Technological greenness and long-run performance

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Green stocks

Previous research analyzes the **short-run performance** of green stocks.

Green stocks have been identified as those with:

- Lower Greenhouse gas (GHG) emissions.
- Higher Environmental, Social, Governance (ESG) scores.

(see, e.g., Monasterolo and de Angelis, 2020; Bolton and Kacperczyk, 2021, 2023; Avramov et al., 2022; Pástor et al., 2021, 2022; Zerbib, 2022; Aswani et al., 2023).

Green stocks: two open questions

1. Greenness
   - Greenness confusion.
     - Divergence of ESG ratings (Berg et al. 2022)
     - 'Financed emissions' sensitive to increases in portfolio value, market cap, inflation
   - Greenwashing concerns
     - Poor firms' disclosure, attempts to look greener than they are

2. What about long-run performance (e.g., Edmans 2023)?
   - Greeness metrics' relevance for the **long-term** value creation.

What we do

We analyse what constitute greeness and why it matters:

- Value generation for shareholders in the long-run

We study firms' **long-run** (5 y.) future operating and financial performance in relation to their investments in green technology:

- Firm's revenues level: introduced in Battiston et al. 2017's Climate stress-test, used by the Network for Greening the Financial System
- Structural nature: less prone to misreporting and greenwashing
- Long-run: key for decarbonization and taming geopolitical risk.

Index of technological greeness

New dataset: we hand-collect the proportion of each firm's revenues (energy capacity in MWh) derived from renewable and fossil fuel sources

We construct a firm-level **index of technological greenness**:

- Tangible and structural measure based on a firm's technology
- **Max score**: +1 (indicating entirely green firms)
- **Min score**: -1 (indicating entirely brown firms)

$$\underbrace{(solar + waste + wind)}_{\text{green}} - \underbrace{(gas + coal)}_{\text{brown}}.$$

Index of tech greenness (cont'd)

Our index has several advantages with respect to ESG scores (E), GHG emissions (G), and patents (P):

- Directly identifies energy capacity investments ($\neq$ P, G, E)
  - less prone to misreporting or greenwashing
- Includes green activities in addition to brown ones ($\neq$ P, G)
- Allows for direct comparisons across firms ($\neq$ P, G levels)

Focus on 1,000 global utility large and stable firms (IQR market cap between 2.6 and 15.6 USD billion).

Long-term perspective

A **long-term perspective** is important for at least two reasons:

- Green tech becomes more accessible and less costly over time.
  - full potential observable with some delay (like any tech)
  - overtaking fossil in terms of capacity/performance (IEA 2023)
- Better understanding of greenness performance decreases regulatory uncertainty, increases consumers' demand (Pastor et al. 2021) and cross-country cooperation

As a result, green firms become more profitable and attractive.

The economic mechanism

Key mechanism: evaluating new information on greeness is costly (highly technical nature)

- Short run. Fundamentals do not change
  - green tech / regulations are fixed
  - stock price mainly reflects green preferences ($P > F$, $E(R) < 0$)
- Long run. Fundamentals do change
  - green tech developments, performance / stringent regulation
  - some investors revise expectations slowly ($P < F$, $E(R) > 0$)

Main findings

Green firms are also 'better' firms, exhibiting:

- a gradual and steady increase in future valuations
- better, less volatile future operating performance:
  – driven by sales growth (green preferences, Pástor et al., 2022).

Green tech stocks earn **higher long-run returns**:

- $1\sigma \uparrow$ tech greeness $\longrightarrow$ about 15% increase in 5y stock returns
- no reversals: suggesting gradual impounding of information
- effect confined to firms with sizable, stable green investments:
  – no greenwashing effect!

Main findings (cont'd)

The long-run returns are higher in **financially developed countries** (intuition: efficient impounding of info, easier access to external finance)

We also show that the results do not merely reflect a country's:

- time trends in energy prices
- level of wealth
- favorable green regulations

Results robust to several proxies for systematic risk (e.g. Fama and French 1993).

Main findings (cont'd)

We also study the **market reaction** to tech greeness disclosure:

- Disclosure of high tech greenness $\longrightarrow$ higher long-run returns.
  - wrt disclosure of low greenness
  - wrt non-publishers (no disclosure)
- Effect is more pronounced after the **Paris Agreement**
- Results are stronger for tech greeness compared with GHG and ESG disclosure: **markets reward sustainability measures of more tangible nature such as technology**.

