Explaining Greenium in a Macro-Finance Integrated Assessment Model

Biao Yang

Bocconi University

Climate Change is Accelerating

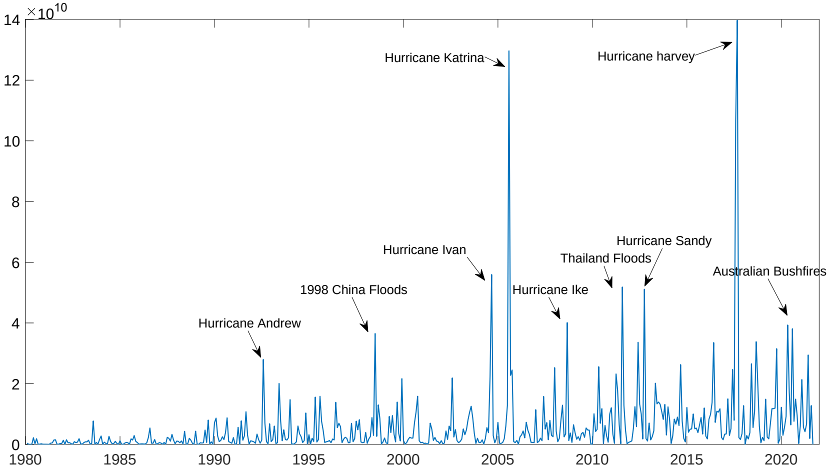

Figure 1: Global economic losses (in USD) due to climate disasters (Source: The International Disaster Database)

This Paper

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- **Empirically:** first to attribute greenium to climate disaster risk with novel evidence
- **Theoretically:** improves traditional climate economics models to explain asset prices

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   - green firms enjoy investment compensation due to climate disasters

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   - Climate feedback + investment friction: heterogeneous disaster exposures of green and brown stocks ⇒ **greenium**
   - Model quantitatively matches IRFs of prices & investments to a disaster ⇐ **New in this paper**

Literature

Climate risk in financial markets

- Chava (2014), Görgen et al. (2019), In et al. (2017), Bolton and Kacperczyk (2020, 2021), Hsu et al. (2020), Bansal et al. (2016a,b), Engel et al. (2020), Choi et al. (2020), Pastor et al. (2019), Barnett et al. (2020), Barnett (2017), Giglio et al. (2020), etc.

This paper: links greenium with climate disaster shocks with novel evidence

IAM and Production-based AP

- **IAM:** Nordhaus (1992, 2013, 2014), Bosetti et al. (2006), Popp (2006), Golosov et al. (2014), Acemoglu et al. (2012), Daniel et al. (2016), Lemoine and Rudik (2017), etc.
- **Production-based AP:** Cochrane (1991), Jermann (1998), Croce (2014), Kaltenbrunner and Lochstoer (2010), Papanikolaou (2011), Kung and Schmid (2015), etc

This paper: bridges and improves the two approaches $\Rightarrow$ AP in IAM and climate risk in macrofinance

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- Disaster Index: a first handy climate disaster risk measure
  - Monthly aggregated economic loss (in USD) due to climate-related disasters
    - 5892 Disasters: Hurricane (1922), Wildfire (197), Flood (3114), Extreme temperature (371), Drought (286), Glacial lake outburst (2)
  - **Source**: The International Disaster Dataset

QUANTIFYING GREENIUM: FACTOR REGRESSION

CUMULATIVE RETURNS

I regress monthly value-weighted return of Brown-minus-Green (BMG) portfolio on **global** AP factors

$$R^{ex}_{BMG;t} = \quad + \quad F_t + \quad {}_t$$

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Factors	Constant	CAPM	FF3	FF5	FF5&MOM
BMG (%)	3.83	2.43	2.17	3.91	3.98
s.e. (%)	(1.39)	(1.18)	(0.98)	(1.22)	(1.25)

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- greenium remains significant after controlling for other risk factors

Quantifying Greenium: Alternative Tests

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- Fama-Macbeth regression See
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- Subcategories of ENSCORE See
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Takeaway: greenium is significantly negative across different specifications

Hedging Disasters: Stock returns

- Frequency: Monthly
- **Specification 1**

$$AR_{i;t} = \quad _i + (\quad _1 + \quad _2 \; ENSCORE_{i;t \quad 1}) \quad logdamage_t + \quad X_{i;t \quad 1} + \quad _{i;t}$$

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$$AR_{i;t} = {}_{i} + ({}_{1} + {}_{2}\ Quintile_{i;t\ \ 1})\ logdamage_t + \ X_{i;t\ \ 1} + {}_{i;t}$$

  where $Quintile_{i;t}$ is a set of dummies indicating which quintile of ENSCORE that firm i is in (5=Green, 1=Brown)

