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CLIMATE CHANGE AND THE FINANCIAL MARKET

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Abstract

Nel contesto finanziario attuale, la comprensione e la gestione del rischio sono essenziali per le decisioni di investimento. Il rischio, in questo ambito, rappresenta l'incertezza legata al rendimento futuro di un investimento e la possibilità di perdite finanziarie.
Un elemento emergente e di crescente rilevanza è il rischio climatico, che, insieme alle dinamiche di mercato tradizionali, influenza significativamente le performance degli investimenti e il contesto socioeconomico globale. La consapevolezza dell'impatto del cambiamento climatico sulle attività economiche ha evidenziato le relative implicazioni finanziarie, richiedendo una riflessione strategica e approfondita negli investimenti.
Storicamente, la letteratura ha cercato di determinare se esiste una ricompensa per la virtù aziendale, spingendosi dall'introduzione degli indici di reputazione per la misurazione della RSI, alla sostituzione dei modelli statici, considerati allora guida per la competizione industriale, con l'innovazione.
Questa tesi si propone di delineare il cambiamento climatico e le sue implicazioni nel settore finanziario. Attualmente, gli investitori si affidano alle agenzie di rating che valutano la salute complessiva di un'azienda, considerando anche i fattori ESG. Tuttavia, questi fattori e i relativi rating variano tra le diverse agenzie a causa delle differenti metodologie adottate.
Viene esaminato uno studio precedente riguardante i fattori ESG, la loro influenza sulle decisioni di investimento e la variabilità dei rating di tre principali agenzie.
Successivamente, ci concentriamo su uno studio del CefES che esamina la considerazione del rischio climatico nel mercato europeo. Tramite una dettagliata metodologia, definiamo le determinanti affinché un'azienda venga considerata "green" o meno. Analizziamo la costruzione, da parte degli autori, di un indicatore di verdezza e trasparenza per esaminare l'impegno dell'impresa verso la mitigazione del cambiamento climatico. Proponendo un insieme di portafogli, dal più "green" e trasparente, a quello "brown", gli autori calcolano poi la potenziale stima del premio di rischio associato, il Greenium, per le aziende più ecologiche e trasparenti. Tramite l'implementazione di tre scenari diversi, basati su tre diverse allocazioni di portafoglio delle maggiori istituzioni europee, vengono analizzate le perdite potenziali, in uno scenario estremo ma plausibile, dove le aziende più rispettose dell'ambiente superano quelle meno ecologiche, dimostrando che una leggera differenziazione nell'allocazione attuale di portafoglio non è sufficiente per limitare le perdite.
Infine, cerchiamo di delineare un insieme di politiche che potrebbero rendere la transizione ad un'economia, a basso impatto, ragionata, incrementale e quindi meno traumatica.

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INTRODUCTION

In today's rapidly evolving financial landscape, understanding and managing risk play a central role in investment decisions. In the context of investment decisions, "risk" represents the uncertainty associated with the future return of an investment and the possibility of financial loss. Investors face various types of risks, including Market Risk, Credit Risk, Interest Rate Risk, Liquidity Risk, Inflation Risk, Political and Geopolitical Risk, and Currency Risk.

An emerging and increasingly significant element is Climate Risk, which, along with traditional market dynamics, significantly influences investment performance and the overall current socio-economic landscape. The awareness of climate change's impact on various economic activities has brought attention to the related financial implications, requiring deep reflection and strategic consideration in investments.

Historically, the literature has sought to determine whether there is a reward for a company's virtue, focusing on corporate performance.

The seminal work by Bragdon and Marlin in 1972 marked the beginning of several in this area, using reputation indices to measure Corporate Social Responsibility (CSR). These indices evaluated companies based on their social performance in various dimensions.

In 1995, Porter and Van Der Linde challenged the view that environmental goals and industrial competitiveness are a trade-off between social benefits and private costs. They argued that this perspective is flawed because industrial competition is driven by innovation rather than static models. Competitive firms excel in productivity through continuous innovation, achieving superior value rather than just lower costs. Well-designed environmental regulations can stimulate innovation, offsetting compliance costs and providing absolute advantages. Effective policy should focus on reducing the trade-off between competitiveness and the environment, emphasizing that regulation can drive innovation, reduce investment uncertainty, and level the playing field during the transition to innovative solutions.

Strict regulations can promote greater innovation and innovative offsets than milder regulations, which often result in incremental changes. Stricter regulations require fundamental changes, such as product and process reconfigurations, which deepen compliance and stimulate corporate focus on emissions. Although compliance costs may rise, the potential for innovative offsets can increase even faster.

The alignment of resource productivity improvement with environmental and competitive goals highlights the private costs companies bear due to pollution. This approach treats pollution as an unproductive use of resources.
The criticism is that regulation might stifle other productive investments or innovation avenues. However, given the incomplete information and limited corporate focus on environmental innovation, this area may not have been fully explored. Effective environmental regulations must maximize innovation opportunities, promote continuous improvement, and minimize uncertainty.

THESIS CONTENTS AND STRUCTURE

This thesis aims to translate what climate change is, defining the current implications in the financial world.
Currently, investors have to rely on rating agencies, entities that rate the overall health of a certain firm, focusing also on ESG factors. However, ESG factors and ratings differ between different agencies due to different rating methodologies. We examine a previous study regarding what ESG factors are, their influence on investment decisions, analyzing the variability in ratings of three big players.
Then, we analyze a CefES study that investigates if Climate Risk is considered in the European market and the potential estimation of an attached risk premium, the Greenium, to more environmentally friendly and transparent firms. In order to do so, the authors extend the definition of "green" beyond a small set of ecological companies, including companies with several green nuances, in terms of energy efficiency and CO2 emissions.
We address the issue of greenwashing, which is the reason why has not yet reached a general agreement on the existence of a green factor, by using corporate disclosures and considering their transparency.
We focus on the study by Pastor et al. (2021) which investigates the implications of past performance for future returns of green assets, guided by the equilibrium model of Pástor et al. (2021).
Finally, we analyze the potential losses of all institutional sectors derived by an extreme but plausible scenario, offered by the Center for European Studies (CefES), where the most ecological and transparent companies outperform the brown companies. Even if the expected magnitude of these losses is not particularly impressive, no one is safe when it comes to climate risk.

Finally, we try to draw up some potential policy practices and recommendations to smooth the compelling transition.

CHAPTER 1

1.1 CLIMATE CHANGE AND FINANCIAL RISK: TRANSITION RISKS

Mitigating climate change necessitates the rapid decarbonization of the economy due to its ongoing threat to society through altered extreme weather patterns and impacts on critical ecosystems. Projections indicate that catastrophic impacts may occur soon from nonlinear effects leading to tipping points in the Earth system.

The Paris Agreement aims to prevent such consequences by stabilizing temperature increases well below 2°C above pre-industrial levels, aiming to manage negative impacts of climate change, although substantial variability will remain.

To limit global temperature, rise to 1.5°C, the Intergovernmental Panel on Climate Change (IPCC) suggests reducing net carbon emissions to zero by mid-century. Consequently, many governments and sub-national entities are adopting laws for carbon neutrality by or before mid-century.

Achieving rapid decarbonization involves large-scale structural changes, with some sectors needing to expand rapidly, others transforming their technological basis, or shrinking and possibly disappearing. This includes sectors involved in fossil fuel extraction and distribution, as well as those using fossil fuels as a crucial input. While some industries, like power production, have competitive low-carbon alternatives, others, like steel and air travel, are in early development stages, with many firms lacking strategic plans for the low-carbon transition. The current debate on low-carbon transition risks focuses on risks in declining, carbon-intensive sectors, such as asset stranding, the unexpected devaluation of assets on balance sheets.

Such a transformation is expected to have significant financial impacts, sparking a debate about the threats to financial stability from a low-carbon transition.

In analysing transition risks to finance, the low-carbon transition is defined as a structural economic change where certain sectors of the economy expand while others shrink, influenced by deliberate policies, shifting preferences, and ongoing technological advancements. To achieve emissions-reduction targets, low-carbon industries must expand quickly, whereas high-carbon industries must rapidly decline.

Low-carbon transition risks for finance are then identified as the threats to financial stability arising from this specific type of rapid structural change. To conceptually understand this relationship, we refer to literature on financial crises and innovation, viewing innovation as a driver of structural change.

The only theoretical approach that places the interaction between finance and structural change at the forefront is the Schumpeterian one (Semieniuk, Gregor, et al. 2021), which focuses on how financial systems and innovation processes interact and drive economic development.

In Schumpeterian business cycle theory, innovative entrepreneurs introduce new, highly productive technologies. Historical examples include the shift from canals and sailing ships to railways and steamships in the 19th century, the replacement of steam-powered transport by internal combustion engines in the early 20th century, and the recent revolution in data processing through electronics.

The financial sector, particularly banks, plays a crucial role by providing credit to entrepreneurs, enabling them to realize their innovative ideas and establish new industries. Initially, this credit creation leads to economic expansion. However, as sunrise industries become more profitable, they attract financial speculation, potentially leading to an overestimation of their growth potential. This speculation can result in over-indebtedness and defaults when the innovation cluster matures, potentially causing a financial crisis. Examples include the 1929 financial crisis linked to bubbles in radio, electricity, and automobiles, the mid-1800s railway investment booms and the 2001 dotcom bubble.

