The Evolving Academic Field of Climate Finance[1]

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Abstract

The urgency and the magnitude of climate change will affect every aspect of our economies, societies, and planet. The academic finance research has begun to study the financial implications of global warming, although this body of literature is small. The literature exhibits distinct geographic tilts in terms of research preferences, draws young researchers, and much remains outside of the traditional finance domain. We explore, quantitatively and qualitatively, the emerging field of climate finance. We discuss its relevance for finance research and teaching and provide implications for financial economist and practitioners—in particular the need to incorporate this massive externality in valuation and risk analyses.

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Finance and economics provide powerful intellectual frameworks to allocate scarce resources to their highest and best uses in society. The academic field of finance is broad, covering several sectors and institutions. The financial system can be understood in terms of the functions that it performs, including payments, risk management, pooling, moving money to the future (investing), moving money from the future (credit), and resolving information asymmetries and moral hazard (Crane et al., 1995). Finance has a number of recognizable core principles and beliefs: the time value of money; the law of one price; the trade-off between risk and return; various irrelevance theorems and imperfections that make decisions relevant; game theoretic implications of moral hazard and information asymmetry; behavioral biases; the role of supply and demand in price formation; the substitution of residual (equity value) for broader concepts of enterprise value and social welfare; the calculation of social value as the sum of consumer and producer surplus; and the power of competition to provide optimal resource allocation, to name a few.

Regardless of which of these perspectives one takes - institutional, functional, or intellectual - the climate crisis will affect virtually every sector of the economy and every function of the financial system. While we have long understood about externalities, the sheer scale of the greenhouse gas induced climate crisis will force us to rethink and refine our financial theories and practices. Other issues have had higher priority until now: With the need to reconstruct Europe and lift Asia and Africa from poverty, it made sense to leave environmental considerations outside of economic models assuming unlimited resources. With new developments in technology and growth of 20th century globalization, we focused on growth with a simplified notion of shareholder maximization. But today, human activity is so large that it is materially changing our environment, threatening the growth that we have enjoyed over the past decades. Due to this feedback loop, climate and environmental considerations are increasingly becoming an integral element of economics and finance (Dasgupta, 2021).

The cost of not addressing the climate crisis are huge, in terms of human hardship, increasing political and intergenerational tensions, and economic losses. The cost of addressing the climate crisis through decarbonization are not trivial either. McKinsey Global Institute (2022) projects that total investment will be $9.2 trillion annually, an increase of $3.5 trillion over current levels. This figure equals to one half of global corporate profits or one quarter of global tax revenues in 2020. These investments will generate substantial private and social value. For example, Adrian et al. (2022) estimate that the net benefits from avoided emissions outweight the costs of ending coal and replacing it with renewables by around $78 Trillion USD, at present value. This amounts to roughly 1.2% of global GDP per year until 2100. Given the scale of the investments required—which are historic in nature, and the need to calculate public and private returns given the externality involved, it's no surprise that finance is increasingly focusing on climate. This is true in financial centers around the world, but also in the academic discipline of finance, where Laura Starks, in her 2023 American Finance Association Presidential Address, called for greater work in this field.

The purpose of this piece is threefold: First, we seek to explain briefly how the climate emergency we face invites us to refine — and in some cases rethink — our work as finance academics. Second, we briefly review the ever-evolving literature of climate finance, first in quantitative terms and then via a brief summary of various strands of research. Third, we offer our observations on gaps in research and teaching where it is possible to merge a deep knowledge of finance and economics with an evolving appreciation for the systemic nature of the climate crisis. We seek to provide a summary of the collective boundaries of current knowledge and to offer suggestions for future work.

1. Why and how does climate matter?

As of mid-2022, the recorded levels of CO_2, the main green-house gas (GHG) was 420 parts per million (ppm)[2]. In the last 800,000 years until a few decades ago, this number has not been above 300 ppm. The link between GHG and global warming is well established in science, and the recent Intergovernmental Panel on Climate Change (IPCC) report lays out the impacts of increasing levels of green-house gas and climate change.