Hedging Disasters: Stock returns

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	(0.012)	(0.012)
ENSCORE *logdamage*	0.0380	
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Quintile 2		0.0239
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Adj. R^2	0.04	0.04

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Takeaway:

- Brown stocks depreciate due to a positive disaster shock
- Green stocks depreciate <u>less</u> compared to brown stocks
- Robustness tests:
  1. Event study on Hurricane Katrina, U.S. Drought & Wildfires
  2. Controlling for geographic characteristics
  3. Excluding financial crisis
  4. Placebo tests using earthquake

HEDGING DISASTERS: INVESTMENTS

- Frequency: Quarterly
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  1. Event study
  2. Alternative measures of investment

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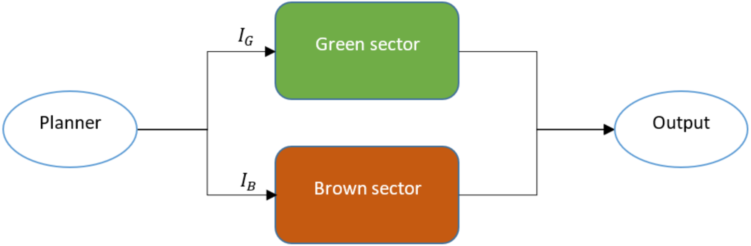

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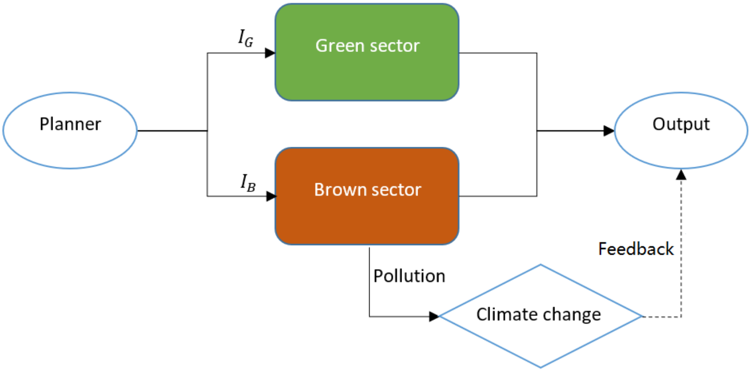
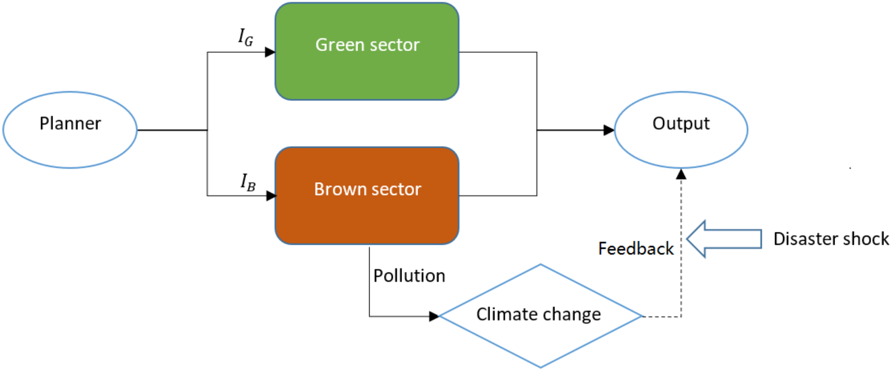


I_G
Green sector
Planner
Output
I_B
Brown sector
Feedback
Pollution
Climate change

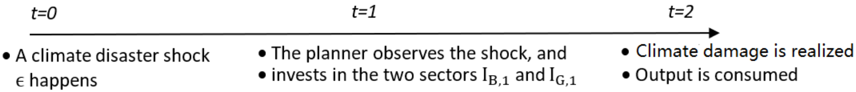
SCHEME



An exogenous disaster shock increases belief on climate feedback $\Rightarrow$ lower brown investment and higher green investment

Model Setup

- Timeline



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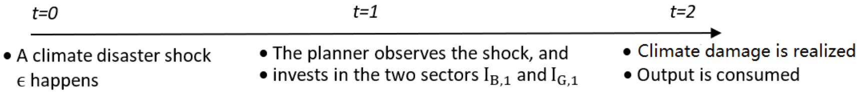

- Production function & climate damage

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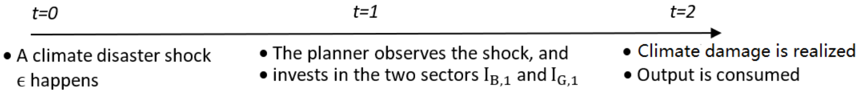

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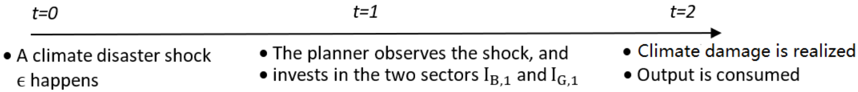

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- Preferences

$$U_1 = W(C_1, E_1[U_2])$$

Disaster Shock Increases Green Investment and the SDF

Proposition 1

Optimal investment in the green (brown) sector increases (decreases) with the disaster shock , i.e.,
$\frac{\partial I_{G;1}}{\partial} > 0$ $\frac{\partial I_{B;1}}{\partial} < 0$.

