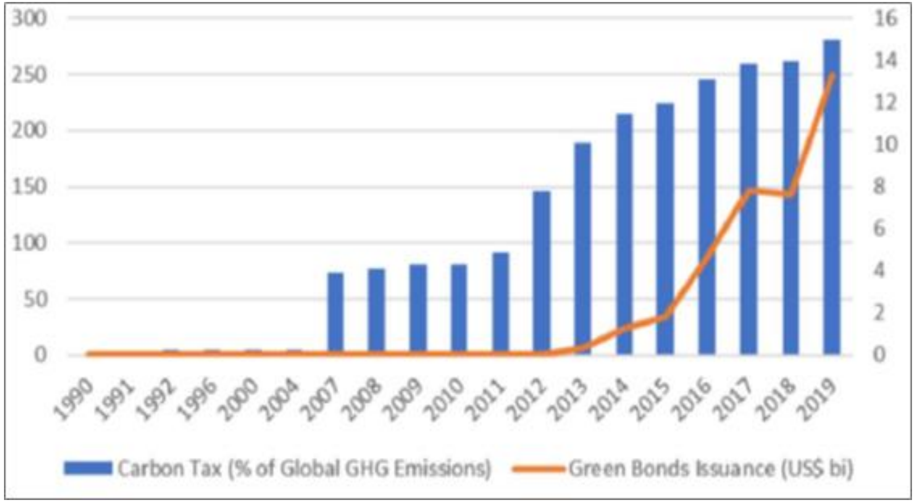
(4) Conclusions

(1) Introduction

Green bonds have expanded recently as an important tool to fund green fiscal policy



Source: Semmler et al. (2021)



Source: Heine et al. (2019)

The effectiveness of financial market for this transition depends on attracting investors and changing mindsets

Financial instability ⟺ "Stranded assets" (Carney, 2018) → Losses and crashes in stock market and banking system → Green swan events, losses due to climate uncertainties and climate disasters (Bolton et al., 2020)

Financial market as a roadblock

- Investor's short-termism (Haldane, Davies et al., 2014, Semmler et al., 2020)
- Reducing green investments

Financial market as a bridge

- Green bonds as bridge finance to scale up + increase elasticity
- Improve intertemporal fairness (Orlov et al., 2018; Sachs, 2014)
- Investor's portfolio benefits

Our study

- Dynamic portfolio model with climate externalities and innovation to study investors' portfolio when pricing long-term climate risks
    - Green innovation creates externalities that benefit green securities in LR.
    - Insisting in fossil fuel investment and R&D might decrease returns and wealth.
    - We use time-varying returns empirically obtained through Harmonic estimations of financial market data for green and fossil fuel bonds and add externality effects (Fast Fourier Transform).

Long-term Effects

- We empirically study the reward-to-risk, yield and volatility differentials between green and conventional bonds

Attractiveness in the present

Some of our conclusions…

- Our dynamic portfolio model with two risky assets provides a tool for online long-term oriented portfolio decisions and lessons for portfolio allocation when climate externalities hold
  - **Green investment** positive externalities ensure <u>better wealth accumulation</u> and can <u>prevent long-term climate risks</u> in financial markets.
  - The policy and **externality effects** <u>increase green bond returns</u> and attract investors.
  - <u>Resources should also be channeled to green innovation</u> to ensure a better wealth trajectory.

- Our empirical studies show that:
  - **Green bonds have** <u>higher reward to risk performance</u>, with <u>lower volatilities</u>.
  - <u>Mixed results for yields</u>, as in the literature (primary and secondary).
  - **Heterogeneities** for different <u>currencies & sectors</u>.

- If climate externalities are not currently priced by investors, policy makers could help increasing the attractiveness of green bonds to ensure better wealth accumulation.

(2) A dynamic portfolio model for green investment

Our model: long-term oriented investors internalize climate risks.

$$V(W,x,t) \equiv max_{\{u_s,c_s,\pi_s\}} \mathbb{E}\{\int_t^T e^{-\delta_0(s-t)} F(c_s W_s, u_s W_s) ds\}$$

$$s.t.\dot{W}(t) = \pi_t \boxed{r^{e^i}_{t_{green}}} W_t + (1-\pi_t) \boxed{r^{e^i}_{t_{fossilfuel}}} W_t - (u_t + c_t) W_t - X(\Pi_t, W_t)$$

Investors channel their wealth to 2 risky assets: green or fossil fuel bonds

u_s Innovation expenses/Wealth c_s Consumption/Wealth π_s % green bond holdings

$$F(c_s W_s, u_s W_s) = w_1 * log(c_s W_s) + (1-w_1) * log(u_s W_s)$$

Investors maximize Utility by choosing GB holdings and consumption and innovation levels.

- We have a Merton (1971, 1973) intertemporal CAPM model (also studied by Campbell & Viceira, 2002).
- We update this approach for climate finance challenges and risks.
- We have a Romer type adjustment (endogenous growth theory), in which innovation also benefits investors by increasing utility and generating positive externalities, if green.

Our model: Green externalities benefit long-term asset returns

Final returns: adjusted through externality effects arising from LT innovation, policy, and social returns

$$r^{e'}_{green}(t) = (1 \boxed{+} \mu(\nu u_t))(\alpha + \gamma * r^{e}_{green}(t)).$$

$$r^{e'}_{fossil\,fuel}(t) = (1 \boxed{-} \mu((1-\nu)u_t))r^{e}_{fossil\,fuel}(t).$$

Obtained with harmonic estimations using the Bloomberg Barclays MSCI Green Bond and Corporate Energy Index (2015-2020)

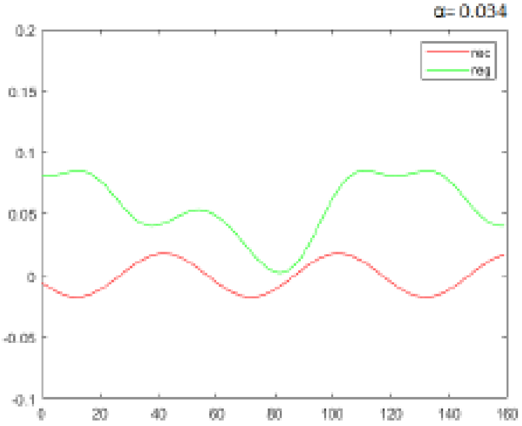
Engineers (v) to green or fossil fuel innovation (u)

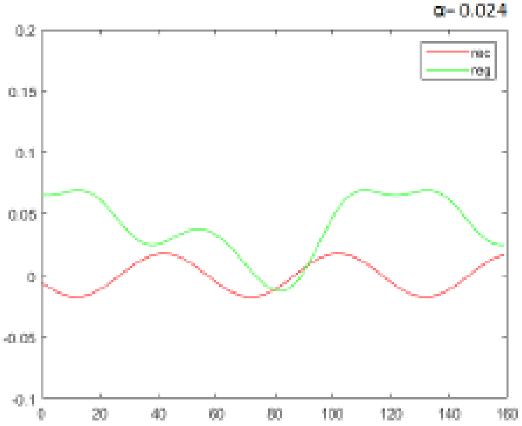
Positive impact of externalities/Climate Policy effect

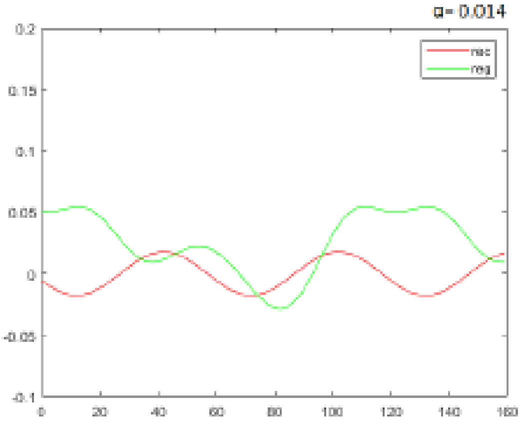
- Long-term oriented investors (e.g.: pension funds) follow low frequency movements of asset returns → We use a Fast Fourier Transform (see Chiarella et al., 2016; Semmler & Hsiao, 2011), sine-cosine function → helps online portfolio decisions.