Throughout the history of the planet, energy from the sun would largely bounce off the Earth's atmosphere. With human-caused increases in the levels of GHG, more of this energy is trapped and absorbed by the air and oceans. With deforestation, less CO_2 is recaptured through natural means. Warming of the air and seas (global warming) combine to cause a number of phenomena. Sea level rise occurs through the melting of polar ice sheets and through thermal expansion, or the increase in volume of water as it warms. Warming also leads to higher levels of condensation in the atmosphere, which together lead to changes in atmospheric patterns which amplify weather phenomenon, including massive heat spells, desertification of regions, reduction in rainfall in some areas and extreme rainfall in others. These factors will impact food systems materially, leading to food imbalances. These physical phenomena will disproportionately harm people living in equatorial regions, residents of coastal cities and others, and especially poorer people who will not have the resources to relocate, to pay for conditioned air, switch away from local agriculture, etc.

The IPCC report estimates that human-induced climate change already affects nature and people. Some 1.9 million animal species and 450,000 plant species have already been lost, half have shifted poleward or to higher altitudes, and 1 million are threatened with extinction. Even if we significantly curb emissions in the coming decades, more than a third of the world's remaining glaciers will melt before the year 2100. Ocean warming has reduced fisheries and food production in some regions leading to malnutrition, while water is increasingly scarce in some parts of the year. Extreme climate has even adversely affected physical and mental health of people, increasing mortality and morbidity, including through the emergence of diseases. We are at risk of triggering irreversible tipping points such as the Greenland ice sheet meltdown, West Antarctica ice sheet collapse, or the Amazon rainforest dieback—all of which which will accelerate the rise of temperatures, sea levels, and volatile weather patterns (Lenton & Ciscar, 2013). Without changes in behavior—reducing GHG emissions and finding ways to capture and store GHG—these adverse *physical risks* are more likely, while their timing is less certain.

Actions to mitigate climate risk—which include changes in the way that we produce and use energy, what we eat, how we move from place to place—give rise to other risks, called *transition risks*. Businesses and investors are increasingly aware of transition risk, as they could find themselves owning and managing legacy businesses with little future and stranded assets. They could find themselves facing new taxes or simply less consumer demand as tastes change. Investors and insurers, especially those with longer horizons perspectives, must concern themselves with both transition and physical risks. More extreme weather events such as hurricanes, floods, or drought-induced wildfires will destroy productive assets. Chronic global warming might lower the productivity of labor or agricultural production resulting in lower profitability. Corporations, insurers, and investors are becoming increasingly aware, and concerned, with these climate-related risks.

[2] For current data, see the NOA's Global Monitoring Laboratory

Within academia, a long line of environmental economists have for decades studied the economics of environmental and climate issues (Ackerman, 2019; Dasgupta, 2021; W. Nordhaus, 1982; Ostrom, 1999; Pindyck, 2013; Stern, 2006; Weitzman, 2011). But until recently environmental concerns were not central to academic research in *finance*. In the last few years, an increasing number of finance researchers—mostly younger scholars—have begun working on climate-related finance topics. We have compiled a fairly exhaustive database of around 500 working and published papers in the field of climate finance that we use to characterize the trajectory and contours of the field. In addition, we augment our understanding of the current state of academic work in climate finance with data from the programs of two of the field's leading conferences: the American Finance Association (AFA) and the European Finance Association (EFA) since 2005, and publications of climate finance papers in the "top three" finance journals (*Journal of Finance, Journal of Financial Economics* and *Review of Financial Studies*

By any measure climate finance is a new field. Our database of 500 papers can be put into context by comparing it with another "new" field in academic finance: household finance. While the comparison is not exact, SSRN's Houshold Finance e-journal has had over 11,000 submissions over the past decade. In another marker, we were not aware of a doctoral course in climate finance until a 2023 offering[3]. In the next section we provide data on the recent research on climate finance. The encouraging signs are that research on climate and finance is increasing, in a global, inclusive and young fashion.