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Takeaway: A positive disaster shock leads to bad economic state: an **adverse** shock with **negative** price of risk.

GREEN STOCK HEDGES DISASTER

DETAILS

Proposition 3

With a convex investment friction (standard q-theory), green (brown) stock appreciates (depreciates) after a positive disaster shock, i.e.,

$$r_{i;1} = E_0[r_{i;1}] + \quad_i ; \quad \forall i \in \{B;G\}$$

where $\quad_G > 0$ *and* $\quad_B < 0$.

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Takeaway: Green stock hedges an adverse shock $\Rightarrow$ a negative greenium

PREFERENCE

- Recursive preference (Epstein and Zin, 1989)

$$W(C; U') = \left((1 \quad)C^{1 \quad \frac{1}{}} + \quad E \quad U'(S')^{1 \quad} \quad S^{\frac{1 \quad \frac{1}{}}{1}} \right)^{\frac{1}{1 \quad \frac{1}{}}}$$

where

- is the subjective discount rate
- is the risk aversion
- is the intertemporal elasticity of substitution (IES)

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where
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  - is the risk aversion
  - is the intertemporal elasticity of substitution (IES)
- Standard setting: $> \frac{1}{}$ i.e., agent prefers early resolution of uncertainty $\Rightarrow$ high price of risk on news shock

Production

- CES aggregation between green & brown outputs (Acemoglu et al., 2012)

$$Y = \left[\omega Y_B^{\frac{\varepsilon-1}{\varepsilon}} + (1-\omega) Y_G^{\frac{\varepsilon-1}{\varepsilon}} \right]^{\frac{\varepsilon}{\varepsilon-1}}$$

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- Capital accumulation with convex investment friction (Jermann, 1998)

$$K'_i = (1-\delta_K) K_i + I_i - K_i G(I_i/K_i) \quad i \in \{B; G\}$$

Climate Feedback

- Climate feedback on the level of output (Golosov et al., 2014)

$$\tilde{Y} = \left[1 - e^{-\gamma(M - \bar{M})}\right] Y$$

where

- γ is the damage intensity (key risk factor for greenium
- M is the carbon concentration

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$$M^0 = (1 \quad _M)M + \ _M M + (K_B = A) \quad ! \quad \text{emission}$$

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- Shocks in the model $_a;\ _x;\quad N(0;\ )$

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- Calibration (i) follows literature, (ii) uses regressions and GMM

  Calibration | Sensitivity analysis | In-sample simulation
- Quantitative performance?

Matching Moments in the data

Table 4: Data and model simulation

	Data		Model	
	Estimate	SE	Macro n IAM	Traditional IAM
Panel A. Economic quantities				
(y) (%)	2.43	(0.31)	2.42	
(c) (%)	2.05	(0.25)	2.77	
(i_B) (%)	3.32	(0.51)	2.98	
(i_G) (%)	6.52	(0.80)	6.40	
Panel B. Climate quantities				
(T) (C)	0.12	(0.01)	0.13	
(M) (ppm)	0.65	(0.06)	0.53	
(E) (ppm)	0.06	(0.01)	0.07	
Panel C. Asset prices				
$E(R_B \quad R_G)$ (%)	3.83	(1.54)	3.22	
$E(R^{ex}_{MKT})$ (%)	6.68	(1.90)	6.43	
$E(r_f)$ (%)	0.85	(0.51)	0.79	

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(E) (ppm)	0.06	(0.01)	0.07	0.04
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$E(R_B \quad R_G)$ (%)	3.83	(1.54)	3.22	0.49
$E(R^{ex}_{MKT})$ (%)	6.68	(1.90)	6.43	-0.72
$E(r_f)$ (%)	0.85	(0.51)	0.79	19.86

Takeaway: Macro- nance IAM is important – captures both quantities and asset prices

IMPULSE RESPONSE FUNCTIONS TO A DISASTER SHOCK

After a disaster shock:

- SDF increase) an adverse shock

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Impulse Response Functions: Model vs. Data

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Model matches IRFs in the data: Novel in the literature

POLICY IMPLICATION: SOCIAL COST OF CARBON

- SCC corresponds to the shadow price of carbon, Q_M, which follows the AP rule

$$Q_M = E\left[{}^{0} \quad {}_{M} Q^{0}_{M} + {}^{0}\tilde{Y}^{0} \quad S \right]$$