Contribution

Our paper contributes to a burgeoning literature on climate finance (e.g., Giglio et al., 2021; Edmans and Kacperczyk, 2022)

Previous research finds **mixed evidence** on green asset returns:

- Measuring GHG: Levels v. Intensity
  (Aswani et al., 2023; Bolton and Kacperczyk, 2023)
- Measuring ESG: Rating disagreement
  (Avramov et al., 2022; Berg et al., 2023)
- Measuring returns: Expected v. Realized
  (Pástor et al., 2021, 2022; Atilgan et al., 2023)
- Green preferences v. Risk considerations
  (Alessi et al., 2021; Pástor et al., 2021; Zerbib, 2022)

Contribution (cont'd)

Consistent with the carbon risk literature (e.g., Bolton and Kacperczyk, 2021, 2023), we show that green tech firms are **less risky**

- Less volatile operating performance
- Lower market beta
- Increasing valuations over time

Nonetheless, we find that greener firms' stocks earn **higher long-run returns** due to initial underpricing and a slow subsequent correction.

Contribution (cont'd)

Over the last decade, green stocks outperformed brown stocks due to higher consumer demand (Pástor et al., 2021, 2022)

We find that green stocks also outperform over **longer time horizons**:

- Market learning (e.g., Hirshleifer and Teoh, 2003)
  - superior performance of green tech firms (especially sales)
- Mispricing is arbitraged away (e.g., Greenwood, 2005)
  - prices gradually catch up with fundamentals.

Contribution (cont'd)

Recent studies look at green tech through **patents** (e.g., Kuang and Liang, 2022; Cohen et al., 2023; Hege et al., 2023; Reza and Wu, 2023)

This is also a **tangible metric** of greenness, but:

- Impact on a firm's operations is unclear (how wide?) (Bolton et al., 2023)
- Correspondingly, impact on firm value is mixed (e.g., Andriosopoulos et al., 2022; Hege et al., 2023).

Model

Setup

We consider the asset pricing model from **Hirshleifer and Teoh (2003)**.

The setup includes:

- One stock
  - wlog (e.g., Chen et al., 2002; Hong and Sraer, 2013)
  - intuition: isolate pricing determinants (no portfolio analysis)
- Two investor types
  - arbitrageurs, or "type A": more able/willing to access info
  - naive traders, or "type N" : driven by green preferences

Setup (cont'd)

Each investor can expend resources c on paying attention to green tech performance information, or spare resources but have less information

With this in mind:

- $f(c) =$ probability that an investor neglects relevant information
  - proportion of naive traders in the economy
  - taken as exogenously given
- $f'(c) < 0$, i.e., more effort leads to fewer evaluation mistakes.

Dates

The economy has **three dates**:

- Time 0. Investors form expectations
- Time 1. New public information arrives about firm value (investors trade with each other)
- Time 2. A dividend is realized and the economy ends (investors receive the final payoff).

Data

Sample

Our sample includes **global utility firms**:

- financial / accounting data for 1,000 firms from 77 countries

New dataset of green-tech capacity:

- revenues shares from renewables (green) and fossil fuel (brown) technologies for 165 firms from 31 countries
- sources: annual reports + Bloomberg + Thomson Reuters.

The sample period is from 2011 to 2021.

Sample (cont'd)

The **median firm** in our sample exhibits:

- Market cap of 5.99 USD billion.
- PPE of 3.92 USD billion.
- Market beta of 0.7.
- Sales growth of 4%.

The large and stable nature of these firms makes them easier to evaluate, with less room for mispricing (e.g., Baker and Wurgler, 2006, 2007; Baker et al., 2012).

Index of tech greenness

We construct a firm-level **index of technological greenness**:

- Tangible and structural measure
- Based on a firm's technology

We hand-collect the proportion of each firm's revenues (= energy capacity in MWh) derived from renewable and fossil fuel sources.