In Schumpeter's view, the risks primarily originate from sunrise industries. Uncertainty about the prevailing technological design and the scale of industry growth creates potential for speculation and over-investment, often leading to financial manias. While the collapse of speculative bubbles can be exacerbated by the failure of sunset industries, Schumpeter believed that the growth of new industries would generally offset the negative impacts of declining sectors, maintaining systemic economic and financial stability. However, the decline of sunset industries can still lead to significant social issues.

Schumpeterian considered to be critical the role of government policy and social dynamic in technologies' fit.

To meet the Paris Agreement targets, many existing enterprises must significantly change their production processes. A substantial portion of emissions from known fossil fuel reserves must be reduced. This reduction will impact the cash flow of industries that supply or use fossil fuels.

If investors do not anticipate this impact, their assets could depreciate prematurely, leading to "stranding." If this asset stranding is extensive, it could cause financial instability and crises.

Drivers influencing the financial sector can impact it directly by changing expectations about transition costs and regulations, and indirectly through transition costs themselves. These impacts mainly manifest as credit risks and market risks.

From Credit Risk follows the loss of assets and income heightens the risk of debt defaults, leading to an increase in non-performing loans for banks.

A rise in the Credit Risk can reduce a bank's profitability, affect its market valuation, and, if severe, cause a bank run and potential default.

The extent of this impact depends on the level of exposition of the banking system to industries, which is expected to decline due to the low-carbon transition.

Market Risks induce effects on Portfolio, where institutional investors and financial institutions holding assets could experience negative portfolio impacts due to the revaluation of assets triggered by the transition.

Transition costs or expectations might prompt financial analysts to revise future cash flow predictions for carbon-intensive firms, reducing the current value of these assets.

Revaluations might also occur due to new valuation models applied by analysts, leading to diminished wealth for those holding the devalued assets.

Transition-related risks are gradually being incorporated into growth and asset pricing theories, with specific impact estimates for investors being developed.

The effects on private financial markets extend beyond direct exposure to carbon-intensive sectors due to financial contagion. Financial institutions are highly interconnected.

Many financial assets serve as collateral in short-term repurchase agreements, so a decline in asset prices can lead to liquidity problems.

Financial institutions could be negatively affected by "second-round effects" even without direct exposure to carbon-intensive sectors, due to their interconnected networks.

Asset price declines can trigger fire sales, where companies sell off assets simultaneously to avoid bankruptcy, creating a cycle of falling asset prices and further sell-offs, known as debt-deflation.

The impact of asset revaluations is being explored through emerging research, which the two main approaches are:

Long-term Projections: Studies project transition scenarios to the future, derive economic gains and costs by sector, and translate these into changes in financial asset prices, assuming a smooth resource reallocation process.
Stress Testing: This approach analyses the reaction of asset prices to specific shocks (e.g., changes in consumer preferences) and their impact on financial institution portfolios. We use this approach for understanding the potential losses, due to climate change, in financial markets.

1.2 THE ROLE OF ESG FACTORS

Investors use ESG criteria to evaluate corporate behaviour and predict future financial performance, making it a vital tool for assessing the sustainability of enterprises.
The ESG (Environmental, Social, and Governance) principle is a framework that incorporates three crucial factors—environmental, social, and governance—into investment analysis and decision-making. According to the Principles for Responsible Investment (PRI), responsible investment involves incorporating these ESG factors into investment decisions and active ownership practices.
Environmental Factors assess the impact of a firm on the natural environment, Social Factors examine a company's relationship with its stakeholders and Governance Factors focus on the leadership of a firm, executive pay, audits, internal controls, and shareholder rights.

ESG is an approach aimed at achieving sustainable development by balancing economic, environmental, social, and governance benefits. It seeks long-term value growth through comprehensive and practical governance.
Since its formal introduction in 2004 (Li, Ting-Ting, et al. 2021), ESG principles have been widely adopted in Europe, America, and other developed regions. This adoption has led to the creation of several key components that support ESG:

- ESG Evaluation Systems: Frameworks to assess a company's adherence to ESG criteria.
- ESG Disclosure Standards: Guidelines for companies to report their ESG activities transparently.
- ESG Index Systems: Benchmarks to track the performance of ESG-compliant companies.

As ESG has become mainstream, it has been extensively examined, practiced, and popularized in both practical and academic fields. The interaction between these dimensions is crucial for fostering sustainable development in enterprises.

ESG principles are instrumental in driving the sustainable development of enterprises by integrating environmental, social, and governance considerations into business practices. This comprehensive approach not only aims to improve financial performance but also to enhance social impact and environmental stewardship.

To promote quality improvement in the global economy and society, it is essential to continue researching and refining ESG principles. The paper systematically reviews existing research on ESG and explores future directions for its development, emphasizing its role as a catalyst for sustainable enterprise growth.

The ESG (Environmental, Social, and Governance) performance index (Li, Ting-Ting, et al. 2021) is instrumental in elucidating the connection between sustainable investment and financial outcomes. Scholars have extensively explored the relationship between ESG activities and economic consequences, with particular emphasis on how environmental, social, and governance factors impact corporate performance and value.

Correlation measures the relationship between the movements of two factors. The aim is to understand how the changes of one factor are related to the changes of the other one. In particular, we are interested in understanding the relationship between ESG dimensions and the corporate value. Research by different authors have provided incongruent correlation results: positive correlation, negative correlation, non-linear correlation and indirect correlation.

- Positive Correlation:

1. Environmental and Social Dimensions: Research suggests a positive correlation between ESG activities and corporate value. Studies like Mackey et al. (2007) and Jayachandran et al. (2013) highlight the benefits derived by the integration of environmental and social standards of performance into compensation.
2. Environmental Dimension: While environmental performance positively impacts corporate performance, environmental screening conditions may reduce financial performance (Barnett and Salomon, 2006; Matsumura et al., 2014).
3. Social Dimension: Philanthropic activities positively affect shareholder wealth (Godfrey, 2005), and corporate philanthropy is associated with improved financial performance (Wang and Qian, 2011).

- Negative Correlation:

Some research indicates a negative relationship between ESG activities and economic consequences. For instance, Manchiraju and Rajgopal (2017) found a negative correlation between CSR and value for shareholders.

- Non-Linear Relationship:

Studies like Barnett and Salomon (2006) and Barnett and Salomon (2012) suggest a non-linear relationship between social performance and financial performance. Zhao and Murrell (2016) also note a complex relationship between corporate social performance and financial performance.

- Indirect Relationship:

Surroca et al. (2010) propose that corporate social responsibility indirectly influences financial performance through factors like innovation and reputation. Similarly, Hawn and Ioannou (2016) differentiate between external and internal corporate social responsibility actions in relation to market value.

ESG practices serve as a crucial mechanism for meeting the diverse needs of stakeholders in the pursuit of enterprise sustainability. Not only do they enhance the social standing of companies, but they also act as a competitive advantage in mitigating risks, thus making the role of ESG in risk prevention a focal point of research.

Koh et al. (2014) propose a risk management perspective on ESG, suggesting that social performance can function as an insurance mechanism, particularly beneficial for companies facing higher litigation risks. Mithani (2017) highlights the strategic importance of philanthropy for multinational companies post disasters, while Zhou and Wang (2020) emphasize the role of corporate social responsibilities in buffering negative spillover effects on subsidiaries' reputations.

Previous works investigate the impact of Corporate Environmental, Social and Governance Initiative on shareholders:

- Environmental (E) Dimension:

Flammer (2013) explores the market response to environmental social responsibility, noting that eco-friendly initiatives not only attract positive shareholder responses but also provide insurance against eco-harmful events, minimizing losses.

- Social (S) Dimension:

Shiu and Yang (2017) find that corporate social responsibility can act as insurance against negative events impacting stock and bond prices, particularly during the first negative event. Jia et al. (2020) examine how corporate social responsibility investment serves as a protective mechanism against external risks, reducing short positions and addressing short-selling threats.

- Governance (G) Dimension:

Gao et al. (2014) uncover a negative relationship between social good and executive insider trading, indicating the importance of governance in corporate social responsibility. Flammer and Kacperczyk (2019) demonstrate how employing corporate social responsibility strategically can deter knowledge encroachment from competitors and prevent valuable information leakage. Bertrand et al. (2021) focus on CEOs' role in improving corporate social responsibility practices to counteract biases when local companies are led by foreign CEOs.

In summary, ESG practices extend beyond mere social responsibility, serving as vital risk management tools across environmental, social, and governance dimensions, ultimately contributing to enterprise sustainability and resilience in a competitive landscape.