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Benchmark	40.38	4.71%	0.83%
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Takeaway: SCC is 40.4 USD per tonne of Carbon : a new lower bound in literature

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- Climate feedback + disaster-driven damage intensity $\Rightarrow$ heterogeneous disaster exposures of green and brown firms
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What we learn:

- Marginal climate damage commands high discount rate, and carbon price is low

Asset4 ESG Score

BACK

SUMMARY STATISTICS

BACK

Table 5: Portfolio summary statistics (annual average)

Portfolios	Brown	Green	BMG
ENSCORE (0 100)	0.13	68.99	-68.86
Observations	475	482	-7
Panel A. Financial characteristics			
Market Value (billion $)	6.23	26.53	-20.3
Book/Market (%)	53.77	60.41	-6.64
Investment/Asset (%)	4.44	1.90	2.54
Revenue/Asset (%)	84.36	87.60	-3.24
R&D/Asset (%)	6.07	3.12	2.95
Tangibility (%)	27.09	31.45	-4.36
Leverage (%)	38.35	40.68	-2.33
Panel B. Geographic characteristics			
Latitude	34.25	39.98	-5.73
Dist2Sea (km)	152.98	120.87	32.11
PDSI[1]	-0.89	-1.57	0.68

[1]: Palmer Drought Severity Index (Palmer, 1965)
*: signi cant at 5%

INDUSTRIES WITH HIGHEST WEIGHTS IN THE H AND L PORTFOLIOS

BACK

High ENSCORE portfolio		Low ENSCORE portfolio	
Industries	FF49 code	Industries	FF49 code
Retail	43	Business Services	34
Utilities	31	Computer Software	36
Petroleum and Natural Gas	30	Retail	43
Communication	32	Communication	32
Business Services	34	Pharmaceutical Products	13
Transportation	41	Petroleum and Natural Gas	30

EVIDENCE OF GREENIUM : RISK-ADJUSTED ABNORMAL RETURN

BACK

EVIDENCE OF GREENIUM : DOUBLE SORTING (1/2)

BACK

1. In each year, I rst divide rms into two groups according to one characteristics of previous year relative to industry peers
2. Then within each group, I further divide rms into ve portfolios according to their ENSCORE

	L	2	3	4	H	L - H	L	2	3	4	H	L - H
	Panel A. MV						Panel B. BV/MV					
L	12.71	12.53	11.93	10.80	11.85	0.87	10.18	8.42	7.35	8.77	7.07	3.11
	(4.48)	(4.53)	(4.56)	(4.41)	(4.61)	(1.53)	(4.11)	(3.74)	(3.8)	(3.49)	(3.03)	(1.63)
H	9.63	9.42	8.92	7.36	6.61	3.02	10.69	8.72	11.24	9.82	7.05	3.64
	(4.1)	(4.29)	(3.73)	(3.29)	(3.24)	(1.44)	(4.25)	(4.79)	(4.55)	(3.74)	(3.93)	(1.59)
	Panel C. I/A						Panel D. REV/A					
L	9.46	10.13	8.07	6.33	6.32	3.14	10.24	8.57	10.51	8.66	6.78	3.45
	(3.99)	(4.32)	(3.8)	(3.49)	(3.33)	(1.53)	(4.42)	(4.32)	(4.1)	(3.82)	(3.34)	(1.58)
H	10.26	6.55	9.57	8.55	6.29	3.98	11.80	9.22	8.29	8.90	7.42	4.39
	(4.36)	(3.92)	(4.01)	(3.76)	(3.23)	(1.59)	(3.83)	(3.97)	(4.09)	(3.81)	(3.17)	(1.32)

Evidence of Greenium: Double sorting (2/2)

BACK

	L	2	3	4	H	L - H	L	2	3	4	H	L - H
	Panel E. R&D/A						Panel F. PPE/A					
L	10.90	10.23	10.30	8.74	7.42	3.48	10.67	9.93	10.54	7.80	6.47	4.20
	(4.44)	(4.34)	(4.1)	(3.36)	(3.4)	(1.71)	(4.07)	(4.45)	(4.51)	(3.45)	(3.4)	(1.58)
H	12.95	8.42	7.70	8.03	7.05	5.90	10.92	7.99	8.80	9.52	8.02	2.90
	(4.82)	(5.22)	(4.41)	(3.61)	(3.62)	(2.45)	(4.47)	(4.33)	(3.79)	(3.96)	(3.19)	(1.7)
	Panel G. Lev						Panel H. Latitude					
L	9.84	8.67	9.34	8.54	6.48	3.36	10.81	8.46	8.77	9.31	6.81	4.00
	(4.1)	(4.08)	(4.37)	(3.35)	(3.13)	(1.72)	(3.98)	(4.23)	(3.79)	(3.71)	(3.23)	(1.34)
H	11.72	9.18	9.63	8.27	8.02	3.69	11.45	11.03	7.45	9.87	7.17	4.28
	(4.54)	(4.19)	(3.72)	(4.04)	(3.4)	(1.64)	(4.43)	(4.32)	(4.65)	(3.36)	(3.36)	(1.76)
	Panel I. Distance to Sea						Panel I. PDSI					
L	11.66	9.99	10.49	9.42	7.64	4.03	9.90	7.44	6.89	8.01	6.76	3.14
	(4.2)	(4.42)	(3.88)	(3.37)	(3.46)	(1.24)	(4.04)	(3.91)	(4.32)	(3.67)	(3.26)	(1.59)
H	9.32	6.60	9.90	7.40	6.59	2.73	11.93	9.19	9.42	12.65	7.48	4.44
	(3.95)	(3.74)	(4.59)	(3.84)	(3.2)	(1.58)	(4.21)	(4.73)	(3.88)	(4.01)	(3.32)	(1.52)