2. An empirical review of research on climate finance

The boundaries of "climate finance" are still porous. In their comprehensive survey on climate finance, Giglio, Kelly and Stroebel (2021) focus on the covariance properties of asset payoffs with climate change as a systematic risk factor, and emphasize the link between climate and macro-economic risks and asset prices. In their introductory piece to the RFS special issue on climate finance, Hong, Karolyi and Sheinkman (2020) offer a broader definition: "Climate finance is the study of local and global financing of public and private investment that seeks to support mitigation of and adaptation to climate change." We adopt this latter broader definition, expanding it to include households and to include the financial implications of climate change as well as the financing to support the necessary investment.[4]

To get a sense of the range and depth of climate research and its increasing relevance, we collected approximately 500 published and working papers and analyzed them in terms of content, authorship, and outlet. To identify the sample, we systematically screened major research repositories with keywords including[5], and then traced the network of citations to find the most extensive list of papers possible. The research repositories included widely-used academic search engines (e.g., Scopus, Web of Science, Google Scholar) and working paper repositories (e.g., SSRN). We examined the bibliography of each paper, tracing earlier climate

[3] In full disclosure, the authors are part of the multi-school teaching team for the Global Doctoral Course, the Financial Economics of Climate and Sustainability.

[4] For this review, we exclude broad work on Environmental, Social and Governance (ESG) metrics.

[5] A non-exhaustive list of keywords used in different combinarions for the systematic review are: climate, finance, financial economics, climate change, carbon, sustainability, GHG emissions, transition risk, physical risk, climate related risks, stranded assets, climate stress testing, net zero, carbon disclosure, carbon emissions, climate policies, carbon neutrality, emissions targets, institutional investors, ESG, environmental.

finance studies that we may have missed in our search. In addition, we looked at the most important conferences in this area in the past 5 years as well as the papers in the top three Finance journals over the past 15 years. Our database includes information on journal impact factors, number of citations, author affiliations, region of authors affiliations, type of research organisation, etc. This allows us to create a map of the main branches of this literature and classify it according to different dimensions that could shed light on the emerging strands as well as summarise the landscape of this field. We do not claim to have captured all papers in this space but believe the sample to be fairly comprehensive and representative as of mid-2022. In order to roughly capture the boundaries of academic work in climate finance (vs. work by and for practitioners), our survey does not generally include reports by consulting firms, banks or financial institutions, except to the extent that they appear in journals, working paper series, or SSRN.

Time and geographic perspective

Our first observation is that the literature on climate finance *is growing.* Figure 1 shows the number of identifiable papers in our sample. Prior to 2018, there were fewer than 20 papers produced annually, but by full year 2021, this figure had grown eight-fold to more than 160 papers produced in that year. The number of published papers has followed the trend, reflecting the increasing acceptance of climate finance as a "legitimate" topic of study.