- We add to the estimated oscillations the positive externalities of green innovation - in the spirit of Acemoglu et al. (2012) direct technical change – as well as other positive climate/policy benefits.

Our model: Green and fossil fuel adjusted asset returns

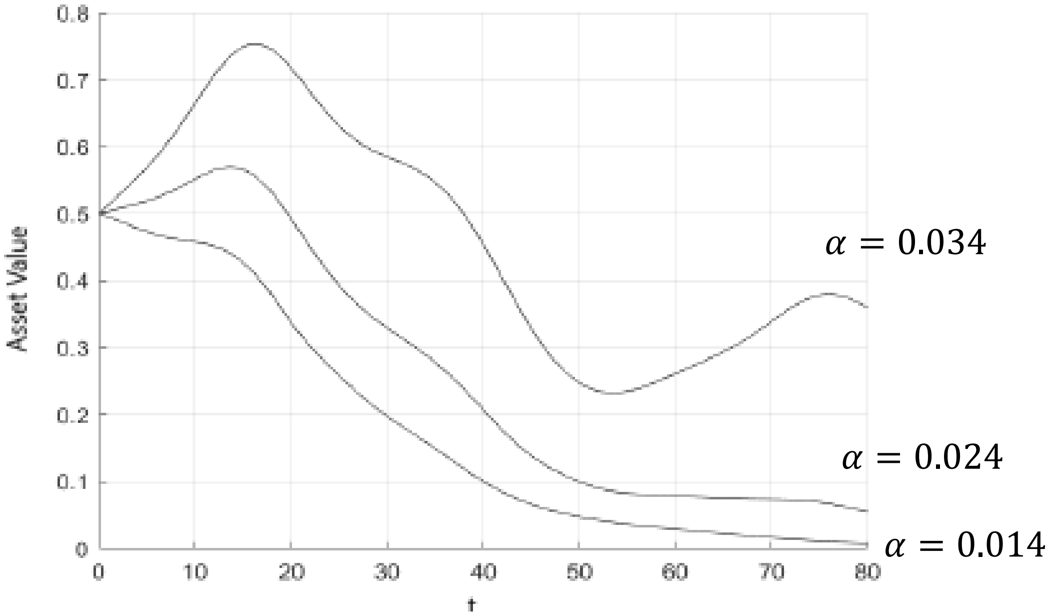






Our model: Wealth dynamics when v=0.5 (50% green engineers)

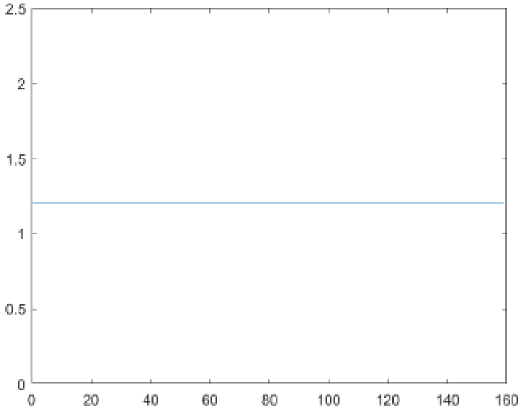
- Numerical solutions obtained through a NMPC algorithm



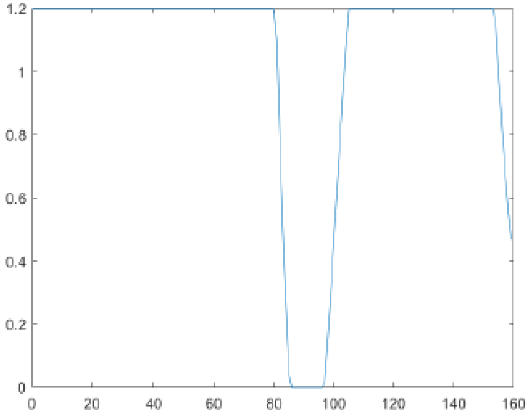
- Green investment positive externalities can prevent long-term climate risks in financial markets.
- The policy and externality effects attract investors to green bonds, but these resources should also be channeled to long-term oriented green investment (R&D).

Our model: Portfolio decision – share of green assets

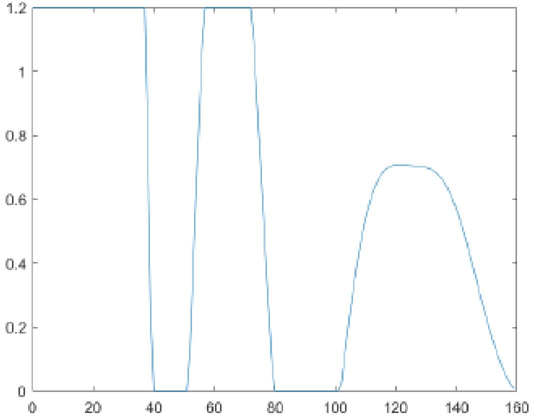
$\alpha = 0.034$



$\alpha = 0.024$



$\alpha = 0.014$



- When green bond long-run returns are higher, investors fully divest fossil fuels (share=1.2).
- In the other cases, investors diversify.

Is it the case for Green convertible bonds?

