



# Carbon Risk

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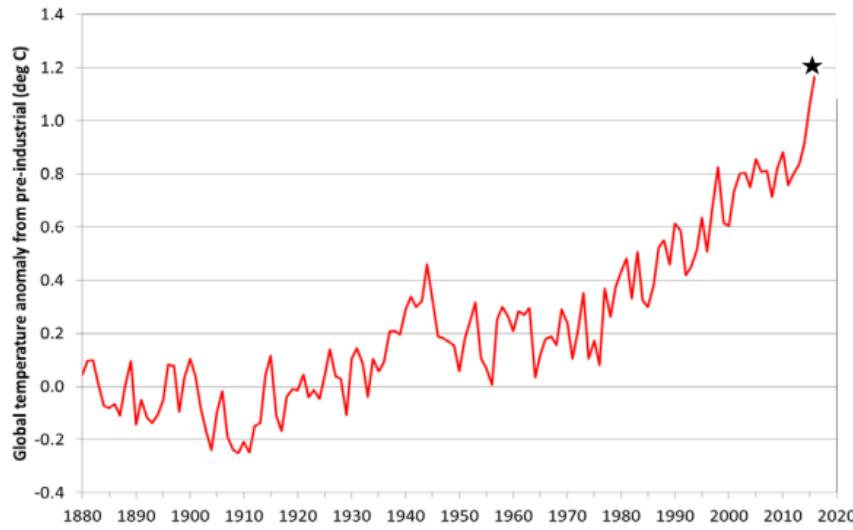
# Outline

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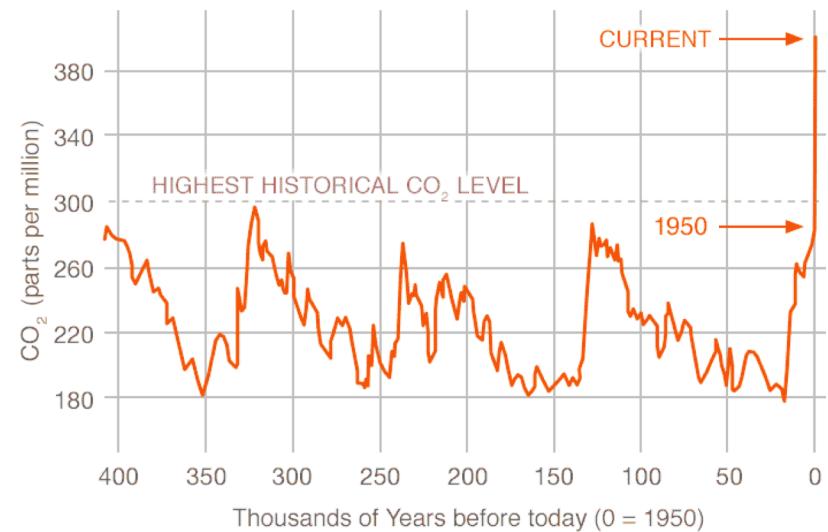
1. Motivation
2. Carbon Risk Factor Construction
3. Applications of Carbon Beta
4. Summary

## Motivation - Climate Change

**Temperature anomaly** is continually increasing



**Atmospheric CO<sub>2</sub> emissions** are rising rapidly



Source: NOAA, NASA, UK Met Office/CRU (2017); climate.nasa.gov (2018)

# Motivation - Industry Transition Process

## New agreements



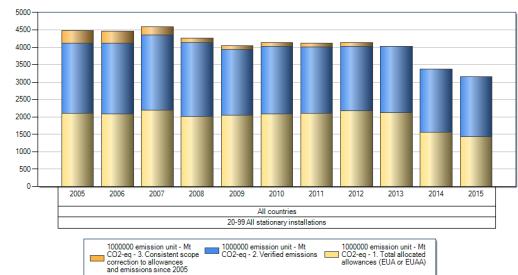
e.g. Paris Agreement

## Shift of interests



e.g. Divestment movement

## Changing business' financials



e.g. Emission certificates

**Definition:** Carbon Risk results from the transition process from a carbon-intensive brown economy to a low-carbon green economy.