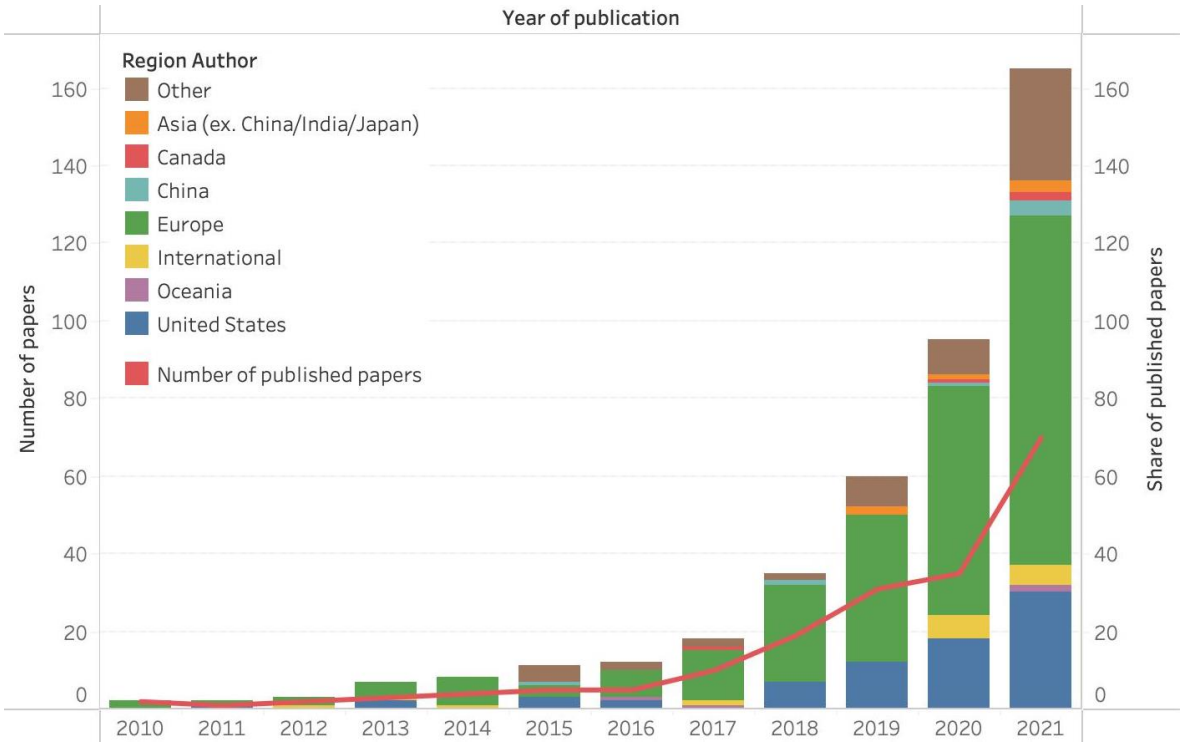

Figure 1: *The bars represent the number of published and unpublished papers by year and by region of first author. The red line represents the number of published papers as of mid-2022.*

While this work is conducted globally, there has been to date more activity by academics *in European institutions* than elsewhere, although this is changing. The share of papers from European-based scholars (in terms of first author) were around 80% in 2017 and 2018, but by 2021 this number decreased to 65%, with the difference mostly emerging from scholars in the

US. But the relative figures mask the growing number of papers from US authors in absolute terms which increased from less than 10 before 2018 to more than 30 in 2021, in our sample. The interest in climate finance has also grown in other countries, and in supranational organisations (e.g., IMF, World Bank). Interestingly, we find fairly low levels of international cooperation, with fewer than than 10% of papers with a European - or American - based first author having second author in a different region.

The growing interest of traditional finance in climate change is also highlighted by the increasing presence of climate finance papers in the two major annual academic finance conferences organised by the European Finance Association (EFA) and the American Finance Association (AFA). Before 2019 fewer than 2 papers were discussed in each conference, but this figure increased to 10 and 4 in the EFA and AFA conferences respectively in 2021 (Figure A1). Similarly, in the top three finance journals – Journal of Financial Economics (JFE), Journal of Finance (JF) and The Review of Financial Studies (RFS) - fewer than 4 papers were published before 2019, but this number increased to 9 in 2020 and 2021 (See Figure A2).

Characterizing authors: institutions and seniority

While academics are the primary authors of climate finance research in our sample, *non-academic institutions* are also important contributors, especially in the financial intermediation branch. In the financial intermediation space, one-fifth of the work comes from central banks, supervisors and other research organisations—where there are many academically trained staff. Instituionally-based research mostly focuses on topics regarding financial regulation and supervision, but also investigates policies for fostering the green transition. In figure 2, we show the number of published papers and working papers or reports by type of organisation, branch and region. The chart also shows that a large part of this research that might be published in academic journals in the future is currently in working papers or resides outside of traditional academic outlets in the form of policy or industry reports.