- The convertible bond market index (ICE BofA US Convertible Index – VXA0) outperformed other market indices such as
  - the S&P 500 Bond Index (SP500BDT)
  - and the S&P 500 (SP500).
- In 2020 the VXA0 Yield-to-date returns (YTD) was 20.9% while the
  - SP500BDT was 7.85%
  - and the SP500 2.97%

Figure B2.1. Yield-to-date returns for convertible bond index vis-à-vis other market indices

Note: Base 100, on 12/31/2019
Source: Bloomberg and S&P

Source: Semmler et al. (2021)

(3) Empirical study: green vs conventional bond performance

Hypothesis

$$SR_p = \frac{\bar{R}_p - R_f}{\sigma_p}$$

Portfolio based (classical) Sharpe ratio

$$SR_b = \frac{R_b - R_f}{v_b}$$

Bond specific Sharpe ratio

- **Externality argument** in dynamic asset pricing
  - green bonds with positive long run externalities → higher returns
  - Conventional/fossil fuel based bonds → lower returns
- **Financial accumulation**
  - <u>Negative externalities</u> feed into <u>uncertainties in the financial market</u> with deteriorating impacts on investment
  - Negative environmental impacts can be seen as disruptive elements with <u>volatility inducing impacts</u>
  - <u>→ better and continuous wealth accumulation with green vs non-green bonds</u>

Empirically we analyze

- **Sharpe ratio** (= reward-to risk ratio) as measure for wealth accumulation
- … also testing primary & secondary **yields** and three different **volatility** measures (30d, 90d, 260d) between green (GB) and conventional bonds (CB)

Empirical literature

- Comparative bond analysis, most studies find
  - a negative green premium based on bond indices (Ehlers & Packer, 2017 [EP'17]),
  - a negative primary market yields premium (Kapraun & Scheins, 2019 [KS'19]; Immel et al., 2020 [I'20]; Löffler et al., 2021 [L'21]).
  - Mixed results for secondary market yields for green and conventional bond yield differentials [KS'19; I'20], which means that a negative premium is found only for specific cases (e.g.: institutional and certified green issuers).

- It is argued that lower yields for green bonds compared to conventional bonds are due **pro-environmental attitude of investors** (L'21) and **better reputation & higher ESG credibility** of certain issuers, which impacts the demand preferences (KS'19).

- As laid out in **this paper**, the risk structure of financial assets is also impacted by environmental factors
  - fossil fuel bonds evoke negative environmental externalities while green bonds are environmentally friendly, i.e. should show positive externalities

Variables in the literature & our paper

- **Most papers**
  - Analyze primary and secondary market yields (KS‘19, L‘21, B‘19)
  - … and maybe add one single measure for volatiliy (L‘21)
  - Control for private vs public issuers but not for different sectors (KS’19, B’21)

- **Our study**
  - Uses various key variables:
    - (i) primary and secondary market yields,
    - (ii) three bond volatility measures (30d, 90d, 260d), and
    - (iii) a bond specific Sharpe ratio as risk adjusted returns
  - Controls for public vs. private issuers and also for different sectors of private issuers: finance, utilities and energy

The SR in the literature & our paper

- **Few papers** analyze green bonds w.r.t. the SR
  - **EP'17**: use a cross-sectional sample of 21 green bonds issued between 2014 and 2017; their paper does not use a bond pairing algorithm that controls for rating → SR results are slightly higher for GB indices though not significant
  - **Han et al. (2020)**: use a CoVaR model → SR of green bonds improve a stock-bond portfolio in different market environments and can provide downside risk protection during the COVID 19 pandemic.
- **Our paper**:
  - Uses a sample that includes 1,529 green bonds, issued between 2017 and 2020
  - Uses a bond pairing algorithm (also controlling for rating)
  - Adds a non-parametric analysis of bond volatility
  - And a very sector specific perspective

Forms of analysis

(A) Multivariate regression across sample

(B) Regression analysis of matched bonds subset

(C) CART volatility analysis

(D) Energy specific analysis

(A) Multivariate regression analysis

- General setup:
  - Base Model (1)

$$Y_i = \beta_0 + \sum_{k=1}^{9} \beta_k X_{k,i} + \epsilon_i$$

  - Sector Model (2)

$$Y_i = \beta_0 + \sum_{k=1}^{9} \beta_k X_{k,i} + \sum_{l=1}^{4} \gamma_l X_{l,i} + \epsilon_i$$

  - Currency models (3, 4)

$$Y_{i,c} = \beta_{0,c} + \sum_{k=1}^{9} \beta_{k,c} X_{k,i,c} + \sum_{l=1}^{4} \gamma_{l,c} X_{l,i,c} + \epsilon_{i,c}$$

Set of variables:

<u>LHS, dep variable, one of:</u>

- Y: yield at issue (YAI), yield to maturity (YTM), bond specific Sharpe ratio (SRb)

<u>RHS, indep variable (k), in general:</u>

- X_1 is a green dummy variable
- X_2 is the S&P rating
- X_3 is the maturity structure
- X_4 is the coupon rate,
- X_5 is the liquidity
- X_6 is the amount of bonds issued in US$ divided by 10^9
- X_7 is the debt-to-assets ratio,
- X_8 is the 90-day bond price volatility rate
- X_9 is date issued [year quarter]

<u>RHS, indep variable (l), three of four (one is baseline):</u>

- X_1-X_4: sectors (finance, energy, utilities, government)

YAI regression

	Dependent variable: Yield at issue			
	(1) Base model	(2) Sector model	(3) USD model	(4) EUR model
Intercept	0.283***	0.262***	0.572***	−0.102
	(0.047)	(0.045)	(0.088)	(0.072)
Green bond (dummy)	−0.119***	−0.106***	−0.133***	0.024
	(0.024)	(0.026)	(0.034)	(0.066)
Maturity: long term (dummy)	0.252***	0.297***	0.377***	0.257*
	(0.043)	(0.048)	(0.055)	(0.099)
S&P Rating	0.001	0.016***	0.051***	0.028*
	(0.002)	(0.003)	(0.009)	(0.012)
Coupon rate	0.930***	0.920***	0.805***	0.890***
	(0.011)	(0.013)	(0.031)	(0.058)
Amount issued (in bnUSD)	−0.049**	−0.043*	−0.159***	−0.046
	(0.017)	(0.017)	(0.035)	(0.061)
Debt to assets	0.001	−0.002***	−0.001**	0.001
	(0.001)	(0.000)	(0.000)	(0.001)
Corp sector: energy (dummy)		0.031	0.003	0.154
		(0.020)	(0.021)	(0.134)
Corp sector: utilities (dummy)		−0.106***	−0.220***	−0.096
		(0.021)	(0.035)	(0.067)
Government sector (dummy)		0.308***	0.304**	0.160
		(0.078)	(0.094)	(0.112)
R^2	0.882	0.884	0.900	0.943
Adj. R^2	0.882	0.884	0.900	0.939
Num. obs.	2969	2969	1794	144

Standard errors are heteroskedasticity robust. $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 1: Analysis 1a - Multivariate regression yield at issue