Source: NY Times (2009), EEA (2015), thenation.com (2015), unepfi.org (2017), Fossil Free (2018) various

## Motivation - Related Literature

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- **Climate change as a general source of uncertainty** for society as a whole  
(e.g. Stern, 2008, AER; Dietz et al., 2016, Nat. Clim. Change; Diffenbaugh et al., 2018, Sci. Adv.)
- Assessment of the **effects of global warming on the world economy**  
(e.g. Nordhaus, 1993, Resour. Energy Econ.; Nordhaus/Yang, 1996, AER; Rogelj et al., 2018, Nat. Clim. Change)
- Optimal **policy for climate change** and policy implications  
(e.g. Fowlie et al., 2016, JPE; Lemoine/Rudik, 2017, AER; Mardones/Flores, 2018, Energy Econ.)
- **Carbon emissions** and their **impact** on the **value of a firm**  
(e.g. Haszeldine, 2009, Science; Krüger, 2015, JFE; Acemoglu et al., 2016, JPE; Fernando et al., 2017, JFQA)
- **Carbon emissions** and their **impact** on the **performance of a firm**  
(e.g. El Ghoul et al., 2011, JBF; Flammer, 2013, AMJ; Oestreich/Tsiakas, 2015, JBF)

### Our Contribution

- **Development of a Carbon Risk Factor**
- **Quantification of Carbon Risk with Carbon Beta**
- Provision of **Carbon Beta applications** and demonstration of their **implications** on various **stakeholders**

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## Carhart model

$$er_{i,t} = \alpha_i + \beta_{1,i} er_{M,t} + \beta_{2,i} SMB_t + \beta_{3,i} HML_t + \beta_{4,i} WML_t$$

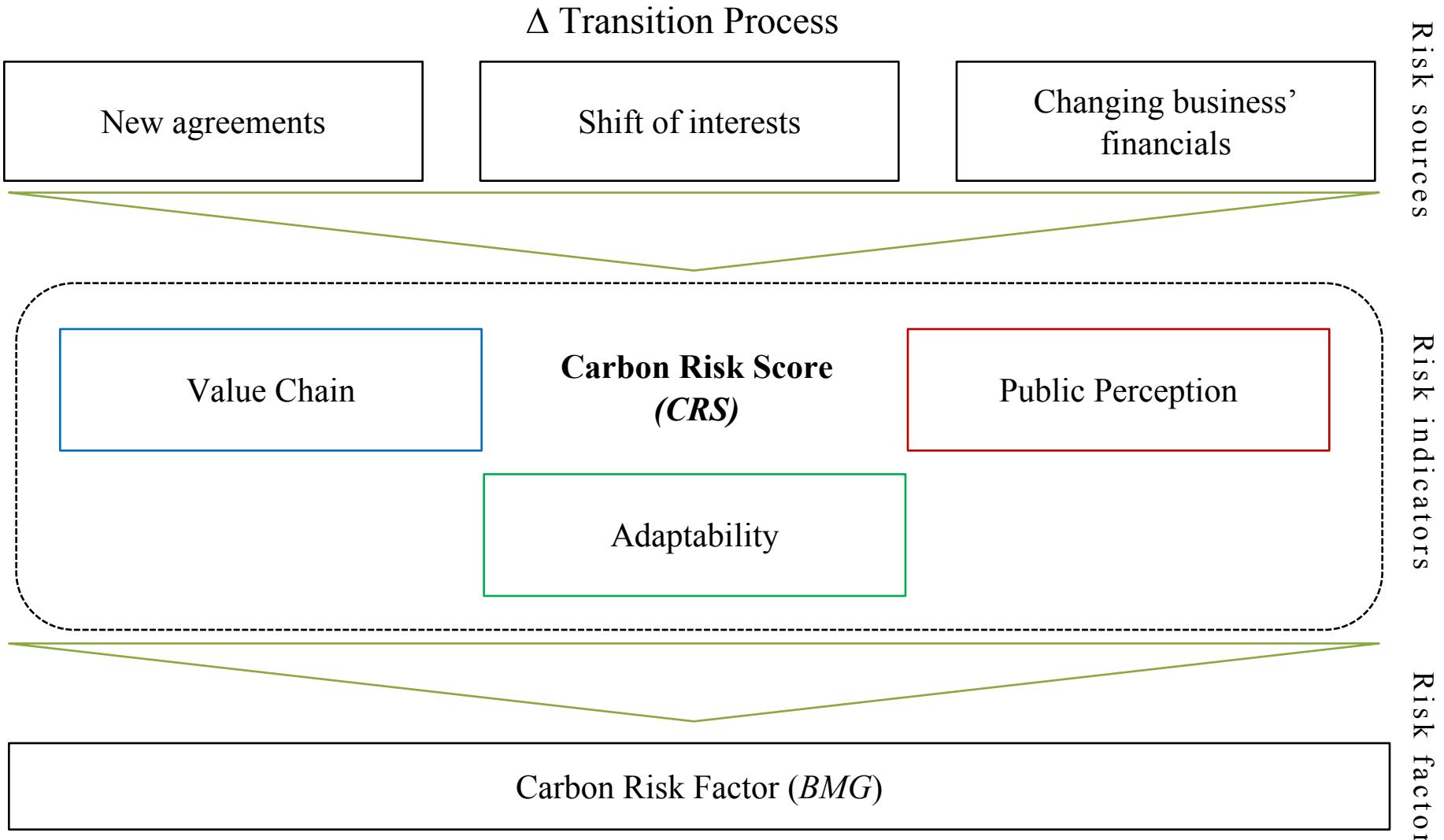
Carbon Risk Factor  
Brown-minus-Green

$$+ \beta_{5,i} BMG_t + \varepsilon_{i,t}$$

Carbon Beta

- Carbon Risk Factor is constructed controlling for size in analogy to, e.g., the HML factor (Fama and French, 1993, JFE)