CHAPTER 2

2.1 ESG RATING AGENCIES

Socially responsible investing is an investing strategy to generate social and financial changes. Through the mandatory disclosure of ESG ratings, companies are facing greater pressure to be socially responsible (Shrivastava and Hart, 1995). For an effective ESG management practice, there should be transparency in evaluation techniques and comparable ratings methods. The disparity in ESG ratings among firms can be attributed to the absence of standardized evaluation criteria. Various agencies assess ESG performance differently, relying on distinct assumptions, interpretations of scope, measures, and weighting factors. This lack of uniformity leads to significant inconsistencies in ratings. Moreover, the absence of a common theory and comparability further exacerbates rating discrepancies, especially as more agencies publish ESG ratings. Consequently, comparing ESG data across agencies becomes challenging. While the disclosure of ESG ratings aims to reduce information asymmetry and facilitate socially responsible investing (SRI), disagreements in ESG ratings suggest a lack of information flow between evaluation agencies, target firms, and investors. This discrepancy may undermine the effectiveness of SRI, discourage investor participation, and potentially harm economic performance.

2.2 DIFFERENT ESG RATINGS AGENCIES COMPARISON

For having evidence of a concrete comparison between different ESG ratings of different agencies, we analyse the paper of Dorfleitner (see below) which investigates what the main divergences in ESG ratings of three big agencies are: the ASSET4 database of Thomson Reuters' Datastream, the KLD ratings by MSCI ESG STATS (Statistical Tool for Analyzing Trends in Social and Environmental Performance) and the ESG data set of Bloomberg Sustainability.

To compare and analyze ratings, authors need to understand the different rating sources and their methods. Rating agencies define and measure CSR performance in various ways. For each agency there're different valuation approaches and different ESG (environmental, social, and governance) data:

- ASSET4 began assessing the ESG performance of about 1000 companies in 2002, and by 2014, it covered over 4300 companies worldwide, including those in major indices like S&P 500, Russell 1000, and MSCI World Index. ASSET4 offers an additional economic dimension to reflect a company's capability for sustainable growth and shareholder value. Rating agencies use positive and negative indicators from reports and public information to score non-financial performance. Unlike financial ratings, there is no consensus on how to measure CSR, making it essential to examine methods and underlying data;
- KLD started in 1991, covering the 500 biggest US companies and stocks in the Domini 400 Social Index. By 2001, it included all firms in the Russell 1000 and by 2003, the largest 3000 US companies. KLD's rating model uses binary indicators for seven ESG-related groups: environmental, governance and social topics (community, human rights, employee relations, diversity, and customers). MSCI ESG Research classifies ESG information into strength indicators (beneficial aspects) and concerns (negative impacts). KLD includes business involvement data for controversial industries. The

number of indicators increased from 71 in 2002 to 80 from 2007 to 2009 but dropped to 62 in 2010 due to consolidation, rising again to 70 by 2012. KLD does not provide a total ESG score, only binary indicators;

- Bloomberg provides ESG data for about 4100 firms in 52 countries, based on research of the 20,000 most actively traded public companies. Bloomberg's scoring model includes over 100 data points related to ESG. Its Total ESG Disclosure Score is tailored to industry-relevant data points, ranging from 0.1 to 100. These scores reflect a company's transparency in non-financial reporting, indicating sustainability levels similar to ASSET4 and KLD.

For the analysis, authors used complete data from KLD, ASSET4 and the Bloomberg ESG scores for companies also rated by ASSET4. Our total sample spans 2002 to 2012 and includes 8561 corporations.

To ensure comparability, authors aggregate KLD indicators using a method from Kempf and Osthoff (2007), transforming concerns into strengths and normalizing scores to 0-100. This method accounts for indicator changes over time, with ESG representing the weighted average of all indicators, and Overall Score (ESG*) including KLD's controversial industry ratings. While different ESG rating institutions aim to measure the Corporate Social Responsibility (CSR), their valuation approaches and underlying data differ, affecting information depth. All three agencies—Bloomberg, KLD, and ASSET4—define CSP through ESG dimensions. ASSET4 includes an economic dimension covering employee and customer satisfaction, insider trading, financial transparency, and brand value, among other factors. In the environmental dimension, all three providers rate similar issues like emissions and resource reduction, but interpretations differ. Social dimensions account for about half of the data points, evaluating aspects like employment quality and human rights, though the extent varies. Governance scores also vary, with KLD providing the least information compared to others.

Althought the three analysed institutions consider the same overall aspects, there are differences in the used methods and in the CSR appraisal. In particular, differences are related to the level of detail and the consideration of some sustainability aspects.

2.3 ESG LEVEL: DISTRIBUTION AND CORRELATION

To investigate the differences among the three ESG rating approaches, the authors (Dorfleitner, Gregor, Halbritter and Nguyen, 2015) first compare their distributions and descriptive statistics. Figure 1 (see below) illustrates the histograms of total ESG scores and the following sub-criteria: environment score (ENV), social score (SOC), governance score (GOV) and capital corp (ECN) for all rated companies during the observation period. The distributions vary significantly among the three data sets due to differing valuation methods. ASSET4's scores show a bimodal distribution, Bloomberg's scores are right-skewed starting from a low value, and KLD's scores are concentrated between 60 and 80.

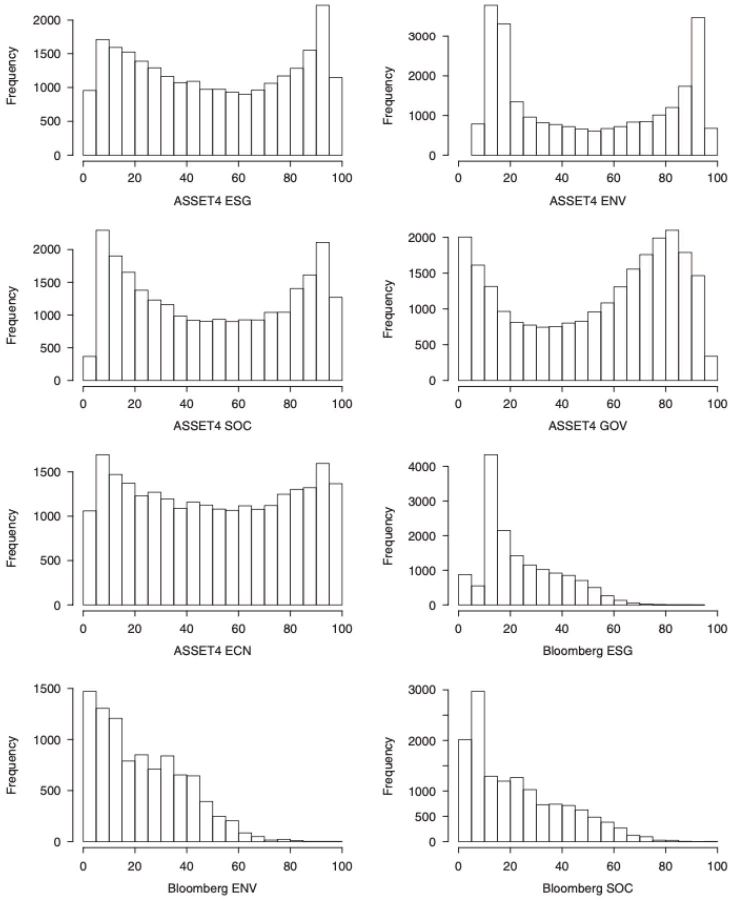

Figure 1: Score histograms.
Notes: This figure presents the histograms for each score type of the three rating agencies ASSET4, Bloomberg and KLD. The histograms include the full panel data set across all companies. The horizontal axis denotes the rating score between 0 and 100, while the vertical axis shows the absolute frequency.

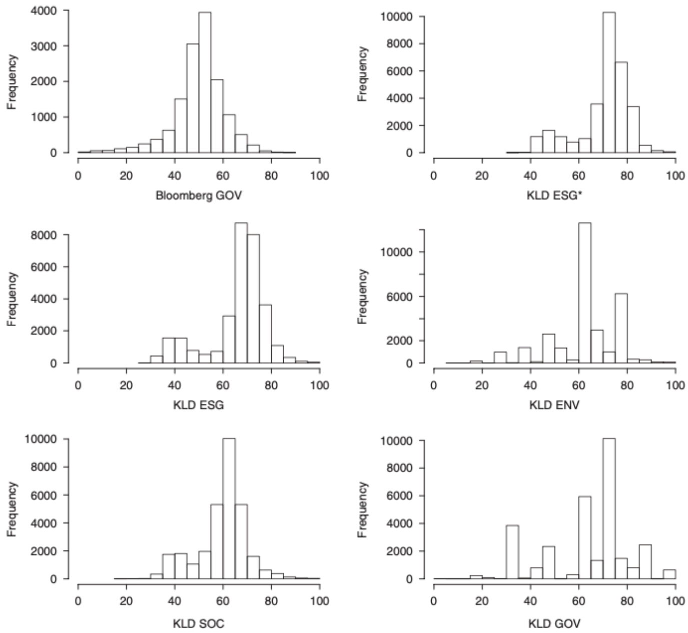

Figure 1: (*Continued*)

Figure 1 available at: Dorfleitner, Gregor, Gerhard Halbritter, and Mai Nguyen. "Measuring the level and risk of corporate responsibility–An empirical comparison of different ESG rating approaches." Journal of Asset Management 16 (2015): 450-466.