YTM regression

	Dependent variable: Yield to maturity			
	(1) Base model	(2) Sector model	(3) USD model	(4) EUR model
Intercept	−1.236***	−1.342***	−1.496***	−0.829***
	(0.086)	(0.087)	(0.128)	(0.091)
Green bond (dummy)	−0.119*	−0.160**	−0.133	−0.168**
	(0.054)	(0.052)	(0.097)	(0.052)
Volatility 90d	0.126***	0.121***	0.153***	0.016*
	(0.010)	(0.010)	(0.013)	(0.008)
Bid-ask spread	−0.530***	−0.366***	−0.549***	−0.275**
	(0.084)	(0.080)	(0.096)	(0.099)
Maturity: long term (dummy)	0.013	0.046	0.235	−0.022
	(0.069)	(0.067)	(0.123)	(0.088)
S&P Rating	0.154***	0.191***	0.258***	0.108***
	(0.008)	(0.009)	(0.016)	(0.007)
Coupon rate	0.596***	0.566***	0.447***	0.771***
	(0.017)	(0.018)	(0.034)	(0.061)
Amount issued (in bnUSD)	−0.524***	−0.572***	−0.682***	−0.361***
	(0.035)	(0.036)	(0.056)	(0.031)
Debt to assets	0.007***	0.004***	0.004**	0.003**
	(0.001)	(0.001)	(0.001)	(0.001)
Corp sector: energy (dummy)		0.250***	0.204*	0.415*
		(0.068)	(0.085)	(0.168)
Corp sector: utilities (dummy)		−0.470***	−0.472***	−0.443***
		(0.041)	(0.058)	(0.049)
Government sector (dummy)		0.692***	1.111***	0.184*
		(0.075)	(0.122)	(0.075)
Date issued 2017Q2 (dummy)	−0.011	0.060	0.106	−0.050
	(0.089)	(0.087)	(0.133)	(0.069)
Date issued 2020Q2 (dummy)	0.477***	0.427***	−0.257	0.173
	(0.118)	(0.111)	(0.290)	(0.112)
R^2	0.755	0.772	0.771	0.690
Adj. R^2	0.753	0.771	0.769	0.685
Num. obs.	4454	4454	2433	1739

Standard errors are heteroskedasticity robust. $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 2: Analysis 1b - Multivariate regression for yield to maturity

SRb regression

	Dependent variable: Bond specific Sharpe ratio (SRb)			
	(1) Base model	(2) Sector model	(3) USD model	(4) EUR model
Intercept	0.727***	0.594***	0.851***	0.135
	(0.063)	(0.055)	(0.078)	(0.070)
Green bond (dummy)	0.603**	0.535**	1.189*	0.004
	(0.215)	(0.204)	(0.537)	(0.029)
Bid-ask spread	−0.519***	−0.441***	−0.405***	−0.489***
	(0.050)	(0.043)	(0.058)	(0.053)
Maturity: long term (dummy)	−0.105***	−0.119***	−0.002	0.078*
	(0.025)	(0.026)	(0.038)	(0.034)
S&P Rating	−0.033***	−0.004	−0.005	0.040***
	(0.010)	(0.007)	(0.011)	(0.004)
Coupon rate	0.161***	0.152***	0.087***	0.183***
	(0.018)	(0.017)	(0.024)	(0.021)
Amount issued (in bnUSD)	−0.270***	−0.289***	−0.443***	−0.227***
	(0.038)	(0.042)	(0.083)	(0.024)
Debt to assets	0.000	−0.002***	−0.000	0.001
	(0.000)	(0.000)	(0.001)	(0.000)
Corp sector: energy (dummy)		−0.132***	−0.165***	0.160*
		(0.026)	(0.035)	(0.067)
Corp sector: utilities (dummy)		−0.100***	−0.202***	−0.116***
		(0.022)	(0.031)	(0.029)
Government sector (dummy)		0.512***	0.949***	0.198***
		(0.089)	(0.213)	(0.059)
Date issued 2017Q2 (dummy)	−0.011	0.002	0.052	−0.024
	(0.048)	(0.047)	(0.059)	(0.076)
Date issued 2019Q4 (dummy)	−0.154*	−0.155*	−0.361*	−0.080
	(0.070)	(0.069)	(0.146)	(0.065)
R^2	0.115	0.133	0.163	0.255
Adj. R^2	0.111	0.129	0.155	0.245
Num. obs.	4028	4028	2357	1532

Standard errors are heteroskedasticity robust. $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 3: Analysis 1c - Multivariate regression for bond specific Sharpe ratio (SRb)

(B) Bond pairing regression analysis

- Bond pairing algorithm ensures that similar assets were compared
  - Similar to standards in literature and based on KS'19
  - Our bond pairing procedure selected green and conventional bonds with the same
    - **issuer** (and therefore the same sector),
    - **currency**,
    - **maturity**, and
    - **S&P rating**
  - A green bond of this subset is required to match with a conventional bond based in these criteria.
  - When more than one conventional matching partners remains for a green bond we allowed for maximum of 10 conventional bonds for each green bond (as in KS'19).
  - The closest matching candidates are identified based on a kNN algorithm that looks for **similar coupon rate values**.
- Outcome: subset of 1,022 paired observations (511 green and 511 conventional bonds).
- Regression: we work with the "green minus conventional" (GMC) differences of the respective variables – α is the constant, and reflects the green premium

$$GMC.Y_i = GMC.\alpha_i + \sum_k \beta_k GMC.X_{k,i} + \sum_l \beta_l X_{l,i} + \epsilon_i$$

YAI pairing

	Dependent variable: Yield at issue		
	(1) Base model	(2) Sector model	(3) USD model
Constant [green premium]	0.565*	0.157	0.396
	(0.232)	(0.885)	(0.840)
GMC Amount issued	0.066	0.295	0.261
	(0.320)	(1.187)	(1.084)
GMC Time to maturity	−0.154***	−0.145	−0.176
	(0.035)	(0.112)	(0.107)
Rating (numeric)	0.032	0.002	0.004
	(0.016)	(0.015)	(0.015)
Government Sector (dummy)		0.089	0.172
		(0.423)	(0.402)
R^2	0.200	0.282	0.346
Adj. R^2	0.178	0.218	0.284
Num. obs.	115	50	47

Standard errors are heteroskedasticity robust. $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 4: Analysis 2a - Paired bond regression results for yield at issue

YTM pairing

	Dependent variable: Yield to maturity			
	(1) Base model	(2) Sector model	(3) USD model	(4) EUR model
Constant [green premium]	0.080	0.428***	0.792***	0.080
	(0.080)	(0.084)	(0.199)	(0.081)
GMC Volatility 90d	−0.028	−0.010	0.115	−0.092*
	(0.050)	(0.048)	(0.111)	(0.043)
GMC Ask-Bid Spread	−0.465*	−0.400*	−0.353	0.124
	(0.183)	(0.176)	(0.225)	(0.254)
GMC Coupon rate	0.262***	0.246***	0.284***	0.078
	(0.065)	(0.068)	(0.073)	(0.050)
GMC Amount issued	−0.627***	−0.699***	−0.979***	−0.276***
	(0.103)	(0.101)	(0.140)	(0.039)
GMC Time to maturity	−0.029*	−0.077***	−0.117***	−0.027*
	(0.012)	(0.013)	(0.020)	(0.013)
Rating (numeric)	0.089***	0.086***	0.048	0.089**
	(0.022)	(0.019)	(0.040)	(0.031)
Corp Sector: Energy (dummy)		0.187	−0.663**	0.255***
		(0.163)	(0.212)	(0.060)
Corp Sector: Utilities (dummy)		0.344***	0.520*	0.164**
		(0.081)	(0.256)	(0.058)
Government Sector (dummy)		−0.396***	−0.593**	−0.449***
		(0.071)	(0.196)	(0.087)
R^2	0.518	0.575	0.736	0.521
Adj. R^2	0.508	0.562	0.714	0.495
Num. obs.	304	304	116	176

Standard errors are heteroskedasticity robust. $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 5: Analysis 2b - Paired bond regression results for yield to maturity