# Concept for identifying carbon risk firms



## Carbon Risk Score (*CRS*) data sample

- Our unique data sample comprises four major databases:
  - Carbon Disclosure Project (**CDP**)
  - **MSCI** ESG Stats and IVA ratings
  - **Sustainalytics** ESG Ratings
  - **Thomson Reuters** ESG dataset
- **41,752 → 1,637 firms in 43 countries**
- **785 → 55 carbon risk proxies**
- **2010 to 2016**
- Financial data from **Thomson Reuters Datastream**

# Determination of 55 Carbon Risk proxies & 3 subscores

## Value Chain Subscore

- Energy Use Total
- CO<sub>2</sub> Equivalents Emission Total
- Clean Technology
- Renewable Energy Use
- Sustainable Supply Chain
- Carbon Intensity
- Renewable Energy Use
- Supplier Environmental Programmes
- Sustainable Products & Services
- Greenhouse Gas Emissions
- Regulatory Opportunities Sources
- Climate related Opp. Sources
- Regulatory Risks Sources
- Climate related Risks Sources
- Opportunities in Clean Tech
- Energy Efficiency
- Opportunities Renewable Energy
- Carbon Emissions
- Regulatory Compliance

## Public Perception Subscore

- Emission Reduction Score
- Resource Reduction Score
- Environmental Score
- Emissions Score
- Overall ESG Score
- Scope of GHG Reporting
- Disclosure Score
- Performance Band
- Climate Change Controversies
- Industry-adjusted Overall Score

## Adaptability Subscore

- Emission Reduction Prod. Process
- Climate Change Risks/Opportunities
- Energy Efficiency Policy
- Emission Reduction Target/Objective
- Energy Efficiency Target/Objective
- Environmental Investments Initiatives
- Environmental Expenditures Investment
- Environmental Expenditures
- Environmental Partnerships
- Environmental Provisions
- Policy Emissions
- Environmental R&D Expenditures
- Innovation Score
- Renewable Energy Programmes
- Environmental Management System
- Air Emissions Programmes
- Environmental Policy
- Green Procurement Policy
- Regulatory Opportunities
- Climate related Opportunities
- Regulatory Risks
- Climate related Risks
- Emission Reduction Target
- Carbon Emissions Score
- Climate Change Theme Score
- Environmental Pillar Score

## Carbon Risk Score (CRS)

- Selection and assignment of Carbon Risk proxies evaluated by a workshop with climate and finance experts

# Descriptive Statistics

## Low correlations between factors

Factor	Mean excess			Correlations				
	return (%)	SD (%)	T-stat.	<i>BMG</i>	<i>er<sub>M</sub></i>	<i>SMB</i>	<i>HML</i>	<i>WML</i>
<i>BMG</i>	-0.25	1.95	-1.17	1.00				
<i>er<sub>M</sub></i>	0.76	4.02	1.74	0.09	1.00			
<i>SMB</i>	0.06	1.39	0.37	0.20	-0.02	1.00		
<i>HML</i>	0.00	1.68	-0.02	0.27	0.19	-0.06	1.00	
<i>WML</i>	0.57	2.53	2.06	-0.24	-0.20	0.00	-0.41	1.00

## Test of factor relevance in *CRS* sample

Carbon Risk Factor shows **expected signs on a significant basis** and **significant increase in adj. R<sup>2</sup>**

5F model including <i>BMG</i>								
	<i>Alpha</i>	<i>erm<sub>M</sub></i>	<i>SMB</i>	<i>HML</i>	<i>WML</i>	<i>BMG</i>	adj. R <sup>2</sup> (%)	Δ adj. R <sup>2</sup> (%) <sup>1)</sup>
Low <i>CRS</i>	-0.001	1.143***	0.142*	-0.062	-0.159***	-0.328***	95.32	1.60***
	2	0.001	1.012***	0.105	0.018	-0.078*	95.61	1.58***
	3	0.002**	1.028***	0.169**	-0.055	-0.116**	94.59	0.32**
	4	0.001	1.046***	0.171**	-0.023	-0.077	-0.096	94.06
	5	0.000	1.011***	0.142	0.006	-0.101*	-0.015	93.55
	6	0.001	0.945***	0.200**	0.060	-0.094*	0.127**	93.99
	7	0.001	0.991***	0.212**	-0.007	-0.074	0.415***	94.06
	8	0.000	1.084***	0.226**	0.022	-0.195***	0.448***	94.45
	9	-0.003**	1.078***	0.085	-0.035	-0.072	0.688***	93.06
	High <i>CRS</i>	-0.001	1.092***	0.214*	-0.008	-0.165**	1.019***	91.52