EVIDENCE OF GREENIUM: FAMA-MACBETH REGRESSION

BACK

$$R_{i;t} = {}_0 + {}_1 ENSCORE_{i;t \quad 12} + {}_2 X_{i;t \quad 12} + {}_{i;t}$$

	(1)	(2)	(3)	(4)	(5)
ENSCORE	-1.37	-1.02	-0.96	-0.86	-0.86
	(0.56)	(0.55)	(0.49)	(0.40)	(0.42)
MV		-0.94	-0.52	-0.52	-0.51
		(0.53)	(0.47)	(0.37)	(0.35)
BV/MV		1.06	1.65	2.82	2.89
		(0.80)	(1.11)	(1.59)	(1.43)
I/A			-0.50	-0.88	-0.82
			(0.55)	(1.08)	(1.13)
REV/A			1.09	1.37	1.48
			(0.38)	(0.64)	(0.64)
R&D/A				2.14	2.03
				(0.99)	(0.98)
PPE/A				-1.30	-1.06
				(0.72)	(0.68)
Lev				0.85	0.83
				(0.81)	(0.80)
Latitude					0.30
					(0.70)
Dist2Sea					-0.42
					(0.42)
PDSI					1.42
					(0.81)
Industry FE	Yes	Yes	Yes	Yes	Yes
Adj. R^2	0.110	0.118	0.118	0.147	0.165
Obs.	475128	446232	435264	203316	188712

EVIDENCE OF GREENIUM: PRICE OF RISK (1/2)

1. I construct a Brown Minus Green factor using the excess return of a low-minus-high portfolio on ENSCORE
2. I identify price of risk using a two-pass regression

$$R_t^p = {}_{0;p} + {}_{1;p} F_t + {}_{BMG;p} \; BMG_t + v_{p;t}$$

$$E[R_t^p] = {}_0 + {}_1 \; \hat{}_{1;p} + {}_{BMG} \; \hat{}_{BMG;p} + u_p$$

where

- R_t^p is the return of a testing portfolio from Kenneth French's data library
- F_t is the FF5 factors

A positive ${}_{BMG}$ means that the greenium exists in a wide cross-section of testing portfolios

Evidence of Greenium : Price of risk (2/2)

BACK

Portfolio sets	MKT	SMB	HML	RMW	CMW	BMG
Size & BV/MV (25)	8.58	1.92	0.89	1.24	2.55	3.55
	(4.34)	(1.69)	(1.75)	(1.29)	(1.72)	(2.29)
Size & INV (25)	8.52	1.31	8.57	-0.94	1.31	5.11
	(4.34)	(1.69)	(2.38)	(1.42)	(1.34)	(2.76)
Size & OP (25)	8.57	2.24	0.65	2.89	2.16	6.87
	(4.34)	(1.69)	(2.13)	(1.07)	(1.96)	(2.43)
Size & BV/MV & INV (32)	8.70	2.01	-0.07	3.74	1.05	7.41
	(4.34)	(1.69)	(1.75)	(1.26)	(1.34)	(1.93)
Size & BV/MV & OP (32)	8.35	2.15	0.63	3.64	-1.11	7.84
	(4.34)	(1.69)	(1.75)	(1.09)	(1.61)	(1.91)
BV/MV & INV & OP (32)	8.67	1.88	6.61	3.10	1.16	0.28
	(4.34)	(1.69)	(1.89)	(1.07)	(1.33)	(1.96)

Evidence of Greenium: Subcategory of ENSCORE (1/3)