It can be useful making a comparison between different agencies average ESG ratings because the rating methods may change over time. Table 2 shows the mean ESG scores of all rated firms averaged over the observation period, revealing no substantial differences between full sample analysis and averaged company scores. However, ASSET4 data exhibits the highest variability, reflected in higher standard deviations, while KLD shows the lowest variability due to its fewer binary indicators.

Table 2: Descriptive statistics: Cross-sectional data

	n	*Mean*	*SD*	*Skew*	*Kurt*	*Min*	*0.25*	*Med*	*0.75*	*Max*
ASSET4										
ESG	4356	44.25	27.14	0.24	1.83	3.11	20.57	41.07	67.56	97.44
ENV	4356	44.07	28.14	0.39	1.70	10.10	17.03	37.82	69.80	96.59
SOC	4356	44.98	27.87	0.27	1.73	4.14	19.37	40.90	70.23	97.15
GOV	4356	47.97	27.99	−0.25	1.64	1.53	20.46	54.08	72.74	95.28
ECN	4356	45.67	24.77	0.11	1.99	1.46	25.05	45.02	65.41	98.01
Bloomberg										
ESG	3411	21.33	13.36	0.85	3.14	0.83	12.54	16.87	29.92	70.91
ENV	2277	20.14	14.56	0.72	2.76	0.78	7.44	16.96	30.36	75.45
SOC	3192	20.77	16.09	0.99	3.11	3.13	7.81	15.44	30.70	80.48
GOV	3113	48.41	9.88	−1.26	6.10	3.57	44.90	50.00	53.57	76.49
KLD										
ESG	5323	66.42	8.38	−0.70	4.22	34.23	62.34	66.74	72.09	98.60
ESG*	5323	70.47	7.36	−0.66	4.12	42.63	66.81	70.67	75.51	98.77
ENV	5323	64.02	9.46	−0.53	4.00	18.18	59.07	63.64	70.57	100.00
SOC	5323	59.14	7.34	−0.16	4.58	32.14	55.24	59.54	63.47	94.71
GOV	5323	65.11	10.86	−0.42	4.04	16.67	59.92	65.22	71.61	100.00

Notes: This table presents the descriptive statistics of the mean ESG scores of all available rated companies averaged over the observation period. It shows the total number of observations, the mean, the standard deviation, the skewness, the kurtosis, the minimum, the quartiles and the maximum of the averaged scores over the available times series of each rated company.

Table 2 available at: Dorfleitner, Gregor, Gerhard Halbritter, and Mai Nguyen. "Measuring the level and risk of corporate responsibility–An empirical comparison of different ESG rating approaches." Journal of Asset Management 16 (2015): 450-466.

To assess year-to-year variability, authors compute the standard deviations, and the z-scoring normalization for ASSET4's scores, of yearly average scores for each provider. ASSET4's standard deviations are between 1.26 and 2.29, compared to Bloomberg's 2.71 to 6.26 and KLD's 8.03 to 12.51.

High standard deviations may indicate changes in valuation approaches or fluctuations in CSP over time. KLD's higher deviations are partly due to changes in indicators and rating methodology in 2010.

An interesting study point regards understanding if good or poor CSP is rated similarly by the three sources. To do so, author generate sub-samples for companies rated by all three and rank their scores within ASSET4, Bloomberg, and KLD quartiles based on market capitalization (large, medium, small). Results show that large companies generally receive better scores, aligning with findings from Humphrey et al. (2011) on ESG impacts on financial performance and risk.

The last relevant task is comparing quartile groups across the three rating agencies, calculating the percentage of companies assigned to the same quartile. Results reveals that ASSET4 and Bloomberg have the highest overlap, while Bloomberg and KLD show the least correlation.

To understand the convergence of ESG ratings, they determine correlations between scores using panel data, focusing on combinations from the same provider or sub-criterion.

Total ESG scores within each provider show high correlation with their sub-scores, ranging from 0.41 to 0.93.

Comparing ESG scores from different sources, ASSET4 and Bloomberg exhibit the highest correlations, particularly in total scores, with sub-criteria correlations between 0.47 and 0.60. KLD shows weak correlations with ASSET4 and Bloomberg, especially in environmental scores, consistent with findings by Semenova and Hassel (2014) and Chatterji et al. (2015).

In summary, the three rating approaches yield distinct results. The levels differ, and correlation analysis indicates that differences cannot be explained by simple linear transformations. Thus, ESG scores from different providers do not largely coincide and are not directly comparable.

2.4 THE IMPACT OF DIVERGENT ESG RATINGS ON THE MARKET

To assess the impact of divergent ESG ratings on the market, a study analyses Korean stocks on the KOSPI and KOSDAQ from 2018 to 2021 (Li, Ting-Ting, et al. 2021).

Firms with ratings from KCGS and MSCI are considered, and their ratings are converted into scores for making a comparison. The difference between these scores is then used as a proxy for ESG disagreement. The study aims to investigate how such rating differences affect information asymmetry, corporate value, trading volume, and investor behaviour.

Analysts serve as source of information for investors that can affect corporate value. However, when there's a larger number of analysts, it can result in different opinions about a company. Literature presents conflicting views on how divergent opinions affect stock prices. We consider two cases: the risk-based hypothesis and the optimism-bias hypothesis.

According to the risk-based hypothesis, investors face increased risk due to divergent opinions and this view suggests that divergent opinions lead to a positive risk premium and affect stock prices in a positive way.

Indeed, the optimism-bias hypothesis claims that divergent opinions may result in lower expected returns, because pessimistic investors may not participate in the market. The last scenario could lead to higher stock return volatility and lower stock returns.

Empirical studies examining split ESG (Environmental, Social, Governance) ratings and stock prices suggest that average ESG ratings are negatively associated with future stock performance, particularly for stocks with low ESG disagreement. However, there's evidence that disagreement in ESG environmental dimension ratings is positively linked to stock returns, then a risk premium for higher disagreement firms. It could lead to higher market premium, stock lower demand, and increased stock volatility and trading volume.

The information asymmetry from split ESG ratings can affects the cost and quality of information and the noise in risky investments.

Li, Ting-Ting et al. (2021), examining the relationship between ESG ratings and information asymmetry, corporate value and trading behaviour, find that split ESG ratings negatively affect corporate value, therefore, it agrees with the optimism-bias hypothesis because higher ESG differences are related to an increase in volatility and decrease in stock price (Miller, 1977). ESG divergence affects also institution investors demand for firms in a negative way.

The results indicate that differing ESG ratings increase risk and hinder investment.

Regulatory efforts would improve SRI by institutional investors and companies would participate in the management of ESG effectively.

Furthermore, firms' voluntary disclosure can reduce the spread in firms' ESG ratings.

The impact of split ESG ratings is analysed In Table 4, Panel A. A split ESG rating means a lack of the firm information flow between the rating agency, firm and investor.

	(1) Vola	(2) IVol2	(3) IVol3	(4) IVol4	(5) Vola	(6) IVol2	(7) IVol3	(8) IVol4
Panel A. Industry and Year-Fixed effect								
D_Split	0.102*	0.105**	0.097*	0.101**				
	(1.68)	(2.02)	(1.93)	(2.03)				
Abs_Split					0.102*	0.101**	0.088*	0.092*
					(1.79)	(2.04)	(1.84)	(1.93)
Rating	−0.016	−0.045	−0.040	−0.029	−0.017	−0.046	−0.040	−0.030
	(−0.16)	(−0.54)	(−0.48)	(−0.35)	(−0.18)	(−0.55)	(−0.49)	(−0.36)
Size	−0.144***	−0.173***	−0.175***	−0.181***	−0.1440***	−0.143***	−0.172***	−0.174***
	(−4.43)	(−5.92)	(−6.10)	(−6.35)	(−4.40)	(−5.85)	(−6.02)	(−6.26)
MB	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.21)	(0.19)	(0.23)	(0.02)	(0.21)	(0.19)	(0.22)	(0.01)
LEV	0.001	0.001	0.002	0.002	0.001	0.001	0.002	0.002
	(0.32)	(0.54)	(0.81)	(0.87)	(0.30)	(0.51)	(0.80)	(0.85)
ROA	−0.014	−0.011	−0.015*	−0.015*	−0.014	−0.010	−0.014*	−0.015*
	(−1.61)	(−1.30)	(−1.85)	(−1.90)	(−1.54)	(−1.23)	(−1.78)	(−1.82)
Own	−0.003	−0.002	−0.001	−0.001	−0.003	−0.002	−0.001	−0.001
	(−0.84)	(−0.56)	(−0.45)	(−0.41)	(−0.89)	(−0.61)	(−0.50)	(−0.46)
For	−0.007***	−0.005**	−0.004*	−0.003*	−0.007***	−0.005**	−0.004*	−0.004*
	(−3.16)	(−2.11)	(−1.87)	(−1.70)	(−3.31)	(−2.20)	(−1.95)	(−1.79)
FCF	0.004	0.005	0.007	0.006	0.004	0.005	0.007	0.006
	(0.74)	(0.94)	(1.49)	(1.37)	(0.69)	(0.89)	(1.44)	(1.32)
Constant	5.772***	6.280***	6.243***	6.297***	5.767***	6.277***	6.240***	6.294***
	(5.73)	(7.20)	(7.39)	(7.52)	(5.71)	(7.16)	(7.34)	(7.47)
Ind FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj.R^2	0.674	0.441	0.421	0.411	0.675	0.442	0.420	0.410
N	298	298	298	298	298	298	298	298