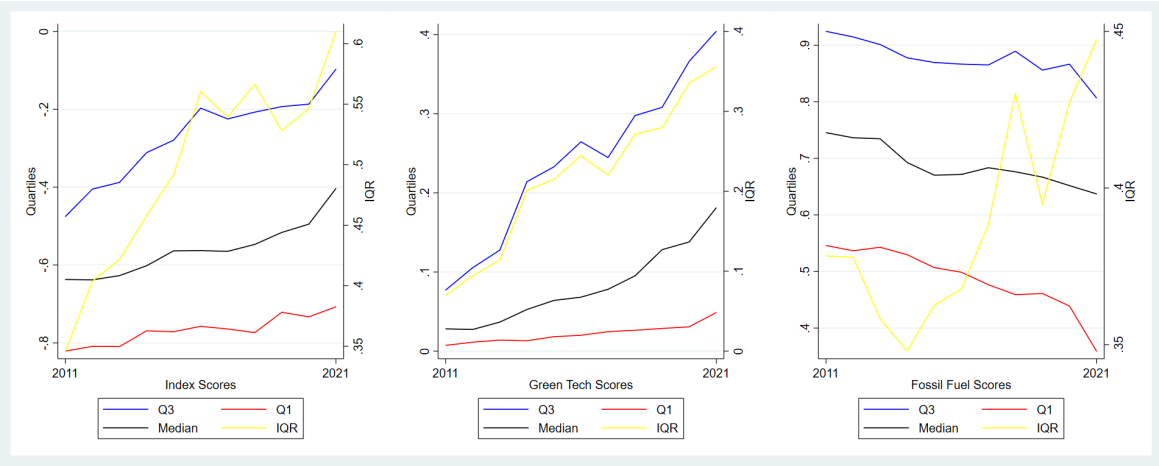
Index of tech greenness

The median firm's green energy capacity (expressed as a percentage of total energy capacity) includes:

- Solar (0.9%)
- Waste (0.7%)
- Wind (6.3%)
- Hydro (15.7%)
- Nuclear (18.5%)

Fossil energy capacity includes gas (32.8%) and coal (33.2%), so the median firm is then predominantly **fossil**.

Index of tech greenness (cont'd)



- Higher greeness (median) and greeness dispersion (IQR) over time.

Test equation

Our **main test equation** is as follows:

$$y_{i,t+h} = \alpha_t + \beta x_{i,t} + \gamma' Z_{i,t} + \epsilon_{i,t+h}. \quad (1)$$

where

- y = stock return of firm i over period $t + h$
- x = index of technological greenness (standardized)
- Z = set of firm-level accounting measures as controls
- α_t = year FE

Standard errors are clustered by firm (we find similar results using alternative specifications).

Test equation (cont'd)

Firm-level controls:

- book-to-market ratio
- natural logarithm of market cap and PPE
- leverage;
- ratio between capital expenditures and total assets
- current stock return
- growth in sales and earnings-per-share
- return on equity
- annualized volatility of daily stock returns.

Main findings

Future cumulative stock returns

	(1) Cum. Returns 1-2	(2) Cum. Returns 1-3	(3) Cum. Returns 1-4	(4) Cum. Returns 1-5
Tech Greenness	0.0522***	0.0883***	0.1335***	0.1511***
	3.60	4.51	4.94	4.19
Controls	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observations	942	793	652	524
R-squared	0.1059	0.1396	0.1940	0.2068

Tech greeness **positively predicts** future cumulative stock returns.

Robustness tests

We find similar results:

- Controlling for market beta (fewer obs)
- Including hydro and nuclear energy sources
- Estimating alternative specifications
  - Firm FE and clustering by year
  - Firm and year FE
  - Pooled OLS regressions with firm-year clustering
  - Fama-MacBeth regressions

Takeaway: robust results and no reversals, consistent with the model's prediction of gradual impounding of information over time.

Economic channel

Caveat: high long-run stock returns may also reflect a **risk premium** for adopting uncertain green technologies

Therefore, we study the economic channel underlying our results:

- Future valuations
- Future operating performance
- Cross-country variation in financial development.

Future valuations

The priors for future valuations are as follows:

- **Info story** implies gradual increase in valuations
  - initial underpricing: $P < F$, $E(R) > 0$
  - impounding of info: $P \longrightarrow F$
- **Risk story** implies decrease in valuations.
  - impounding of a risk premium: $P \downarrow$, $E(R) > 0$
  - intuition: investors shun the stock

Future valuations (cont'd)

	(1) MB t+1	(2) MB t+2	(3) MB t+3	(4) MB t+4	(5) MB t+5
Tech Greenness	0.0321*	0.0601*	0.0943**	0.1311**	0.1799***
	1.83	1.83	2.26	2.47	2.79
Controls	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Observations	1095	942	793	652	524
R-squared	0.6858	0.5331	0.4707	0.3983	0.3848

Tech greeness **positively predicts** future valuations.