BACK

	L	2	3	4	H	L - H
Panel A. Emission score						
$E[R^{ex}]$	10.59	9.05	9.16	7.48	7.78	2.81
	(4.03)	(4.18)	(4.16)	(3.62)	(3.25)	(1.23)
CAPM	2.63	1.05	1.53	0.77	1.10	1.54
	(1.22)	(1.53)	(1.47)	(1.03)	(0.87)	(1.06)
FF3	2.82	1.14	1.95	1.07	1.54	1.28
	(0.99)	(1.55)	(1.39)	(1.01)	(0.77)	(0.91)
FF5	4.74	0.78	2.21	0.82	1.99	2.74
	(1.15)	(1.69)	(1.47)	(1.1)	(1)	(1.31)
FF5 & MOM	4.76	0.76	2.27	0.76	1.95	2.81
	(1.16)	(1.71)	(1.44)	(1.12)	(1.05)	(1.38)

EVIDENCE OF GREENIUM: SUBCATEGORY OF ENSCORE (2/3)

BACK

	L	2	3	4	H	L - H
			Panel B. Innovation score			
$E[R^{ex}]$	10.11	10.42	9.04	10.79	8.81	1.30
	(4.46)	(5.36)	(4.36)	(4.37)	(4.16)	(1.13)
CAPM	2.17	0.68	1.32	3.55	1.57	0.60
	(1.52)	(1.75)	(1.87)	(2.19)	(1.37)	(1.09)
FF3	2.39	0.89	1.64	3.70	1.90	0.49
	(1.51)	(1.65)	(1.85)	(2.14)	(1.41)	(1.14)
FF5	4.99	2.86	2.17	4.92	3.11	1.88
	(2.07)	(1.51)	(2.12)	(2.72)	(2.05)	(1.32)
FF5 & MOM	5.09	3.05	2.33	4.93	3.23	1.86
	(2.02)	(1.52)	(2.05)	(2.68)	(2.05)	(1.32)

Evidence of Greenium: Subcategory of ENSCORE (3/3)

BACK

	L	2	3	4	H	L - H
	Panel C. Resource score					
$E[R^{ex}]$	9.81	9.38	9.09	8.11	7.56	2.25
	(4.29)	(4.52)	(3.52)	(4.02)	(3.18)	(1.44)
CAPM	1.60	1.29	2.00	0.89	0.94	0.66
	(1.14)	(1.44)	(1.04)	(1.21)	(1.02)	(1.1)
FF3	1.74	1.18	2.30	1.18	1.43	0.31
	(0.98)	(1.45)	(1)	(1.25)	(0.81)	(0.96)
FF5	3.68	2.58	3.21	0.80	1.70	1.98
	(1.12)	(1.78)	(1.16)	(1.13)	(0.91)	(1.07)
FF5 & MOM	3.72	2.66	3.08	0.77	1.68	2.04
	(1.1)	(1.73)	(1.22)	(1.12)	(0.93)	(1.12)

Evidence of Greenium: U.S. sample

BACK

	L	2	3	4	H	L - H
$E[R^{ex}]$	12.73	12.05	10.66	11.22	8.37	4.36
	(4.55)	(4.58)	(3.92)	(3.64)	(3.26)	(1.88)
CAPM	2.61	1.79	1.47	2.26	0.07	2.54
	(1.45)	(1.79)	(1.64)	(1.31)	(0.95)	(1.64)
FF3	2.25	1.88	1.36	2.20	0.05	2.20
	(1.18)	(1.84)	(1.62)	(1.32)	(1)	(1.6)
FF5	2.97	0.81	0.62	1.25	-0.40	3.37
	(1.24)	(1.64)	(1.82)	(1.39)	(1.16)	(1.49)
q5	4.33	3.98	2.71	1.76	-0.82	5.15
	(1.54)	(1.39)	(1.48)	(1.29)	(1.03)	(1.47)

EVIDENCE OF GREENIUM : SUBSAMPLE

BACK

	$E[R^{ex}]$	CAPM	FF3	FF5	FF5_MOM
Full sample	3.83	2.43	2.17	3.91	3.98
	(1.39)	(1.18)	(0.98)	(1.22)	(1.25)
2004-2019	3.80	2.45	2.46	4.77	4.98
	(1.48)	(1.21)	(0.97)	(1.17)	(1.21)
2005-2019	3.42	2.19	2.22	4.56	4.71
	(1.58)	(1.29)	(1.03)	(1.21)	(1.24)
2006-2019	3.71	2.51	2.51	4.51	4.58
	(1.67)	(1.34)	(1.07)	(1.33)	(1.36)
2007-2019	4.04	2.97	2.71	4.84	4.86
	(1.76)	(1.35)	(1.14)	(1.41)	(1.43)
2008-2019	4.39	3.37	2.79	4.89	4.88
	(1.86)	(1.42)	(1.23)	(1.57)	(1.58)
2009-2019	5.98	4.12	2.31	3.56	3.52
	(2.1)	(1.99)	(1.37)	(1.55)	(1.5)

EVIDENCE OF GREENIUM: SUBSAMPLE (FIXING FIRMS)