SRb pairing

	Dependent variable: Bond specific Sharpe ratio (SRb)			
	(1) Base model	(2) Sector model	(3) USD model	(4) EUR model
Constant (green premium)	2.383***	1.787**	2.454*	−0.153
	(0.620)	(0.644)	(1.154)	(0.115)
GMC Ask-Bid Spread	−2.745***	−2.224**	−1.207	−0.059
	(0.806)	(0.736)	(0.998)	(0.073)
GMC Coupon rate	1.790***	1.907***	2.023***	−0.007
	(0.481)	(0.501)	(0.561)	(0.023)
GMC Amount issued	−5.240***	−5.257***	−7.196***	−0.096**
	(0.985)	(1.002)	(1.161)	(0.036)
GMC Time to maturity	0.012	0.023	0.023	0.013*
	(0.035)	(0.035)	(0.040)	(0.006)
Rating (numeric)	−0.301***	−0.291**	−0.422**	0.011
	(0.084)	(0.091)	(0.141)	(0.014)
Corp Sector: Energy (dummy)		2.046**	−0.248	0.093**
		(0.786)	(0.755)	(0.034)
Corp Sector: Utilities (dummy)		1.434**	1.800	0.052
		(0.479)	(1.000)	(0.029)
Government Sector (dummy)		0.755	−0.112	0.209***
		(0.568)	(0.974)	(0.057)
R^2	0.536	0.549	0.664	0.246
Adj. R^2	0.525	0.531	0.638	0.165
Num. obs.	209	209	113	84

Standard errors are heteroskedasticity robust. $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 6: Analysis 2c - Paired bond regression results for bond specific Sharpe ratio (SRb)

Volatility pairing (coefplot)

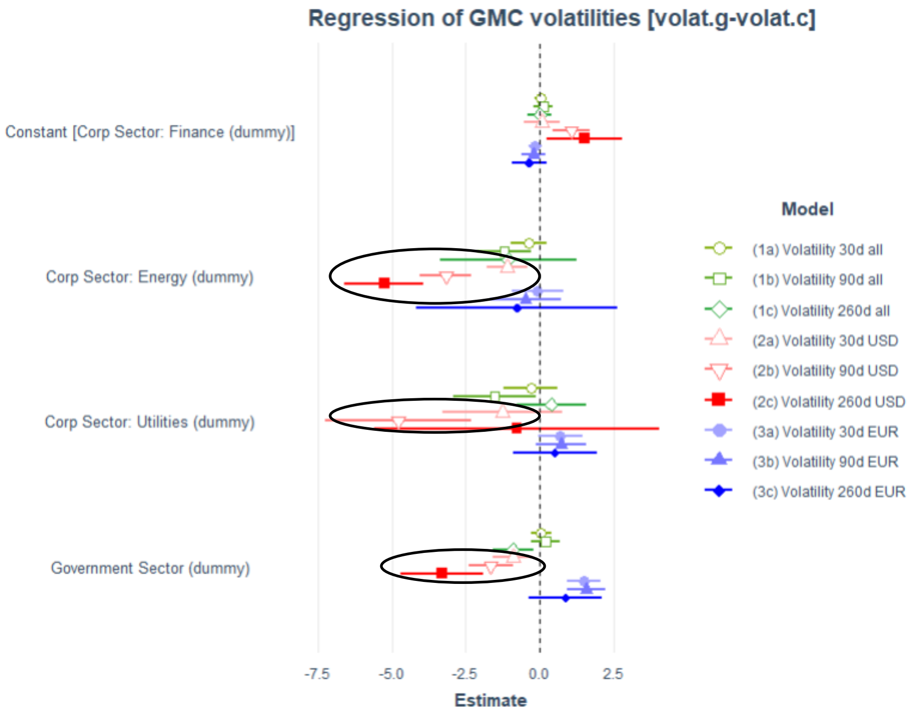


Figure 7: Analysis 2d - Paired bond regression results for bond specific volatilities (volat)

Volatility pairing (table)

	Dependent variable: Volatilities (30d, 90d, 260d)								
	(1a) vol30d.all	(1b) vol90d.all	(1c) vol260d.all	(2a) vol30d.USD	(2b) vol90d.USD	(2c) vol260d.USD	(3a) vol30d.EUR	(3b) vol90d.EUR	(3c) vol260d.EUR
Constant [Corp Sector: Finance]	0.039	0.124	0.015	0.092	1.076***	1.536*	−0.144	−0.193	−0.349
	(0.091)	(0.164)	(0.203)	(0.304)	(0.316)	(0.639)	(0.119)	(0.203)	(0.294)
Corp Sector: Energy (dummy)	−0.373	−1.192*	−1.059	−1.093**	−3.170***	−5.259***	−0.060	−0.464	−0.758
	(0.308)	(0.467)	(1.179)	(0.354)	(0.436)	(0.675)	(0.444)	(0.598)	(1.718)
Corp Sector: Utilities (dummy)	−0.288	−1.517*	0.402	−1.257	−4.788***	−0.774	0.697	0.733	0.533
	(0.463)	(0.703)	(0.600)	(1.028)	(1.252)	(2.416)	(0.380)	(0.435)	(0.713)
Government Sector (dummy)	0.049	0.205	−0.902*	−0.903**	−1.645***	−3.316***	1.504***	1.591***	0.878
	(0.175)	(0.250)	(0.353)	(0.337)	(0.381)	(0.699)	(0.280)	(0.334)	(0.624)
R^2	0.005	0.057	0.033	0.057	0.305	0.345	0.177	0.126	0.024
Adj. R^2	−0.002	0.048	0.022	0.034	0.287	0.318	0.164	0.111	0.001
Num. obs.	413	312	265	125	117	77	190	183	132

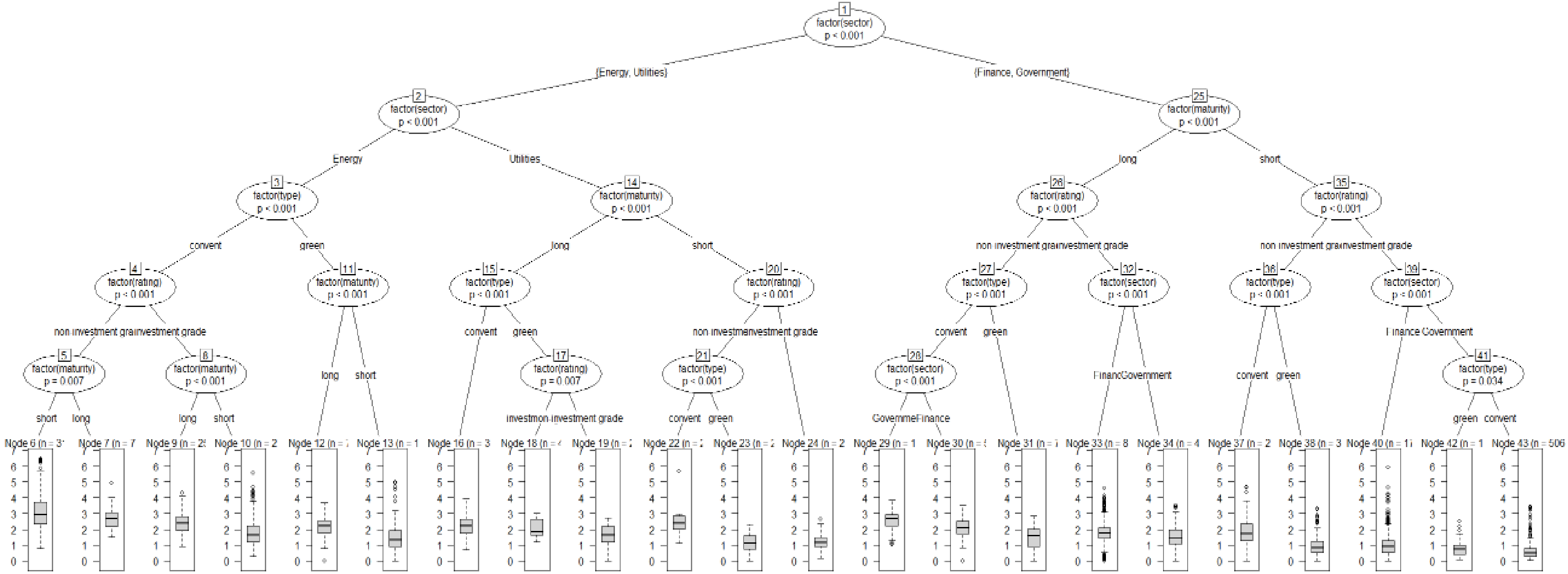
Standard errors are heteroskedasticity robust. $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 7: Analysis 2d - Paired bond regression results for bond specific volatilities (volat)