<sup>1)</sup> Significance levels are based on an F-test for nested models

## Full sample

- **39,537 firms in 111 countries**
- **2010 to 2016**
- Financial data from **Morningstar Direct** and **Thomson Reuters Datastream**

# Comparison of common factor models in the full sample

***BMG* enhances explanatory power at a larger extent than common risk factors**

## Single stock regressions

	Avg. $\Delta$ adj. R <sup>2</sup> (%)	F-test at sign. level 5% (%)
(1) Fama/French vs. Carhart	0.10	5.98
(2) Fama/French vs. Fama/French + <i>BMG</i>	0.71	11.55
(3) CAPM vs. Fama/French	1.02	11.49
(4) CAPM vs. CAPM + <i>BMG</i>	0.84	12.05
(5) Carhart vs. Carhart + Pastor/Stambaugh factor	0.01	5.01
(6) Carhart vs. Carhart + <i>BMG</i>	0.69	11.55

# Robustness Asset Pricing

- **Equal-weighted and value-weighted** factor calculations ✓
- **Different factor models** (Fama/French, 1993; Carhart, 1997; Asness/Frazzini, 2013; Frazzini/Pedersen, 2013; Fama/French, 2015; Hou/Xue/Zhang, 2015) ✓
- **Democratic orthogonalization** of factors (Klein/Chow, 2013) ✓
- **Decomposition of R<sup>2</sup>** (Klein/Chow, 2013) ✓
- **Factor spanning tests and split sample tests** for deciles-table (Fama/French, 1993) ✓
- Various **test asset portfolios** and **combined test asset portfolios** (size/value, size/profitability, size/investment, sector portfolios, industry portfolios) (Lewellen/Nagel/Shanken, 2010) ✓
- **Further Asset Pricing tests** (Gibbons/Ross/Shanken, 1989; Fama/French, 2016; Barillas/Shanken, 2017, Fama/French, 2017; Hou/Xue/Zhang, 2017) ✓