(*continued*)

	(1) Vola	(2) IVol2	(3) IVol3	(4) IVol4	(5) Vola	(6) IVol2	(7) IVol3	(8) IVol4
Panel B. Firm and year fixed effect								
D_Split	0.129*	0.126**	0.130**	0.133**				
	(1.99)	(2.31)	(2.49)	(2.57)				
Abs_Split					0.127**	0.123**	0.121**	0.124**
					(2.15)	(2.49)	(2.54)	(2.62)
Constant	13.780	1.638	1.056	2.142	13.545	1.437	0.988	2.060
	(1.65)	(0.21)	(0.14)	(0.27)	(1.62)	(0.18)	(0.13)	(0.26)
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Firm FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Adj.R^2	0.688	0.462	0.439	0.432	0.688	0.462	0.438	0.431
N	298	298	298	298	298	298	298	298

Note(s): This table reports the effect of Split ratings on volatility. We define *D_Split* as the indicator variable that equals 1 if two ESG rating agencies report different ratings, and 0 otherwise; *Abs_Split is the absolute* value of differences in ESG rating score from *MSCI* and *KCGS*. Total volatility (Vola) is the standard deviation of the firm's daily returns for the year. Idiosyncratic volatility (iVol) is the standard deviation of residuals from the asset pricing model, (1) Capital asset pricing model (iVol2), (2) Fama–French three-factor model (iVol3) and (3) Carhart four-factor model (iVol4), respectively. Beta loadings are estimated using each model for the period $t = -260$ days up to $t = -10$ days with a minimum of 100 observations. IVOL is fitted to the daily data for each year. The set of control variables consists of the following firm characteristics: the average value of the ESG score (Rating); the natural log of total assets (Size), leverage (LEV), market to book value (MB); return on assets (ROA); equity ownership held by largest shareholder (Own); the percentage of the firm's shares owned by a foreigner (For) and the free cash flow (FCF). Panel A includes the industry and year fixed effect and Panel B includes the firm and year fixed effect. All standard errors are clustered by firm, and all continuous variables are winsorized at the 1st and 99th percentiles. *T*-statistics are in parentheses. The symbols *, ** and *** indicate significance at the 10, 5 and 1% levels, respectively
Source(s): Tables by authors

Table 4 available at: Kim, Ryumi, and Bonha Koo. "The impact of ESG rating disagreement on corporate value." Journal of Derivatives and Quantitative Studies: 선물연구 31.3 (2023): 219-241.

The authors use the volatility and idiosyncratic volatility in order to understand whether split ESG ratings lead to information asymmetry.

Idiosyncratic volatility indicates the risk unique to the specific firm stock and it cannot be explained by the market volatility.

Vola is the total volatility: a larger Vola means higher information asymmetry. iVol4 is the idiosyncratic volatility measure and it indicates the standard deviation of residuals from the

volatility. The positive relationship found between split ratings and idiosyncratic volatility suggests that split ESG ratings contribute to higher information asymmetry.
These results confirm previous research findings, showing that disagreement in the stock market correlates with higher volatility.
The robustness of previous results is confirmed by Panel B of Table 4.

Results of the authors about the analyses of the relationship between split ESG ratings and Cumulative Abnormal Return (CAR) are consistent with prior studies: split ESG ratings are negative related with CAR, they reduce stock prices in the short term.

These results indicates that disagreement in ratings may lead to lower expected returns, thus it supports the optimism-bias hypothesis.

2.5 GREEN TASTES AMONG INVESTORS AND PRICE IMPLICATIONS

Sustainable investing approach integrates environmental, social, and governance (ESG) criteria, with environmental factors taking precedence.

Investors often cite enhanced returns as a key reason for adopting ESG criteria, and asset managers frequently market these investments as having superior risk-adjusted returns, supported by studies showing historically higher returns for sustainable strategies.
However, the SEC mandates that past performance is not indicative of future results, a caution particularly relevant for green assets.

This study investigates the implications of past performance for future returns of green assets. Following the equilibrium model of Pástor et al. (2021), green assets have lower expected returns than brown ones because investor prefer green assets, also for their role as hedges against climate risk. Although green assets may show higher realized returns during periods of increased demand for green investments, this is not indicative of future performance.
The analysis made by the authors focuses on the U.S. stock market, using MSCI's environmental ratings from November 2012 to December 2020. During this period, stocks in the top third of greenness outperformed those in the bottom third by 174%. However, this outperformance is attributed to an unanticipated rise in climate concerns, rather than a fundamental shift in expected returns. Using the media index for climate concerns by Ardia et

al. (2021), it is shown that climate concern shocks are positively correlated with green asset returns.
The study of Pástor et al. (2022) purges unanticipated shocks to compute an ex post estimate of the green-minus-brown (GMB) expected return. When climate shocks are set to zero, GMB's performance is flat, indicating no inherent outperformance of green assets without these shocks. This finding aligns with the authors' model (PST model), which suggests that green asset outperformance during periods of rising climate concerns is followed by lower expected returns.
Panel regressions on individual stocks reveal a positive cross-sectional relationship between greenness and returns, which disappears when accounting for climate concern shocks. This suggests that these shocks explain the green stocks better performance during the sample period.

The study's results have significant implications for both research and practice. They caution against using recent average returns to estimate future returns, especially for green assets. The findings also suggest that greener firms have lower costs of capital than recent stock performance might indicate, which is beneficial for ESG investors aiming to exert social impact.
Realized returns are often used for expected returns computation. However, as claimed above, high realized returns do not indicate high expected returns. A relevant example is the high returns on green assets in last ten years, where they were mainly driven by environmental concerns news rather than reflecting high expected returns. We demonstrate that the portfolio's recent outperformance disappears when the effects of unexpected increases in climate concerns are removed, constructing a green-minus-brown portfolio with US stock data. Additionally, the portfolio's implied cost of capital, another proxy for expected returns, consistently indicates negative expected returns. A two-factor asset pricing model incorporating a theoretically motivated green factor helps explain the historic underperformance of 2010s value stocks. Moreover, our findings suggest that small stocks tend to underreact to climate news.

Results serve as a cautionary note for studies examining the pricing of climate risk. The authors find that green stocks generally outperform brown stocks when climate concerns rise, aligning with similar findings by Engle et al. (2020) and Ardia et al. (2021). Stocks that act as better hedges for climate shocks have a negative risk premium if investors are averse to such shocks.

2.6 GREENIUM

As the previous section's last paragraph claims, we analyse research by the Centre for European Studies (2020) to understand if the European market considers Climate Risk as a greenness and transparency factor and the estimation of an attached negative risk premium (Greenium) to more environmentally friendly and transparent firms. The greenness and transparency factor computed by authors is based on firms' environmental disclosures and on firm greenhouse gas (GHG) or CO2 emissions.

In a greener and more transparent portfolio there are transparent companies with a lower emission intensity.

The greenness and transparency factor is based on 942 companies listed on the STOXX Europe Total Market Index.

If we considered the actual composition of investment funds' portfolios, labelled as green, we would agree that these funds are less environmentally friendly than their consideration. Therefore, a fund might limit its exposure to carbon-intensive sectors and, at the same time, invest in financial stocks. The individual company could emphasize the environmental dimensions where it performs best and neglecting those where it does not perform as well.

Focusing the exposure on a small range of 100% green players is not a viable option because a crucial feature for asset managers is Portfolio diversification. Companies' low-carbon transition is a much needed but gradual process, and, for all these reasons, a realistic approach would be to broaden the definition of 'green' also to firms that reach, within the relevant sector, the highest level of efficiency in energy and the lowest CO2 emissions.

Multiple providers of environmental ratings use this approach, assessing the sustainability of firms making comparisons with peers.

The study suggests the existence of an omitted factor because the portfolios built by the authors, based on firms' environmental performance and disclosures, are associated with a positive intercept.

Then the authors include, based on the greener and more transparent portfolio and the brown portfolio, a greenness and transparency factor.

Results show that the Greenium is negative and highly significant. This means that investors accept a lower reward for their investments (linked to greener firms), ceteris paribus. The risk is viewed as significant, and the market attaches value in greener assets' investments because it acts as a hedging strategy towards worse environmental facts.

Therefore, results suggest that the market does price climate risk.

An investor could price her holdings through a mis specified model (omitted greenness and transparency factor), without considering the climate risk, and the mispricing could affect the assets held by systemically important financial institutions (SIFIs).
Systemic risk consequences could emerge as asset returns on SIFIs could be negatively affected by climate change.
In the medium-term there could be a drop in the dividend of brown firms due to the application of policies that require firms, with high emissions, to face with higher costs.
Meantime, carbon-intensive assets will become ‘stranded’ (see Campiglio et al., 2017).