Operating performance

The priors for operating performance are as follows:

- **Info story** implies better performance.
  - intuition: green tech makes firms more efficient
- **Risk story** implies worse performance.
  - intuition: green tech makes firms less efficient

We look at both the first and the second moment of ROE.

Operating performance: First moment

	(1) Cum. ROE 1-2	(2) Cum. ROE 1-3	(3) Cum. ROE 1-4	(4) Cum. ROE 1-5
Tech Greenness	0.0220***	0.0372***	0.0589***	0.0760***
	2.70	2.79	2.99	2.95
Controls	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observations	942	793	652	524
R-squared	0.2619	0.2734	0.2791	0.2556

Tech greeness **positively predicts** future cumulative operating performance, mostly driven by sales growth.

Operating performance: Second moment

	(1) SD ROE t+1	(2) SD ROE t+2	(3) SD ROE t+3	(4) SD ROE t+4	(5) SD ROE t+5
Tech Greenness	-0.0077***	-0.0059**	-0.0068**	-0.0073**	-0.0066
	-2.61	-1.99	-2.10	-2.00	-1.65
Controls	Y	Y	Y	Y	Y
Year FE	Y	Y	Y	Y	Y
Observations	1095	942	793	652	524
R-squared	0.2544	0.3353	0.2364	0.1784	0.1658

Tech greeness **negatively predicts** volatility of future operating performance; results are similar for market beta; risk explanation unlikely.

Financial development

Green tech firms may benefit from financial development in two ways:

- More efficient **impounding of info** (Bartram and Grinblatt, 2021)
- Easier access to **external finance** (Rajan and Zingales, 1998)

These are crucial requirements for the success of structural green tech investments, so our results should be stronger in high-FD countries.

Financial development (cont'd)

We test this conjecture exploting cross-country variation in FD

- FD = total banking credit / real GDP
  – intuition: our firms depend on debt, so banking system is key
- We predetermine this variable as a 1990-2010 average
  – address potential endogeneity issues
  – smooth out booms and busts in the financial system.

Financial development (cont'd)

All countries	(1) Cum. Returns 1-2	(2) Cum. Returns 1-3	(3) Cum. Returns 1-4	(4) Cum. Returns 1-5
Tech Greenness	0.0264*	0.0545**	0.0971***	0.1095**
	1.85	2.45	2.90	2.52
Tech Greenness × Banking FD	0.0654***	0.0859***	0.0995**	0.1195**
	3.59	3.21	2.53	2.36
Banking FD	0.0060	-0.0063	-0.0267	-0.0431
	0.30	-0.22	-0.68	-0.87
Controls	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Observations	937	789	649	522
R-squared	0.1169	0.1524	0.2098	0.2283

Tech greeness **positively predicts** future cumulative stock returns, especially in financially developed countries.

Financial development (cont'd)

One concern is that financially development may capture other dimensions of a country that also affect green tech firms:

- Country-specific time trends in energy prices
  - Proxy: country × year FE
- The level of wealth, which helps reach sustainability goals
  - Proxy: GNI per capita (average 1990-2010)
- The presence of favorable regulations for green companies
  - Proxy: % green energy consumption (average 1990-2010)

To tease out these channels, we carry out a **horse race**.

Financial development (cont'd)

All countries	(1) Cum. Returns 1-2	(2) Cum. Returns 1-3	(3) Cum. Returns 1-4	(4) Cum. Returns 1-5
Tech Greenness	-0.0054	-0.0060	-0.0141	-0.0176
	-0.45	-0.33	-0.59	-0.52
Tech Greenness × Banking FD	0.0444***	0.0577**	0.0798**	0.0809**
	2.63	2.31	2.54	2.01
Tech Greenness × GEC	0.0363*	0.0646**	0.0925**	0.1269**
	1.85	2.10	2.41	2.48
Tech Greenness × GNI per capita	0.0288***	0.0376**	0.0464**	0.0605**
	2.72	2.32	2.13	2.04
Controls	Y	Y	Y	Y
Country FE	Y	Y	Y	Y
Year FE	Y	Y	Y	Y
Country-Year FE	Y	Y	Y	Y
Observations	937	789	649	522
R-squared	0.1138	0.1301	0.1700	0.2114

Tech greeness **positively predicts** future cumulative stock returns in the most financially developed countries, controlling for alternative channels.