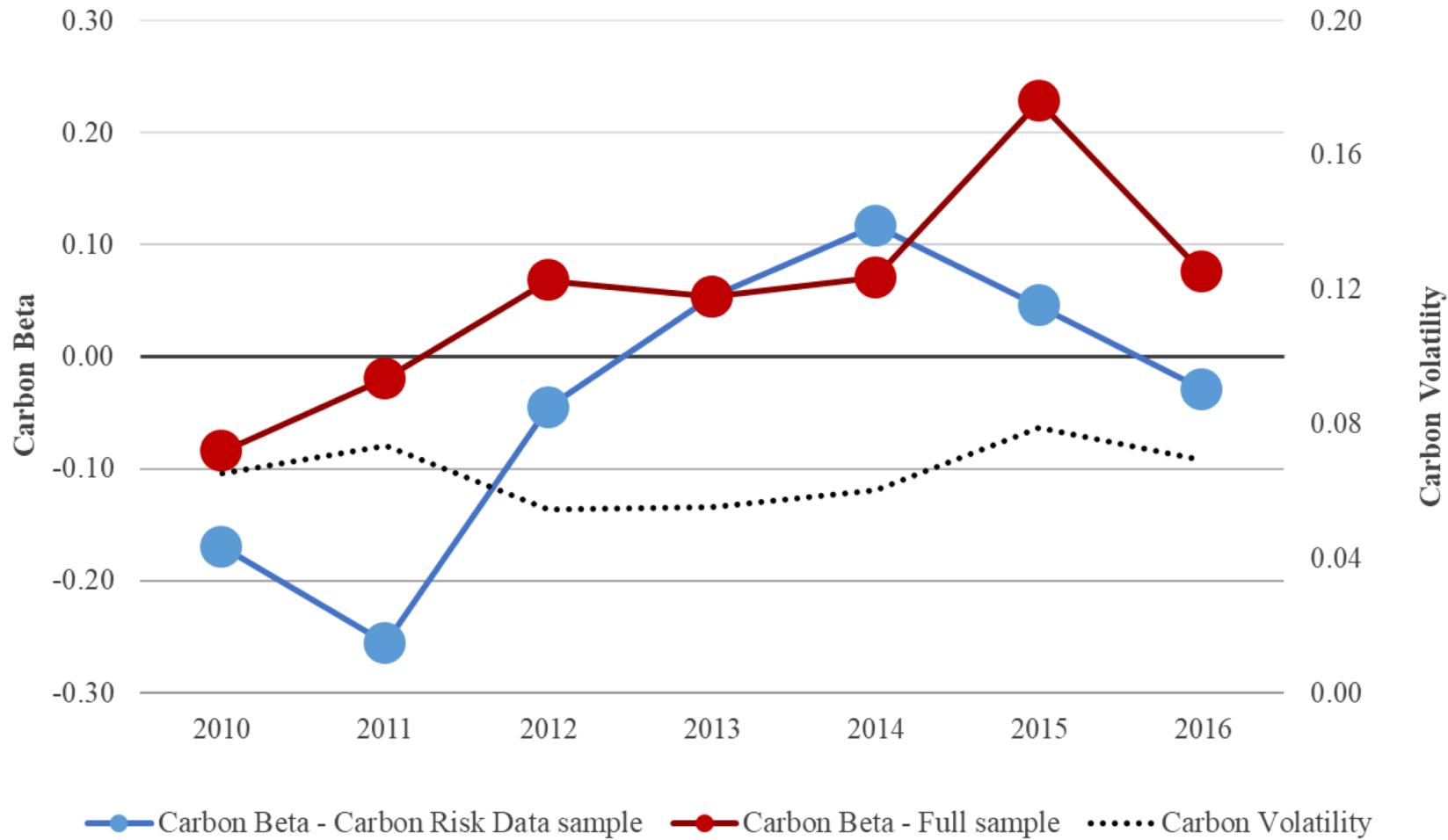
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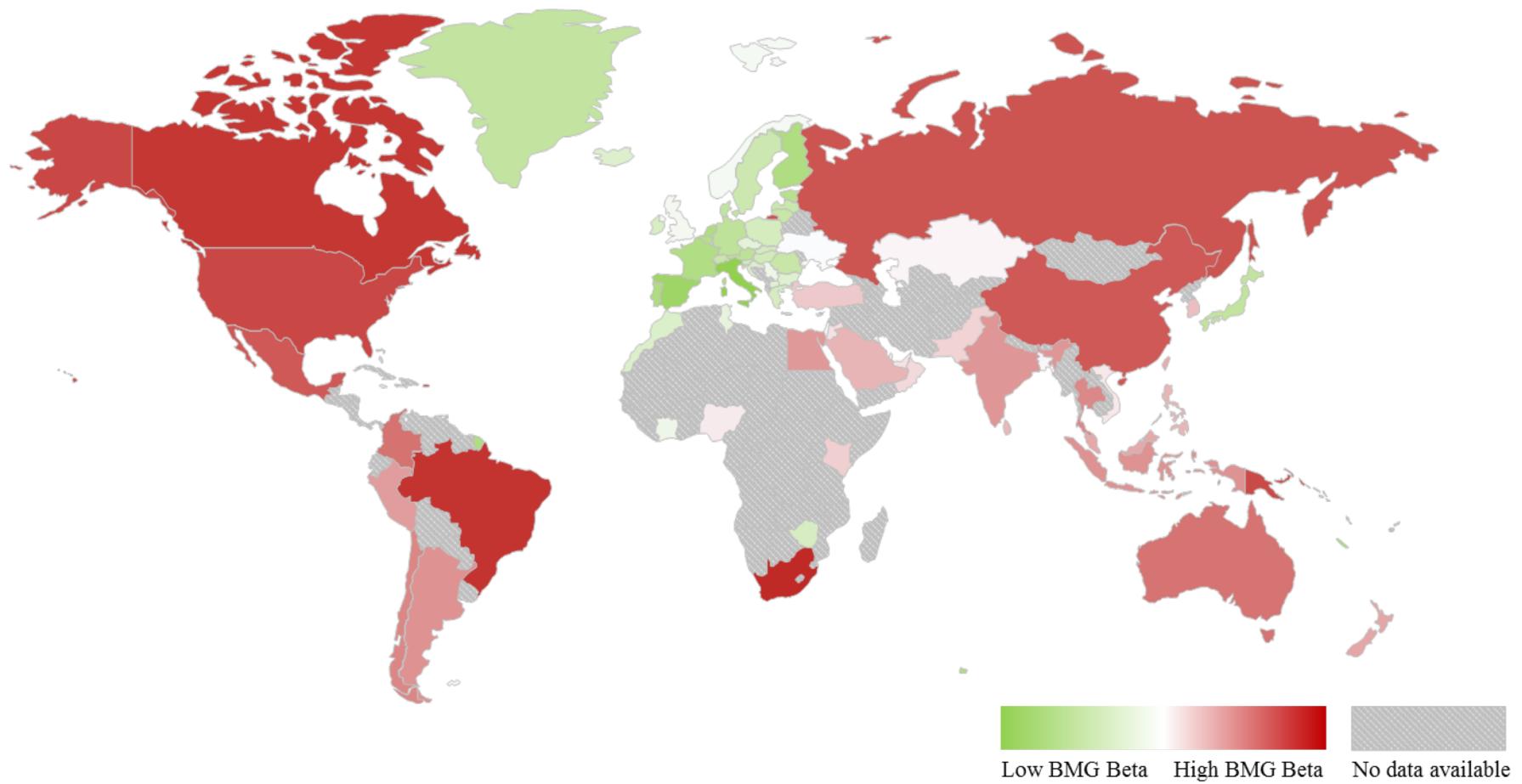
## Carbon Beta over time