CHAPTER 3

3.1 SYNTHETIC GREENNESS AND TRASPARENCY INDICATOR

Evaluating a company's environmental commitment involves various indicators, but there is no consensus on a single synthetic proxy for environmental performance (Oikonomou et al., 2012). The primary source of information is firms' environmental disclosures, typically found in annual reports, Corporate Social Responsibility (CSR) or Sustainability reports. These disclosures help investors can differentiate between green companies and those that are either not environmentally friendly or lack transparency.

For providing a comprehensive assessment of a company's environmental performance, authors of the CefES consider two dimensions: the environmental transparency, reflecting the quality of firms' environmental disclosures, and greenhouse gas (GHG) emissions.
To measure environmental transparency, the authors use the Bloomberg E score. It quantifies the completeness of a firm's disclosure regarding its environmental impact.
Positing that higher transparency equates to a stronger commitment, authors utilise the E score to get a firm's transparency concerning its commitment to environmental sustainability.

Research by Marquis et al. (2016) supports this approach, indicating that more environmentally responsible firms are more likely to disclose information as they generally perform better than their peers. In contrast, firms with poorer environmental performance are less likely to engage in voluntary disclosures, especially in countries with higher scrutiny and environmental norms.

Thus, to create a comprehensive index of a company's environmental performance, the authors combine the E score with quantitative data on emissions.
The synthetic greenness and transparency indicator, G (i, y) for company i in year y, is defined as follows:

$$G_{i,y} = \gamma K_{i,y} + (1-\gamma) E_{i,y}, \text{ with } \gamma \in [0,1]$$

where $K_{i,y}$ is the ranking's inverse of firm i in term of emission intensity, and $E_{i,y}$ is the firm i ranking in term of E score. The parameter γ manages the two index components' loading.

To partly account for the limited reliability of environmental ratings and scores (see Chapter 2), authors use the E score in combination with data on carbon emissions.

Figure 1 shows the total number of companies, from 2005 to 2017, for which E score and emission intensity are available. In the last ten years, environmental performance disclosure reporting has reached around 700 EUROSTOXX companies in 2017.

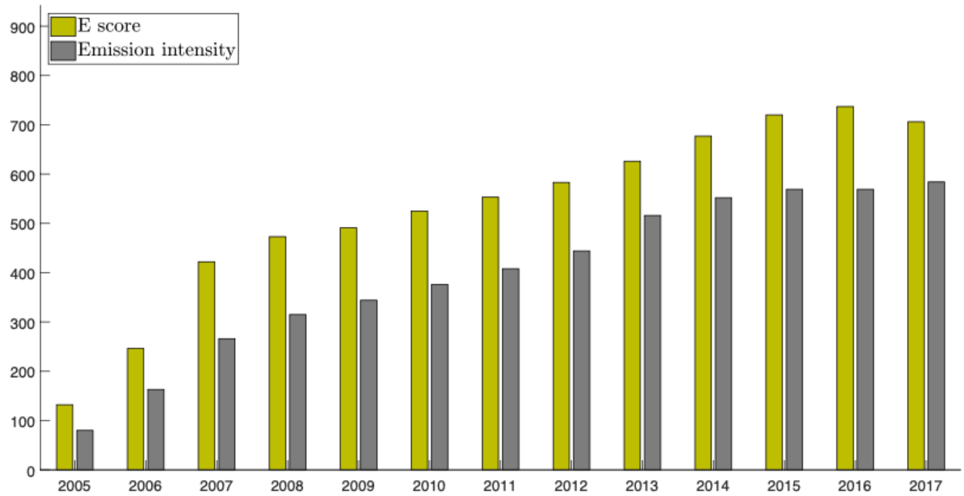

Figure 1: Total number of companies for which E score (yellow bar) and emission intensity (gray bar) are available.

Figure 1 available at: Alessi, Lucia, Elisa Ossola, and Roberto Panzica. "The greenium matters: greenhouse gas emissions, environmental disclosures, and stock prices." Publications Office of the European Union, Luxembourg, April (2020).

In Europe, sectoral emissions information is provided by Eurostat, at the NACE-2 digit level. We consider the 2017 companies' brown portfolio.

3.2 LINEAR FACTOR MODEL

The authors opt for a time-invariant model because the greenness and transparency indicator is only available for a short sample.

The excess return R (i, t) complies with the following linear factor model:

$$R_{i,t} = a_i + \sum_{k=1}^{K} b_{i,k} f_{t,k} + \varepsilon_{i,t},$$

where $f_{t,k}$ is the k-th observable factor, with k = 1,...,K

$$a_i = \sum_{k=1}^{K} b_{i,k} \nu_k,$$

where ν_k is a parameter defined for each k-th factor

The formulas are present in Alessi, Ossola and Panzica Paper (2020), the complete demonstration can be found in the Appendix of the same Paper.

The authors write the previous equation as the expected excess returns and risk premia linear relation:

$$E[R_{i,t}] = \sum_{k=1}^{K} b_{i,k} \lambda_k.$$

The time-invariant risk premium associated to each k-th factor is:

$$\lambda_k = E[f_{t,k}] + \nu_k.$$

Risk premia refer to the extra return that compensate investors for their additional risk with holding a risky asset, therefore, it is an incentive for investors to take on the risk associated with uncertain returns.

Alessi et al. (2020) use three factor models which factors included are the market factor, the size factor, the book-to-market factor, the momentum factor.

Model	Factors	K
CAR + G	$f_{m,t}, f_{smb,t}, f_{hml,t}, f_{mom,t}, f_{g,t}$	5
3FF + G	$f_{m,t}, f_{smb,t}, f_{hml,t}, f_{g,t}$	4
CAPM + G	$f_{m,t}, f_{g,t}$	2

Figure available at: Alessi, Lucia, Elisa Ossola, and Roberto Panzica. "The greenium matters: greenhouse gas emissions, environmental disclosures, and stock prices." Publications Office of the European Union, Luxembourg, April (2020).

On Kenneth French's website can be found the time series of factors and the risk-free.

The case study's time range varies from 2006 to 2018, considering all individual stocks in the stock Europe TMI on August 2018.
Financial firms are excluded from the case study. Final dataset comprises 942 stocks.

The authors build portfolios based on the first, the second, the third, the fourth and the fifth quintile of the distribution. Top-ranked firms on the fifth quintile are labelled as 'greener and more transparent'.
Companies active in highest emissions' industries are included in brown portfolio.
The portfolios are comparable in terms of companies' size and firms' leverage.

Portfolio	Mean	Std	Kurt	Skew	Sharpe	t-stat
$\tilde{R}$	1.102	0.497	3.744	-0.391	0.204	2.522
$\tilde{R}^g$	0.943	0.502	4.097	-0.593	0.188	2.315
$\tilde{R}^c$	1.732	0.586	5.210	-0.632	0.296	3.643
$\tilde{R}^b$	1.425	0.638	6.985	-0.909	0.224	2.754

Table 1 available at: Alessi, Lucia, Elisa Ossola, and Roberto Panzica. "The greenium matters: greenhouse gas emissions, environmental disclosures, and stock prices." Publications Office of the European Union, Luxembourg, April (2020).

For assessing the performance of a portfolio, the authors use the Sharpe ratio (Table 1). The third portfolio from upper outperforms the others. Both mean return and the Sharpe ratio are not monotone because environmental level is not the only determinant of a portfolio's performance.
Focusing on the differences between greener and transparent portfolios on different quintiles, the authors found that the average return decreases as the level of the indicator increases.

Then, Alessi et al. (2020) investigate the drivers of the excess returns for the portfolios.
We can see that, through Table 2, the estimated market factor is positive and significant.
Greener and more transparent firms tend to be less correlated with the market compared to browner firms and, therefore, the exposition to the market factor is lower than the brown ones.
The exposition to the size factor has a negative sign for the transparent and greener and more transparent portfolios and a positive sign for the non-transparent and brown portfolios. This evidence suggests that greener firms are linked to bigger firms.
The estimated value factor loading is, except for the brown portfolio, negative and significant and it might mean that the portfolios have a larger share of firms with a lower book-to-market value.
Finally, the positive and significant intercept suggests the existence of an omitted factor.

Portfolio	$\tilde{R}$	Green	$\tilde{R}^c$	Brown
		CAR model		
$\hat{a}$	0.005***	0.004***	0.011***	0.007***
$\hat{b}_m$	0.953***	0.945***	1.061***	1.112***
$\hat{b}_{smb}$	-0.208***	-0.261***	0.476***	0.702***
$\hat{b}_{hml}$	-0.176***	-0.194***	-0.144**	-0.141
$\hat{b}_{mom}$	0.056***	0.046	-0.028	0.029
R^2_{adj}	0.979	0.947	0.940	0.864
		3FF model		
$\hat{a}$	0.005***	0.005***	0.011***	0.008***
$\hat{b}_m$	0.944***	0.938***	1.065***	1.107***
$\hat{b}_{smb}$	-0.213***	-0.264***	0.478***	0.700***
$\hat{b}_{hml}$	-0.212***	-0.224***	-0.126**	-0.159
R^2_{adj}	0.978	0.947	0.940	0.865
		CAPM		
$\hat{a}$	0.006***	0.005***	0.012***	0.009***
$\hat{b}_m$	0.899***	0.891***	1.032***	1.063***
R^2_{adj}	0.966	0.931	0.916	0.822

Table 2 available at: Alessi, Lucia, Elisa Ossola, and Roberto Panzica. "The greenium matters: greenhouse gas emissions, environmental disclosures, and stock prices." Publications Office of the European Union, Luxembourg, April (2020).