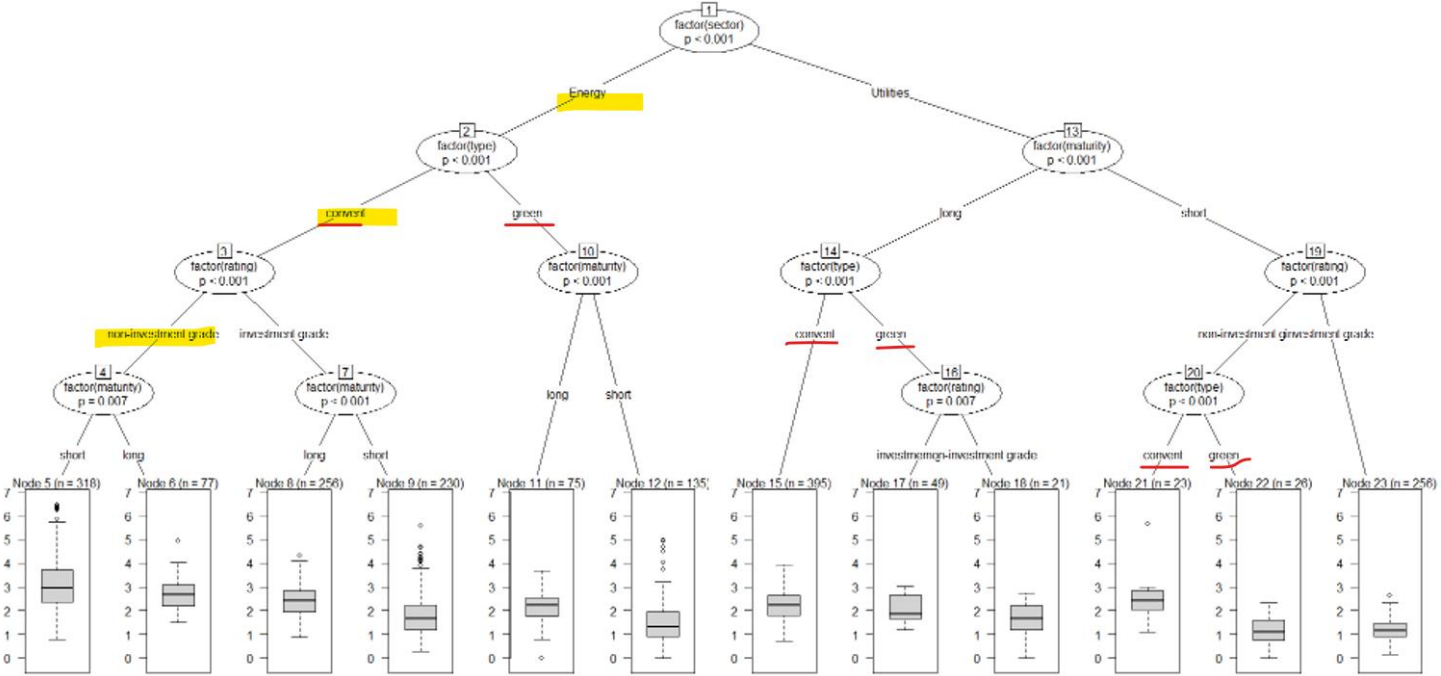
(C) Classification and regression tree (CART) analysis of volatility

- **Idea of the CART analysis**
  - identify the most essential drivers in the volatility structure of bonds
  - A CART analysis uses a decision tree that results from a supervised learning predictive model to predict the value of our target variable, which is a bond volatility measure based on a set of binary input variables (our categorical regressors)
- **Benefits**
  - CART is non-parametric and therefore does not rely on data belonging to a particular type of distribution,
  - CART is not significantly impacted by outliers in the input variables, and
  - CART can use the same variables more than once in different parts of the tree and therefore uncover complex inter-dependencies between sets of variable
- **Variables**
  - (i) bond type (i.e., green or conventional),
  - (ii) sectors (i.e. Finance, Energy, Utilities, Government)
  - (iii) maturities, (i.e. long term, short term)
  - (iv) ratings (i.e. investment grade, non-investment grade)