**Carbon Beta is increasing over time from 2010 to 2016**



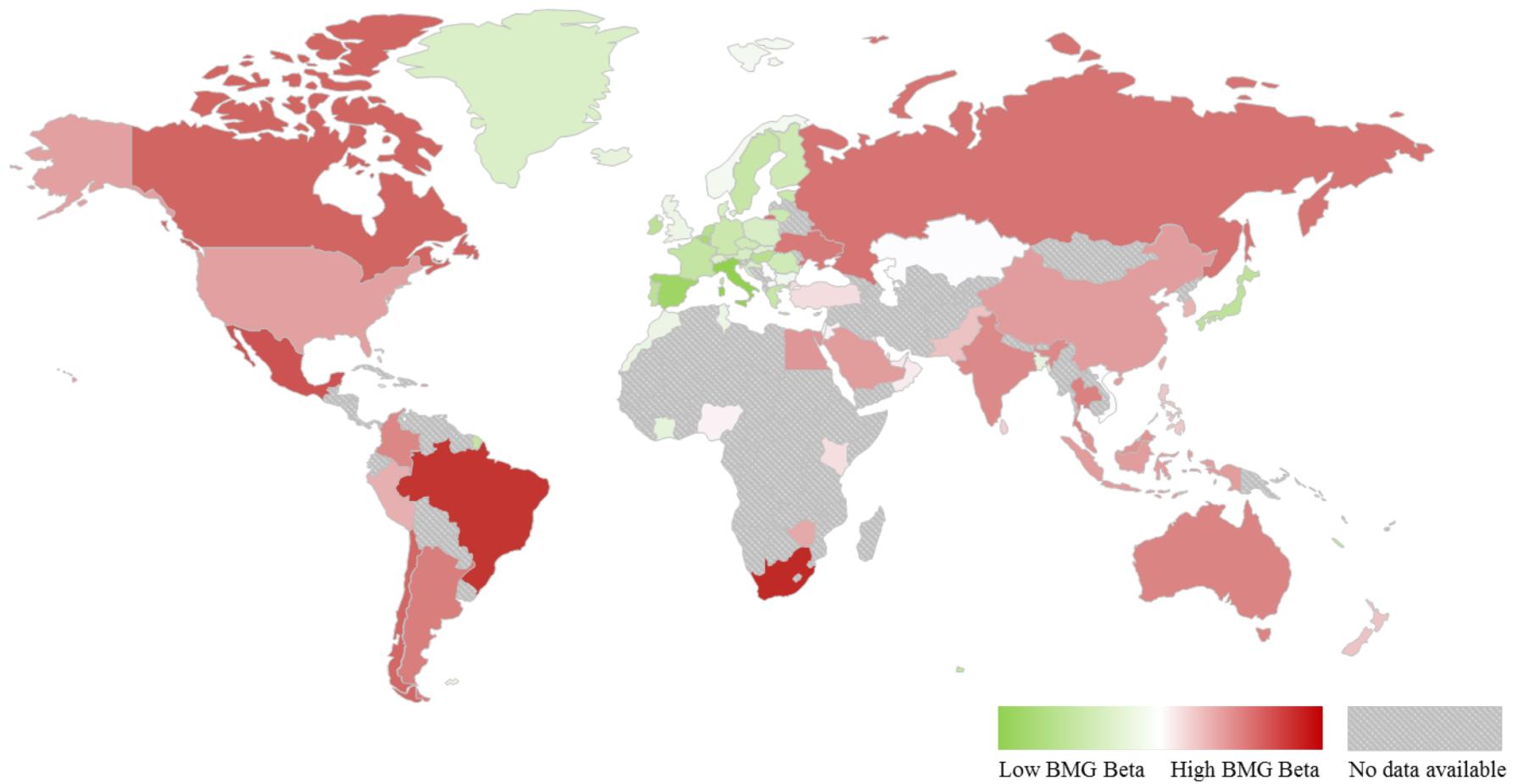
## Carbon Beta landscape

**Carbon Betas are widely distributed across the world with different country exposures**



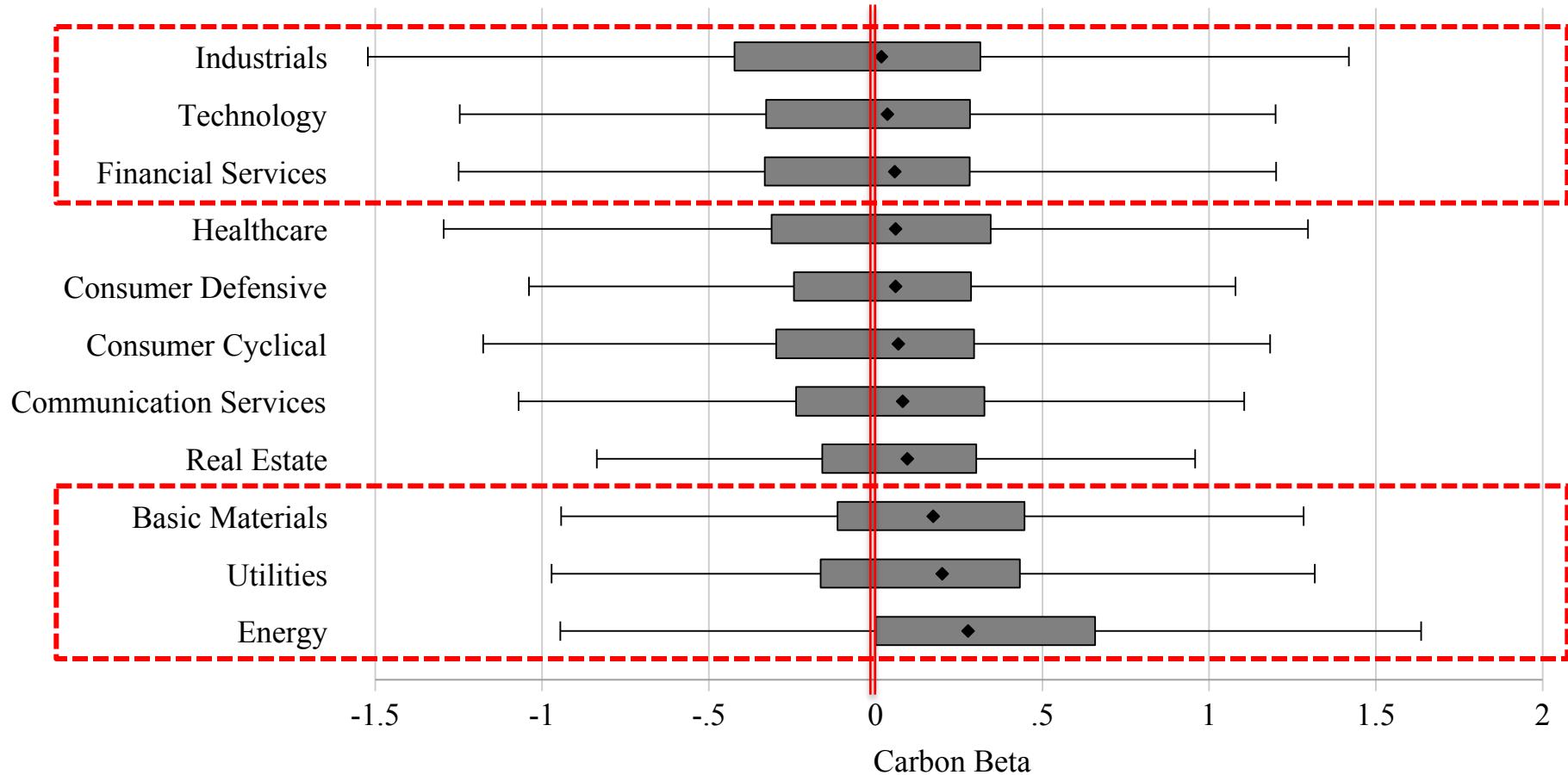
## Carbon Beta in the financial industry

The **financial industry** has a **direct role** to play via the **financing of firms**



## Carbon Beta industry breakdown

**Carbon Betas are high in the Energy the Utilities and the Basic Materials sector and low in the Industrials, Technology and Financial Services sector**



# Managing Carbon Beta in industry portfolios

**Portfolio manager can manage Carbon Beta exposures without sacrificing industry preferences or performance effects**

## 11 Industry Portfolios

	Carbon Beta	Sharpe Ratio	Excess Return	Standard Deviation
All firms	0.07	0.16	0.05	0.37
Worst-in-class	0.55	0.17	0.06	0.38
Best-in-class	-0.39	0.14	0.05	0.36
Best-worst	-0.93***	-0.03	-0.01	-0.02***