The greener portfolio and the brown portfolio monthly returns difference is defined as the greenness and transparency factor:

$$f_{g,t} = \tilde{r}^g_t - \tilde{r}^b_t.$$

The authors consider the same previous linear factor models, adding the greenness and transparency factor. The aim is understanding if the greenness and transparency factor affects the European stock returns.

Alessi et al. (2020) estimate the risk premia for the considered factors. Following the estimation procedure proposed in Gagliardini et al. (2016), they estimate the linear factor model by using the OLS estimator, they test whether the model is correctly specified by using the residuals and they compute the estimator v(k).

Each factor's risk premium estimate is given by the sum of E[f(k), t] and the estimate of v(k).

CAR + G model			
$\hat{\lambda}_m$	10.659**	$\hat{\nu}_m$	4.625***
	(-4.913, 26.232)		(3.876, 5.373)
$\hat{\lambda}_{smb}$	3.326**	$\hat{\nu}_{smb}$	1.655***
	(-1.354, 8.006)		(0.682, 2.627)
$\hat{\lambda}_{hml}$	-4.582*	$\hat{\nu}_{hml}$	-3.203***
	(-10.723, 1.560)		(-4.510,-1.896)
$\hat{\lambda}_{mom}$	8.986**	$\hat{\nu}_{mom}$	-0.412
	(-1.463, 19.436)		(-3.117, 2.293)
$\hat{\lambda}_g$	-9.860***	$\hat{\nu}_g$	-4.076***
	(-17.017, -2.702)		(-6.221, -1.931)
3FF + G model			
$\hat{\lambda}_m$	10.534*	$\hat{\nu}_m$	4.499***
	(-5.038, 26.106)		(3.766, 5.231)
$\hat{\lambda}_{smb}$	2.634	$\hat{\nu}_{smb}$	0.963***
	(-2.046, 7.314)		(0.007, 1.918)
$\hat{\lambda}_{hml}$	-5.903**	$\hat{\nu}_{hml}$	-4.525***
	(-12.045, 0.238)		(-5.812, -3.238)
$\hat{\lambda}_g$	-7.545***	$\hat{\nu}_g$	-1.781**
	(-14.722, -0.407)		(-3.886, 0.325)
CAPM + G			
$\hat{\lambda}_m$	11.137*	$\hat{\nu}_m$	5.102***
	(-4.435, 26.708)		(4.397, 5.807)
$\hat{\lambda}_g$	-7.282***	$\hat{\nu}_g$	-1.498**
	(-14.440, -0.125)		(-3.360, 0.364)

Table 4 available at: Alessi, Lucia, Elisa Ossola, and Roberto Panzica. "The greenium matters: greenhouse gas emissions, environmental disclosures, and stock prices." Publications Office of the European Union, Luxembourg, April (2020).

The estimated Greenium, negative and statistically significant at the 1% level suggests that investors are willing to accept lower returns to hold assets that are more environmentally friendly and transparent. It means that these assets act as a hedge against risk, in this case against climate risk.

However, the preference for environmentally friendly and transparent stocks might also be influenced by factors as a 'taste for assets', not linked to financial returns.

The coefficient νˆg is negative and significant at the 1% level in the first model and at the 5% level in the second and third models in Table 4. This component of the risk premium might be linked to market imperfections (see Daniel and Titman, 1997; Haugen and Baker, 1996). In this case it can indicates that market characters may possess information that is not entirely captured by past returns. The difference between the broader information set available to investors and the historical information set used in the model could be reflected in νk.

The authors investigate, through robustness checks, whether adding or removing weight to one of the indicator's components has an impact on the results but the results are comparable with the previous one: the Greenium is negative and significant across the majority of the robustness checks.

3.3 CLIMATE STRESS TESTS ON ACTUAL HOLDINGS

Climate stress tests refer to analytical assessments conducted on financial portfolios to evaluate their resilience and performance under various hypothetical climate-related scenarios. These tests simulate the impact of different climate risks, such as regulatory changes, physical climate events (e.g., extreme weather), and transitions to a low-carbon economy, on the value and stability of the assets within a portfolio. These stress tests provide insights into how climate change could affect financial returns and risk exposures.

Climate stress tests are relevant for several reasons. It first plays the role of risk assessment and management, by understanding how assets might perform under adverse climate scenarios, investors and financial institutions can better manage and mitigate risks associated with climate change.

Second, it deeply affects various investment decision-making. In fact, its results inform investment strategies by highlighting which assets are more resilient to climate risks and which are more vulnerable and potentially avoiding assets that could suffer significant losses in adverse climate scenarios.

Third, by simulating the financial impacts of climate-related events, these tests help quantify potential losses and the likelihood of credit defaults.

One more essential function, more future oriented but necessarily to implement now, is encouraging sustainable practices by reducing firms' carbon footprint and so enhancing their environmental performance.

The direct consequence is that data and insights gained from climate stress tests support policymakers in developing regulations and policies aimed at enhancing financial system resilience to climate change.

3.4 METHODOLOGY FOR CLIMATE STRESS TESTS

This analysis (limited to equity holdings) focuses on transition risks, due to the lack of specific data on individual companies' exposure to physical risks. It examines the potential effects of transitioning to a low-carbon economy (transition risks) on firms operating in climate policy relevant sectors.

With the model provided by Alessi et al. (2020), it's possible estimating that in a scenario where greener companies outperform brown companies, institutional sectors would be hit by losses.

The authors use a linear factor model approach to test, in a climate-stressed scenario, the equity portfolios' performance of global institutional sectors and European SIFIs:

$$R_{i,t} = a_i + \sum_{k=1}^{K} b_{i,k} f_{t,k} + \varepsilon_{i,t}, \tag{2}$$

When the factors, included in models, are asset returns themselves and are assumed to be priced by the same model in the equation above, there is a coincidence between risk premier and the factor means (see, e.g., Jagannathan and Wang, 2002).

Alessi et al. (2020) utilize data on equity exposures and sector classifications from Battiston et al. (2017) to assess how resilient investors are to climate risk.

Factor	Mean	Std	Kurt	Skewn	f_m	f_{smb}	f_{hml}	f_{mom}
f_m	6.035	1.885	4.690	-0.642	1			
f_{smb}	1.671	0.641	3.195	-0.129	-0.034	1		
f_{hml}	-1.378	0.788	3.582	0.519	0.533	-0.062	1	
f_{mom}	9.398	1.313	19.610	-2.546	-0.439	-0.009	-0.506	1
f_g	-4.350	1.291	4.563	0.103	-0.224	-0.483	-0.206	0.268

Table 3 available at: Alessi, Lucia, Elisa Ossola, and Roberto Panzica. "The greenium matters: greenhouse gas emissions, environmental disclosures, and stock prices." Publications Office of the European Union, Luxembourg, April (2020).

Battiston et al. (2017) provides aggregated holdings of 2015 for various institutional sectors: individuals, governments, non-financial companies, other credit institutions and other financial services. They also define institutional financial sectors according to the ESA classification.

The study classifies the equity holdings of individual financial institutions by climate-policy-relevant sectors. Focusing on SIFIs allows to examine the distribution and resilience of financial institutions' investments in sectors that are crucial for climate policy.

Considering ω_κ as the equity exposure to a relevant sector for climate-policy κ and $r_{\kappa,t}$ as the monthly average value weighted portfolio return of sector κ., the equity portfolio of an investor j at time t is:

$$r_{j,t} = \sum_{\kappa=1}^{7} \omega_\kappa r_{\kappa,t},$$

The authors compute the MES considering the potential event $f_{g,t} > q_{0.95}$, which it indicates the 95th percentile of the distribution of $f_{g,t}$.

Considering three cases (the case 0, the case 1 and the case 2), defined in terms of portfolio allocation, the authors compute the marginal expected shortfall for determining the losses amount of different portfolio allocation. The MES is the expected equity loss conditional on a particular factor return taking a loss greater than Γ. The three cases are the following:

- CASE 0: investors' portfolio allocation reflects the actual allocation of institutional sectors and financial institutions. It is defined as the equation above.
- CASE 1: investors' portfolio allocation exposure to the fossil sector is half compared to the case 0. The relevant assumption is that investments are reallocated to greener stocks.

$$r_{j,t} = \frac{1}{2}\omega_{j,1} r_{1,t} + \frac{1}{2}\omega_{j,1} r_t^{+} + \sum_{\kappa=2}^{7} \omega_{j,\kappa} r_{\kappa,t}$$

- CASE 2: potential investors' portfolio allocation scenario focused only on greener and more transparent stocks.

$$r_{j,t} = \sum_{\kappa=1}^{7} \omega_{j,\kappa} r_{\kappa,t}^{+},$$

In the case 0, the estimated average MES at the global level is -1.5%, or USD 387 bn.
Looking at the case 1 in Table 8 below, we understand that halving the exposure to carbon-intensive activities would reduce the MES marginally.
For avoiding losses at all, we need a new portfolio reallocation, as the case 2 in Table 8.
Considering Table 8, an average loss of 1,6% for European SIFIs, corresponds to almost USD 7 bn.
The analysis is based only on first-round losses, but the stress-testing literature has shown that second-round effects may amplify first-round losses. Hence, it's worth considering that the 2008 global financial crisis was triggered by write-downs on the value of loans due to the subprime crisis.