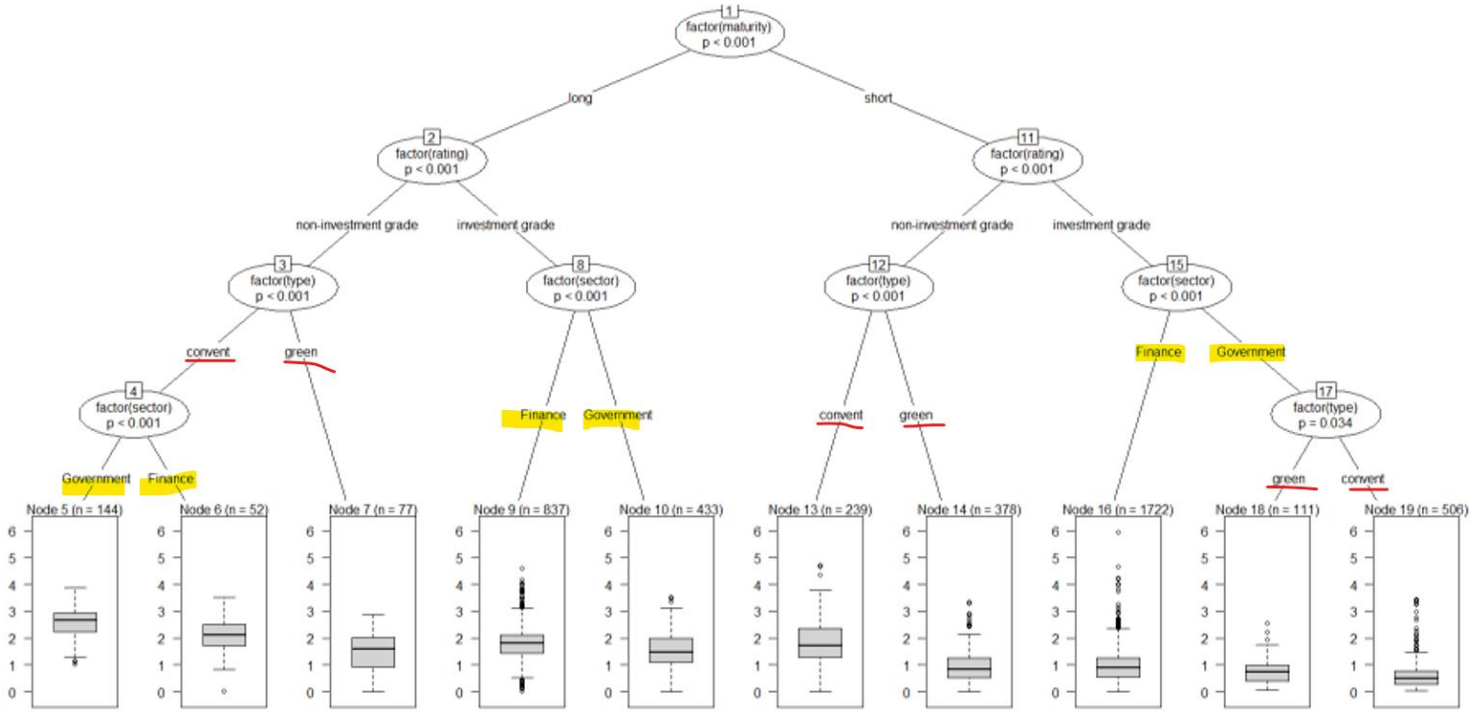
CART on volatility (90d) – whole tree



CART on volatility (90d) – left branch



CART on volatility (90d) – right branch



(D) Energy sector analysis

$$Y_i = \beta_0 + \sum_{k=1}^{9} \beta_k X_{k,i} + \beta_{10} X_{1,i} \cdot X_{2,i} + \epsilon_i$$

- Idea
  - Since our sample does not include issuers who sold both types of bonds, in the green and "brown" energy universe, it is not possible to carry out a pairing analysis and control for issuer specific effects in the energy sector.
  - Therefore, we run a non-matching analysis to compare the specificities of the energy sectors.
- Results:
  - **Green dummy & yields**: no clear evidence of a green premium for bonds in the energy sector.
  - **Green dummy x volatilities interaction & yields**: volatilities of green bonds are associated with lower yields (especially in the case of 260d volatilities as shown by models 1c and 2c, but also in the 90d case of model 1b) → this suggests that the volatility risk premium for brown energy bonds is higher than for green energy bonds, or said differently, the volatility of brown bonds is associated with higher risk premia (higher yields) than in the case of green bonds.
  - **Green dummy & Sharpe ratio**: weak evidence of higher Sharpe ratios for green bonds in the general case (model 1a) and in the USD 90 day case (see model 2b).

YTM energy sector

	Dependent variable: Yield to maturity								
	(1a) M.30d	(1b) M.90d	(1c) M.260d	(2a) M-USD.30d	(2b) M-USD.90d	(2c) M-USD.260d	(3a) M-EUR.90d	(3b) M-EUR.90d	(3c) M-EUR.260d
Intercept	−3.011***	−3.344***	−3.513***	−2.564***	−2.807***	−3.433***	−4.222***	−5.067***	−3.982***
	(0.221)	(0.288)	(0.279)	(0.258)	(0.292)	(0.355)	(0.970)	(1.271)	(0.746)
Green bond (dummy)	0.007	0.471	0.532	−0.163	0.210	0.666	0.843	1.928	0.789
	(0.328)	(0.428)	(0.429)	(0.443)	(0.404)	(0.558)	(0.721)	(1.324)	(0.432)
Volatility 30d	0.265***			0.298***			0.515		
	(0.018)			(0.020)			(0.283)		
Green x Volatility 30d	−0.091			−0.031			−0.355		
	(0.097)			(0.161)			(0.237)		
Volatility 90d		0.172***			0.214***			0.415	
		(0.019)			(0.022)			(0.283)	
Green x Volatility 90d		−0.169*			−0.100			−0.570	
		(0.082)			(0.079)			(0.396)	
Volatility 260d			0.061***			0.067***			0.056
			(0.009)			(0.013)			(0.039)
Green x Volatility 260d			−0.110*			−0.155***			−0.062
			(0.049)			(0.039)			(0.067)
Bid-ask spread	0.045	0.101	0.331*	−0.440**	−0.469*	0.150	0.974	2.372	1.196
	(0.158)	(0.211)	(0.142)	(0.141)	(0.191)	(0.205)	(0.874)	(1.551)	(0.622)
Maturity: long term (dummy)	−0.706***	−0.610***	−0.135	−0.749***	−0.698***	−0.186	−1.300	−1.492	−0.610
	(0.146)	(0.174)	(0.129)	(0.148)	(0.182)	(0.165)	(0.730)	(0.995)	(0.356)
S&P Rating	0.304***	0.317***	0.292***	0.250***	0.241***	0.247***	0.284**	0.274*	0.175*
	(0.020)	(0.027)	(0.026)	(0.026)	(0.036)	(0.043)	(0.106)	(0.104)	(0.069)
Coupon rate	0.594***	0.593***	0.650***	0.712***	0.706***	0.800***	0.470	0.202	0.726**
	(0.039)	(0.046)	(0.052)	(0.070)	(0.070)	(0.103)	(0.307)	(0.469)	(0.222)
Amount issued (in bnUSD)	−0.703***	−0.352*	−0.512***	−0.940***	−0.538***	−0.734***	0.545	1.129*	0.847**
	(0.127)	(0.145)	(0.153)	(0.139)	(0.151)	(0.183)	(0.442)	(0.494)	(0.312)
Debt to assets	0.009***	0.011***	0.014***	0.002	0.004	0.010**	0.008	0.009	0.016***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)	(0.008)	(0.009)	(0.004)
Year issued 2018 (dummy)	−0.134	−0.266	−0.076	−0.167	−0.318*	−0.122	−0.100	−0.181	0.129
	(0.118)	(0.144)	(0.131)	(0.131)	(0.155)	(0.171)	(0.313)	(0.419)	(0.312)
Year issued 2019 (dummy)	0.006	−0.175	0.169	0.026	−0.169	0.203	−0.461	−0.736	−0.029
	(0.111)	(0.137)	(0.139)	(0.129)	(0.154)	(0.183)	(0.496)	(0.770)	(0.297)
R^2	0.837	0.812	0.797	0.843	0.824	0.782	0.902	0.859	0.895
Adj. R^2	0.834	0.809	0.793	0.839	0.820	0.776	0.885	0.835	0.875
Num. obs.	653	640	534	485	503	386	77	76	70

Standard errors are heteroskedasticity robust. $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 8: Analysis 4a - Energy sector regression: yield to maturity