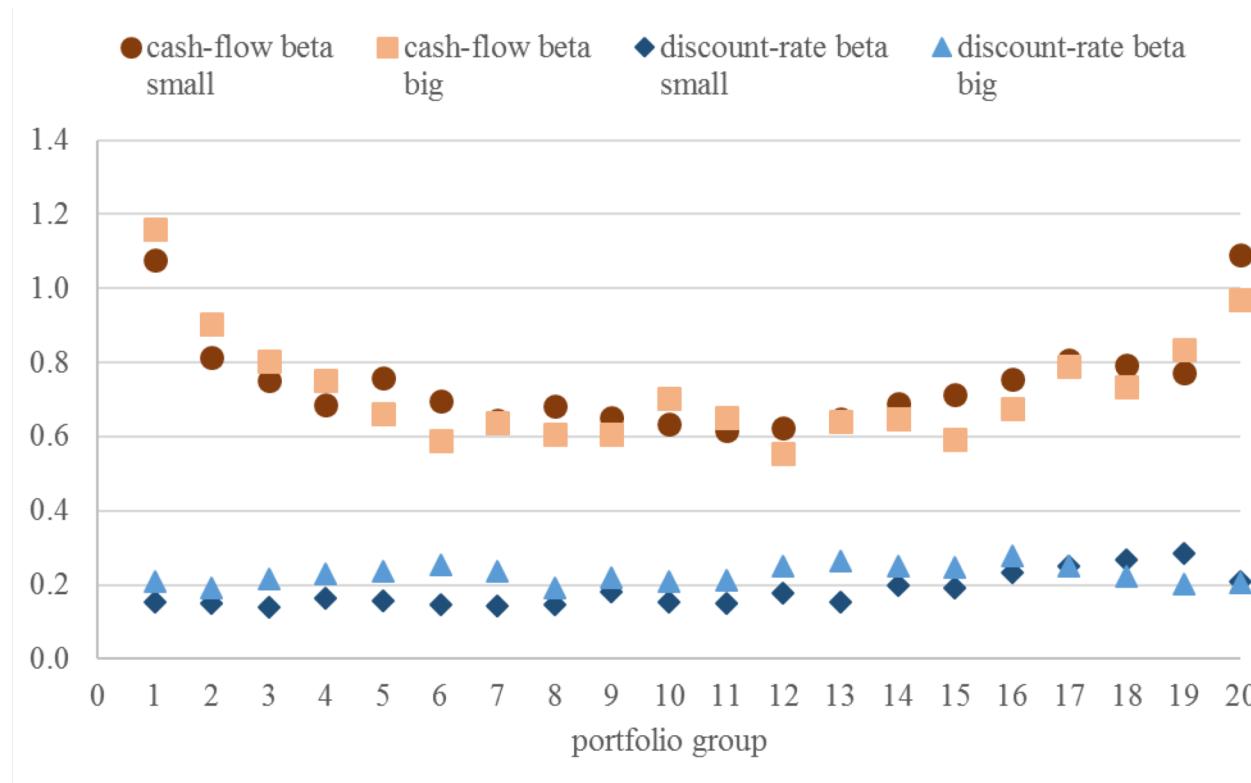
# Explaining Carbon Betas in the full sample

**Carbon Betas** are related to fundamentals such as **R&D** and **PPE**

	(1)	(2)	(3)	(4)
R&D expenditures	-0.020***	-0.020***	-0.021***	-0.021***
PPE assets	0.036***	0.0084**	0.035***	0.036***
Leverage ratio	0.015***	-0.0075***	0.015***	0.015***
Book-to-market ratio	-0.16***	-0.0037	-0.16***	-0.15***
Cash	-0.040***	-0.0069***	-0.040***	-0.038***
Return on assets	-0.0033	-0.011***	-0.0043	-0.00019
Net sales	-0.022***	0.0030	-0.020***	-0.021***
Country fixed effects	no	yes	no	no
Industry fixed effects	no	no	yes	no
Time fixed effects	no	no	no	yes
R <sup>2</sup>	0.12	0.39	0.12	0.15
Within R <sup>2</sup>		0.0071	0.12	0.11
N	30,664	30,663	30,664	30,664

## Beta decomposition of Carbon Beta portfolios

**Cash-flow beta** is distinctively **higher** than the **discount-rate beta** and **extreme portfolios**, i.e. green and brown firms, have **higher cash-flow betas**



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## Main contribution

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### Constructing a Carbon Risk Factor and measure Carbon Risk

- **CRS** is able to **identify firms** with **high potential carbon risk**
- Carbon Risk Factor (**BMG**) **enhances explanatory power** of common factor models
- **Carbon Beta** is an applicable **measure for carbon risk**

### Applications of the Carbon Beta

- **Carbon Betas** can be described over **time, regions and industries**
- **Portfolio managers and investors** can directly manage carbon risk in their portfolios without neglecting preferences or having performance effects
- **Analysts and regulators** can understand the carbon risk of firms