	MES (%)			MES (Bn $)		
	Baseline	Scenario 1	Scenario 2	Baseline	Scenario 1	Scenario 2
DEUTSCHE BANK AG via its funds	-1.455	-1.321	-0.032	-2.348	-2.131	-0.052
BPCE SA via its funds	-1.590	-1.539	0.112	-2.325	-2.251	0.164
BNP PARIBAS via its funds	-1.621	-1.518	-0.141	-1.090	-1.021	-0.095
UNICREDIT SPA via its funds	-1.482	-1.415	0.145	-0.438	-0.418	0.043
BARCLAYS PLC via its funds	-1.512	-1.394	-0.079	-0.572	-0.528	-0.030
CREDIT SUISSE GROUP AG via its funds	-1.420	-1.325	0.158	-1.300	-1.212	0.145
BANCO SANTANDER SA	-1.912	-1.904	-0.486	-0.155	-0.154	-0.039
UBS GROUP AG via its funds	-1.432	-1.314	0.097	-2.604	-2.390	0.176
ING BANK NV	-2.225	-2.049	-1.120	-0.042	-0.039	-0.021
SOCIETE GENERALE GESTION	-1.571	-1.496	0.088	-0.771	-0.734	0.043
Average and Total	-1.647	-1.552	-0.167	-6.971	-6.496	0.222

Table 8 available at: Alessi, Lucia, Elisa Ossola, and Roberto Panzica. "The greenium matters: greenhouse gas emissions, environmental disclosures, and stock prices." Publications Office of the European Union, Luxembourg, April (2020).

3.5 POLICY RECOMMENDATIONS

Policy measures aimed at internalizing the carbon externality are crucial drivers of climate-related risks. The primary strategy in climate change mitigation involves incentive-based regulations that price carbon, either through taxes or cap-and-trade systems. According to the IPCC (2018) assessment, scenarios limiting global warming to 1.5°C require a median global carbon price of $91 per metric ton of CO2 (tCO2) by 2025 and $179/tCO2 by 2030, with interquartile ranges extending up to $175/tCO2 and $361/tCO2, respectively (Huppmann et al., 2018). However, only 1/5 of greenhouse gas emissions were subject to any pricing, and less than 5% of these were aligned with the levels needed to meet the Paris Agreement goals (Huppmann et al., 2018).

Effective mitigation policies could significantly raise the costs for high-carbon products for both industries and consumers. Regulations may also directly restrict the sale of high-carbon products. For instance, ten countries have announced plans to ban new internal combustion engine cars, with some bans set to take effect as early as 2030 (Meckling & Nahm, 2019).

Furthermore, public subsidies, regulations, and investments can reduce the prices of low-carbon products. These measures enhance the competitiveness of low-carbon products by creating markets, providing financing, fostering innovation, and directly affecting prices (Block & Keller, 2011; Mazzucato & Semieniuk, 2017). Something like central banks' refinancing lines, prudential requirements and lending quotas, regulate the sector of Finance (Campiglio et al., 2018; Volz, 2017).

It is essential to distinguish between mitigation policies, which aim to accelerate the transition to a low-carbon economy, and policies designed to stabilize the financial system, which are discussed in the subsequent section.

The innovation is what reduce the costs of low-carbon impact technologies (Kavlak, McNerney, & Trancik, 2018; Nemet, 2019). This reduction in costs follows a nonlinear process, commonly modelled as s-curves of adoption (Rogers, 2003). As these technologies become cheaper, their adoption increases, which further lowers costs through economies of scale and learning effects, eventually establishing them as the "new normal" (Arthur, 1989). This shift in the technological paradigm (Dosi, 1982) accelerates structural changes and alters relative demand ratios, often leading to underestimates of the adoption rate of low-carbon technologies (Creutzig et al., 2017).

Once the adoption process begins, it can significantly impact prices without the need for additional policy interventions. As a new socio-technical regime becomes established, it progressively requires less external support for further diffusion (Geels, 2002). Technological trajectories can also shape policy by providing new, affordable alternatives and by creating path dependencies that limit future options (Schmidt & Sewerin, 2017; Fouquet, 2016).

Buyers' preferences significantly influence demand and prices of technologies. These preferences are shaped by institutional contexts and their evolution (Bowles, 1998). As more people adopt a technology, network effects can further accelerate its adoption (McShane, Bradlow, & Berger, 2012; Pettifor et al., 2017). This demand-pull effect can impact both the speed and direction of technological change, often interacting with government procurement policies (Boon & Edler, 2018).

3.6 POLICY RECOMMENDATIONS: HOW TO MITIGATE FINANCIAL TRANSITION RISKS

After the 2008 financial crisis, supervisors and central banks have focused their efforts to improve the financial regulation and identify systemic financial risks. They have begun incorporating climate change into systemic risk assessments and policy responses. This shift primarily addresses the risk of abrupt asset valuation changes due to stranded assets, with increased focus on sovereign risks from both physical and transition risks.

For scaling up investment in green activities, policies should support green factors and push toward green asset purchases by central banks. Regulatory measures aim to provide information and incentivize shifts away from high-carbon assets to reduce future transition impacts. Key strategies include enhancing transparency through taxonomies of green and dirty assets, mandatory risk disclosures, climate-related stress testing, and climate-calibrated capital rules. Thus, to reduce financial risks in industrial fields, it would be effective introducing an appropriate redistributive and industrial policies. For example, government revenue from carbon taxes or emission permits can be redistributed to offset household transition costs, making carbon pricing progressive. Just transition policies and maintaining company solvency during transitions can further mitigate impacts.

Summing up, integrating climate stress tests into financial research is crucial for understanding and mitigating the systemic risks posed by climate change. These stress tests allow financial institutions to evaluate the potential impacts of various climate-related scenarios on their portfolios, including the risks associated with transitioning to a low-carbon economy and the physical risks from climate change itself. By simulating extreme yet plausible scenarios, climate stress tests can reveal vulnerabilities within financial systems that might otherwise remain hidden. This information is vital for developing robust risk management strategies and ensuring financial stability. Moreover, climate stress tests enhance transparency, allowing investors to make more informed decisions and fostering greater market discipline. They also support regulatory bodies in crafting policies that address risks, reducing the likelihood of abrupt market corrections due to stranded assets or sudden changes in asset valuations. As the financial sector increasingly acknowledges the importance of climate-related risks, integrating climate stress tests becomes an essential component of comprehensive financial governance, ensuring that both individual institutions and the broader financial system are better equipped to navigate the uncertainties of a changing climate.

CONCLUSION

In the contemporary financial environment, risk management is pivotal in investment decisions, with climate risk emerging as a critical consideration alongside traditional market dynamic. Climate risk, particularly low-carbon transition risk, impacts financial stability by affecting asset valuations, especially in carbon-intensive sectors. Transition risks involve structural economic shifts where high-carbon industries decline while low-carbon sectors grow due to policies, technological advancements, and changing preferences. These shifts pose direct and indirect financial risks, manifesting as credit and market risks. Investors use Environmental, Social, and Governance (ESG) criteria to evaluate corporate behaviour and predict future financial performance, fostering sustainable investment practices. However, discrepancies in ESG ratings across agencies create inconsistencies and complicate comparisons, potentially undermining socially responsible investing (SRI). The financial sector must consider climate risks to avoid mispricing assets, particularly for systemically important financial institutions (SIFIs). Climate change, through physical and transition risks, can adversely affect asset returns and macroeconomic stability. As low-carbon policies increase costs for high-emission firms, carbon-intensive assets may become stranded, impacting financial stability. Climate stress tests are essential analytical tools that simulate the impacts of various climate-related scenarios on financial portfolios, aiding risk assessment and management. These tests inform investment strategies by identifying resilient assets and quantifying potential losses. Moreover, they support policymakers in developing regulations to enhance financial system resilience. Technological innovations and policy interventions can accelerate the adoption of low-carbon technologies, reducing transition costs and promoting sustainable practices. Green-supporting regulatory measures and industrial policies can facilitate the transition by enhancing transparency, mandating risk disclosures, and implementing climate-calibrated capital rules. Redistributive policies, such as carbon tax revenues, can mitigate transition costs for households and businesses. Integrating climate stress tests into financial research is crucial for identifying systemic risks and developing robust risk management strategies. These tests enhance transparency, support informed investment decisions, and assist regulatory bodies in crafting effective policies. As climate risks gain recognition in the financial sector, stress tests become indispensable for comprehensive financial governance, ensuring resilience in a changing climate.

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