BACK

	$E[R^{ex}]$	CAPM	FF3	FF5	FF5_MOM
2003-2019	2.33	0.90	0.71	1.73	1.78
	(1.66)	(1.68)	(1.43)	(1.34)	(1.35)
2004-2019	2.06	0.67	0.69	2.10	2.26
	(1.76)	(1.7)	(1.4)	(1.36)	(1.38)
2005-2019	3.31	1.98	2.05	4.16	4.41
	(1.64)	(1.37)	(1.07)	(1.18)	(1.22)
2006-2019	3.12	1.99	2.06	3.66	3.74
	(1.61)	(1.4)	(1.13)	(1.33)	(1.35)
2007-2019	3.32	2.29	2.20	3.84	3.87
	(1.73)	(1.48)	(1.23)	(1.4)	(1.43)
2008-2019	3.91	2.83	2.48	4.01	3.98
	(1.99)	(1.6)	(1.3)	(1.36)	(1.38)
2009-2019	4.94	3.20	2.18	2.91	3.00
	(1.81)	(1.81)	(1.41)	(1.39)	(1.39)

EVIDENCE OF GREENIUM: CARBON EMISSION INTENSITY

BACK

	L	2	3	4	H	L - H
			Panel A. Carbon emission/Total asset			
$E[R^{ex}]$	4.70	6.64	7.41	6.85	9.23	-4.53
	(5.74)	(4.49)	(4.76)	(4.09)	(3.53)	(3.41)
CAPM	0.07	2.43	3.00	2.71	5.44	-5.38
	(2.95)	(2.14)	(2.07)	(2.43)	(2.57)	(3.25)
FF3	-0.12	2.51	2.94	2.96	5.59	-5.71
	(2.89)	(2.15)	(2.07)	(2.41)	(2.48)	(3.22)
FF5	-0.81	3.11	2.77	2.07	4.75	-5.57
	(2.85)	(2.5)	(2.13)	(2.64)	(2.39)	(3.02)
FF5 & MOM	-0.77	3.05	2.77	2.05	4.74	-5.51
	(2.85)	(2.39)	(2.13)	(2.59)	(2.35)	(2.91)
			Panel B. Carbon emission/Revenue			
$E[R^{ex}]$	4.96	8.07	6.88	7.13	9.06	-4.10
	(5.27)	(4.48)	(4.72)	(4.25)	(3.53)	(2.99)
CAPM	0.80	3.43	2.54	2.85	5.32	-4.53
	(2.68)	(1.82)	(2.32)	(2.25)	(2.58)	(3.02)
FF3	0.87	3.39	2.46	3.02	5.50	-4.63
	(2.67)	(1.71)	(2.32)	(2.25)	(2.51)	(3.03)
FF5	0.44	3.59	1.52	2.47	4.78	-4.34
	(2.45)	(2.21)	(2.41)	(2.51)	(2.41)	(2.61)
FF5 & MOM	0.41	3.51	1.57	2.46	4.76	-4.34
	(2.43)	(2.06)	(2.46)	(2.48)	(2.34)	(2.6)

EVIDENCE OF GREENIUM: MSCI ENSCORE

BACK

	L	H	L - H
$E[R^{ex}]$	10.02	7.73	2.29
	(3.59)	(4.19)	(2.54)
		Panel A. CAPM	
	4.21	0.47	3.74
	(2.45)	(1.82)	(2.45)
		Panel B. FF3	
	3.16	-0.74	3.89
	(2.54)	(1.44)	(2.68)
		Panel C. FF5	
	1.33	-2.89	4.22
	(2.44)	(1.53)	(2.59)
		Panel D. FF5 & MOM	
	1.57	-2.37	3.94
	(2.37)	(1.61)	(2.6)

Evidence of Greenium: annual change of ENSCORE

BACK

	L	2	3	4	H	L - H
ENSCORE	-7.30	-1.11	1.06	5.40	18.26	-25.57
ENSCORE	33.22	32.22	22.71	28.43	40.66	-7.44
$E[R^{ex}]$	7.62	8.76	8.49	7.70	7.02	0.60
	(3.48)	(3.75)	(4.37)	(3.43)	(3.64)	(0.8)
CAPM	1.55	2.48	1.79	1.60	0.78	0.77
	(1)	(0.74)	(1.35)	(0.79)	(0.88)	(0.82)
FF3	1.59	2.50	1.80	1.63	0.82	0.77
	(0.96)	(0.73)	(1.4)	(0.77)	(0.74)	(0.82)
FF5	1.76	2.94	1.50	0.73	1.46	0.30
	(1.12)	(0.94)	(1.37)	(0.97)	(0.85)	(0.93)
FF5&MOM	1.72	2.91	1.43	0.57	1.43	0.29
	(1.15)	(0.98)	(1.33)	(1.12)	(0.86)	(0.95)