Does it pay to disclose?

In the last part of the paper, we study the **market reaction** to a firm's greenness disclosure

We divide our empirical tests in three parts:

- Disclosure of technological greenness
  - Top 30% v. non-publishers
- **Horse race** with alternative measures of greenness
  - Top 30% green tech, top 30% ESG, bottom 30% GHG (scope 1)
- Market reaction after **Paris Agreement** and the **Trump election**
  - two-year returns after 2016, world v. US

Publishers in our sample: $Tech = 17\%$, $ESG = 31\%$, $GHG = 22\%$.

Green tech disclosure: Top 30% v. Non-publishers

	(1) Cum. Returns 1-2	(2) Cum. Returns 1-3	(3) Cum. Returns 1-4	(4) Cum. Returns 1-5
Top 30% Tech Greenness	0.1461***	0.2615***	0.3784***	0.4289***
	4.49	5.14	5.17	4.49
Year FE	Y	Y	Y	Y
Observations	4410	3767	3155	2580
R-squared	0.0670	0.0617	0.0617	0.0692

Top 30% green-tech publishers earn higher long-run stock returns than non-publishers.

Green tech disclosure: Horse race

	(1) Cum. Returns 1-2	(2) Cum. Returns 1-3	(3) Cum. Returns 1-4	(4) Cum. Returns 1-5
Top 30% Tech Greenness	0.1170***	0.2079***	0.3131***	0.3572***
	3.92	4.38	4.49	3.85
Top 30% ESG	0.0363	0.0771**	0.0963*	0.1239*
	1.56	2.14	1.90	1.83
Bottom 30% GHG	0.0749**	0.1273***	0.1962***	0.2180**
	2.29	2.59	3.03	2.54
Year FE	Y	Y	Y	Y
Observations	5082	4340	3631	2965
R-squared	0.0644	0.0629	0.0654	0.0731

Top 30% green-tech publishers earn higher long-run stock returns than non-publishers, controlling for top ESG and bottom GHG publishing.

Green tech disclosure: 2016 effect

Dep. Variable: Cum. Returns 1-2	(1)	(2)	(3)	(4)
Top 30% Tech Greenness	0.1263**			0.1233***
	2.46			3.15
Top 30% Tech Greenness × 2016	0.1709***			0.0763**
	3.50			2.06
Top 30% Tech Greenness × 2016 × US	-0.2138***			-0.2246***
	-2.92			-3.07
Top 30% ESG		0.0281		-0.0286
		0.44		-0.46
Top 30% ESG × 2016		0.3114***		0.2561***
		4.16		4.32
Top 30% ESG × 2016 × US		-0.2054***		-0.1158**
		-2.75		-2.13
Bottom 30% GHG			0.1135**	0.1132**
			2.02	2.50
Bottom 30% GHG × 2016			0.2046***	0.0695
			2.93	1.56
Bottom 30% GHG × 2016 × US			-0.2302***	-0.0880*
			-3.61	-1.93
Controls	Y	Y	Y	Y
Observations	5082	5082	5082	5082
R-squared	0.0372	0.0364	0.0364	0.0415

PA effect for green tech disclosure only holds outside the US, controlling for ESG and GHG disclosure

Concluding remarks

Takeaways

Investing in green stocks then seems to be **lucrative** in the long run

– Green tech firms are also better firms!

This is an **important result**:

- An orderly transition to a greener economy may entail more economic and financial advantages than previously thought.
- **Green firms**: investment opportunity and source of resilience to exogenous shocks.

Policy recommendations

Our findings make a case for the introduction of **systematic requirements** for tech greenness disclosure:

- Markets around the world recognize it
- Less prone to greenwashing issues
- Less sensitive to political changes in environmental policies

Policy makers' ebbing on ambition regarding green regulation and policy may have negative implications on economic **competitiveness** and markets' **performance**.

Thanks for your attention!

Appendix: Information

As in Chen et al. (2002), we assume that the stock's initial fundamental value (at time 0) is equal to $F + \epsilon$, where $\epsilon \sim N(0, 1)$

At time 1, new info arrives on green tech and modifies the fundamental value to $F + \Delta + \epsilon$

- Arbitrageurs correctly incorporate Δ
- Naive traders do not

Intuition: green tech is difficult to evaluate and can only be priced by expending resources c (which arbs do).