SRb energy sector

	Dependent variable: Bond specific Sharpe ratio (SRb)								
	(1a) M.30d	(1b) M.90d	(1C) M.260d	(2a) M-USD.30d	(2b) M-USD.90d	(2C) M-USD.260d	(3a) M-EUR.30d	(3b) M-EUR.90d	(3C) M-EUR.260d
Intercept	0.409***	0.196***	0.083*	0.581***	0.304***	0.125***	−1.165	−1.367**	−0.555**
	(0.117)	(0.057)	(0.036)	(0.099)	(0.041)	(0.037)	(0.739)	(0.417)	(0.185)
Green bond (dummy)	0.272*	0.098*	0.015	0.391	0.085*	0.002	−0.119	−0.226	0.018
	(0.132)	(0.048)	(0.030)	(0.263)	(0.042)	(0.040)	(0.315)	(0.205)	(0.060)
Bid-ask spread	−0.005	0.010	−0.015	−0.316***	−0.119***	−0.052**	0.895	0.777*	0.512*
	(0.085)	(0.043)	(0.026)	(0.050)	(0.021)	(0.016)	(0.708)	(0.377)	(0.221)
Maturity: long term (dummy)	0.017	0.020**	0.013***	0.003	0.005	0.004	0.093	0.116**	0.037
	(0.012)	(0.006)	(0.004)	(0.008)	(0.004)	(0.003)	(0.070)	(0.039)	(0.020)
S&P Rating	−0.355***	−0.182***	−0.052**	−0.117**	−0.091***	−0.020	−0.411*	−0.282	−0.159*
	(0.064)	(0.033)	(0.020)	(0.038)	(0.022)	(0.017)	(0.192)	(0.144)	(0.064)
Coupon rate	0.137***	0.043***	0.028***	0.116***	0.063***	0.035***	0.104	−0.123	−0.039
	(0.025)	(0.011)	(0.008)	(0.019)	(0.010)	(0.009)	(0.197)	(0.093)	(0.042)
Amount issued (in bnUSD)	−0.414***	−0.088**	−0.109***	−0.301***	−0.091***	−0.086***	0.274	0.645*	0.170**
	(0.068)	(0.033)	(0.019)	(0.052)	(0.020)	(0.015)	(0.368)	(0.287)	(0.056)
Debt to assets	0.000	0.001	0.000	−0.000	0.000	0.000	−0.001	0.001	0.001
	(0.001)	(0.001)	(0.000)	(0.001)	(0.000)	(0.000)	(0.003)	(0.002)	(0.001)
Year issued (dummy 2018)	0.071	−0.040	−0.003	0.012	−0.070**	−0.029	0.335	0.206	0.086
	(0.070)	(0.031)	(0.018)	(0.045)	(0.022)	(0.018)	(0.278)	(0.165)	(0.057)
Year issued (dummy 2019)	−0.095	−0.085**	−0.022	−0.004	−0.058*	−0.016	−0.099	−0.234	−0.097
	(0.056)	(0.026)	(0.019)	(0.044)	(0.023)	(0.018)	(0.214)	(0.121)	(0.052)
R^2	0.250	0.253	0.252	0.312	0.385	0.285	0.612	0.569	0.648
Adj. R^2	0.239	0.243	0.239	0.299	0.374	0.268	0.558	0.507	0.593
Num. obs.	650	637	528	485	503	386	75	73	67

Standard errors are heteroskedasticity robust. $^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

Table 9: Analysis 4b - Energy sector regression: Bond specific Sharpe ratio (SRb)

Discussion

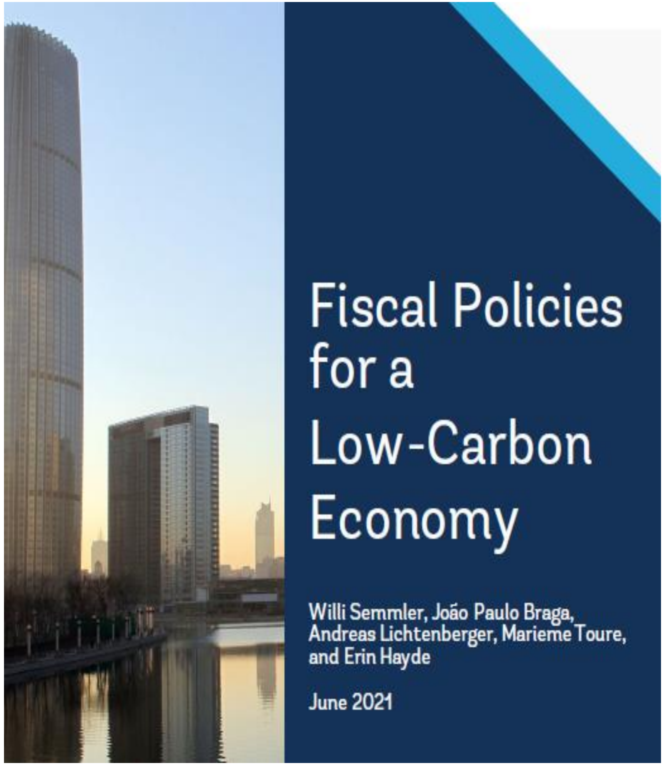
- Consistent with hypothesis
  - SRb is higher for GB in unpaired + paired analysis
  - Volatilities for conventional bonds appear higher (especially in energy sector; see results of bond pairing, CART, and energy sector regressions)
- Consistent with literature
  - Negative risk premia for multivariate regression of YAI
- However, inconsistencies:
  - Different results for multivariate regression vs. bond pairing regressions (YAI and YTM)
  - Strong currency heterogeneity (very different effects for EUR)
- Limitations:
  - Only cross sectional (October 1, 2020)
  - Sample restrictions (many N/A for YAI, very unbalanced sample)

(4) Conclusion

Conclusion

- Our **dynamic portfolio model** with two risky assets provides a tool and lessons for portfolio allocation when climate externalities hold
  - *Green investment positive externalities can prevent long-term climate risks in financial markets → ensure better wealth trajectories for investors.*
  - *The policy and externality effects increase green bond returns and attract investors, but these resources should also be channeled to long-term oriented green investment (R&D).*
  - *Green convertible bonds should be considered, even for sovereigns.*
- Main conclusion from **empirical studies**
  - *Better investment opportunities for green bonds based on risk adjusted bond performance also on an empirical level → mostly higher SRb and lower volatilities (strongest differences in energy sector).*
  - *Mixed results for yields, similar to literature (primary/secondary, different regression setups).*
  - *Heterogeneities for different currencies & sectors.*
- **Policy makers** can help increasing the attractiveness of green bonds in the present.
- **Green investment** provides better wealth accumulation in the long-run, associated with positive climate externalities. In the present, green investors seem to benefit from lower volatilities & higher Sharpe ratios.
  - *A higher SR helps attracting investors to green assets, ensuring investors are protected of future market instabilities arising from climate change and benefit from climate positive externalities.*

See also:



Thank you!

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https://documents.worldbank.org/en/publication/documents-reports/documentdetail/998821623308445356/fiscal-policies-for-a-low-carbon-economy