EVENT STUDY ON RETURNS

$$R_{i;t\,!\,\,t+M} = \quad + \quad Brown_i + X_{i;t} + \quad _{i;t}$$

M	1m	2m	3m	6m	12m
Panel A. Hurricane Katrina (obs.=721)					
	-19.61	-17.93	-9.10	-8.76	-8.79
	(8.48)	(6.18)	(5.19)	(3.74)	(2.34)
Adj. R^2	0.14	0.20	0.09	0.19	0.18
Panel B. 2012 US drought (obs.=844)					
	-22.61	-11.83	-6.53	-5.11	-7.18
	(10.81)	(6.62)	(4.89)	(3.14)	(2.54)
Adj. R^2	0.16	0.13	0.12	0.04	0.22
Panel C. 2018 California wild res (obs.=1475)					
	-24.50	-6.12	-5.49	-2.92	-0.62
	(6.88)	(5.2)	(4.37)	(3.44)	(2.41)
Adj. R^2	0.06	0.06	0.05	0.13	0.12

EVENT STUDY ON INVESTMENT

$$I{=}A_{i;t} = \quad + \quad \text{Brown}_i + X_{i;t} + \quad _i$$

	I A	I PPE
	Panel A. 2012 US drought	
	-4.62	-6.73
	(2.18)	(2.74)
Adj. R^2	0.02	0.01
Obs.	829	827
	Panel B. 2018 California wild res	
	-4.28	-5.19
	(2.02)	(2.25)
Adj. R^2	0.03	0.01
Obs.	1381	1374

BACK

DERIVATION OF THE STOCK RETURNS

BACK

Capital accumulation under investment friction

$$K_{i;2} = G(I_{i;1}; K_{i;1}) = I_{i;1} K_{i;1}^{1} \quad ; \quad \forall i \in \{B; G\}$$

where $0 < \quad < 1$

Returns are related to investments (Cochrane 1991)

$$R_{i;1} = \frac{\overbrace{Q_{i;1} G'_{K_{i;1}}}^{\text{capital gain}} + \overbrace{MPK_1}^{\text{dividend}}}{Q_{i;0}} = \frac{1}{Q_{i;0}} \quad \frac{}{1} \frac{I_{i;1}}{K_{i;1}} + \frac{Y_1}{K_{i;0}} \quad ; \quad \forall i \in \{B; G\}$$

where $G'_{K_{i;1}} = \frac{\partial G}{\partial K_{i;1}}$, and $Q_{i;1} = \frac{1}{G'_{I_{i;1}}}$ is Tobin's Q of sector i.

Sensitivity analysis

BACK

Table 6: Sensitivity analysis

	Benchmark	Subjective Discount rate	IES	Substitution		R&D efficiency	
		= 0.95	= 0.1	" = 1.5	" = 10	= 0.05	= 0.1
SCC	40.38	30.24	11.82				
r_{SCC}	4.71%	6.56%	15.91%				
Risk-free rate	0.83%	4.67%	17.37%				
Climate damage	0.51%	0.41%	0.18%				
Temperature	0.95	0.80	0.36				
$I_G = I_{total}$	62.80%	59.84%	55.49%				
I_G	61.38%	59.11%	55.32%				
R&D=Y	0.89%	0.53%	0.20%				

Takeaway

- Subjective discount rate & IES are essential to quantify the SCC

SENSITIVITY ANALYSIS

BACK

Table 6: Sensitivity analysis

	Benchmark	Subjective Discount rate	IES	Substitution		R&D ef ciency	
		= 0:95	= 0:1	" = 1:5	" = 10	= 0:05	= 0:1
SCC	40.38			40.65	39.44	40.34	40.43
r_{SCC}	4.71%			4.69%	4.80%	4.72%	4.71%
Risk-free rate	0.83%			0.78%	0.94%	0.75%	0.95%
Climate damage	0.51%			0.70%	0.03%	0.55%	0.45%
Temperature	0.95			1.24	0.07	1.01	0.86
$I_G = I_{total}$	62.80%			45.17%	98.36%	48.64%	76.81%
I_G	61.38%			44.47%	98.09%	47.58%	75.29%
R&D=Y	0.89%			0.65%	1.36%	0.47%	1.46%

Takeaway

- Subjective discount rate & IES are essential to quantify the SCC
- Substitution & R&D ef ciency matter for equilibrium allocation btw. green/brown investments

CALIBRATION

BACK

Table 7: Calibration

Literature		Regression		GMM	
	1.8%	$_M$	0.98		0.92
	3.35%	$_T$	0.17		$2{:}5 \quad 10^{5}$
$_x$	0.96	$_M$	0.45		1.71
$'_x$	0.2	$_T$	0.092		0.074
$!$	0.59		3.088		0.67
$''$	3			b	7.99
$_K$	0.06				1.64
	0.34				
	0.974				
	10				
	2				
	$5.05 \quad 10^{5}$				
k	4				
$_H$	0.1				

CALIBRATION

BACK