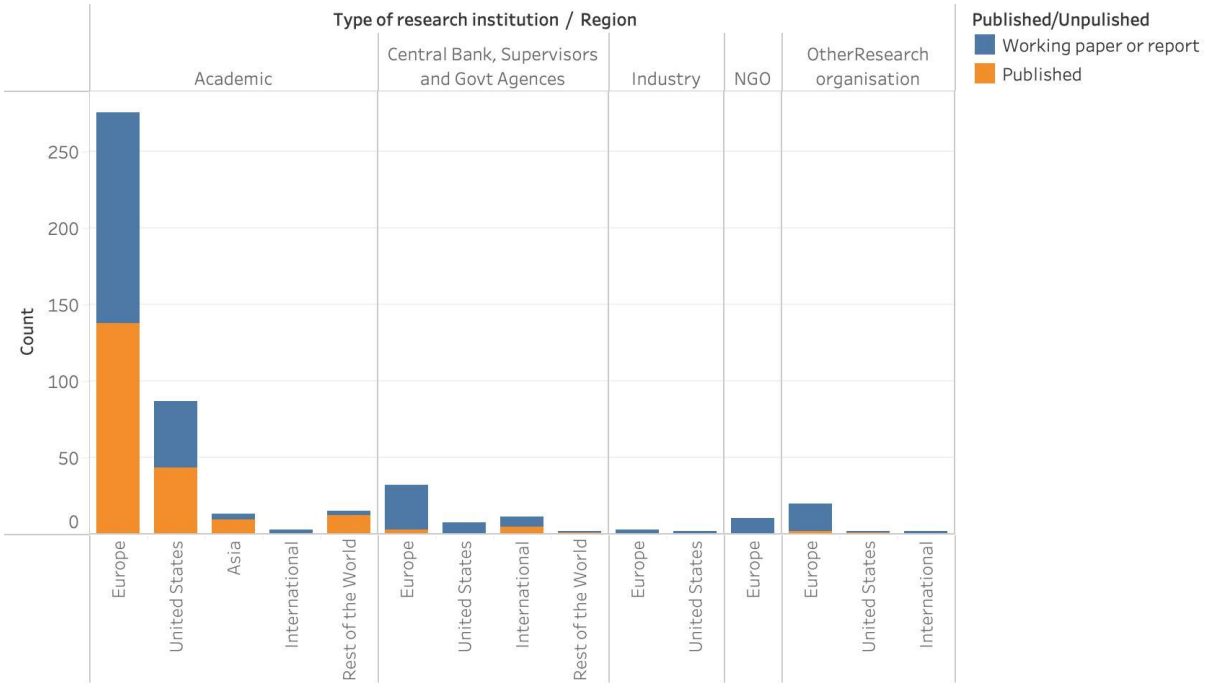

Figure 2: *Number of published working papers or reports by type of institution and geography*

This emerging field seems to especially attract *younger researchers*, as also reported by Hong et al., (2020) in their characterization of submissions to a special issue on climate finance by the Review of Financial Studies. In table 1, we show that more than 70% of papers in our sample are from academics below the level of Full Professor. The largest share of papers in our sample is from authors in an early research career position and about 9% PhD students. However, senior academics are increasingly finding these issues of relevance. In 2020 and 2021 we find that the absolute number of publications from academics at Professor level has increased.

Author	**Percentage of papers**
PhD Student	9%
Early career researcher (incl. post doc)	35%
Assistant professor	9%
Associate professor	17%
Professor	30%

Table 1: *The table reports the share of published and unpublished papers by first author seniority.*

Channels for publication and dissemination

The climate finance literature is increasingly published in finance journals, but also has a sizeable presence in *other outlets*. Prior 2018, the three top Finance journals (*Journal of Finance*, *Journal of Financial Economics* and *The Review of Financial Studies*) published very few climate finance papers, but after this date there were almost a total of 10 published papers every year in our sample. The bulk of work prior 2018 was published in journals outside of traditional finance, and still today a large share of this literature is published in non-finance journals. In particular, climate finance work is published in academic journals that focus on climate and sustainability issues such as *Nature Climate Change*, *Ecological Economics*, the *Journal of Environmental Economics and Management* among others, which often have high impact factors. See Figure 3. The breadth of journals highlights the diversity of disciplines and methods used in this research, which oftentimes span beyond traditional finance. However we note that the citations/paper of publications in the top finance journals is substantial.

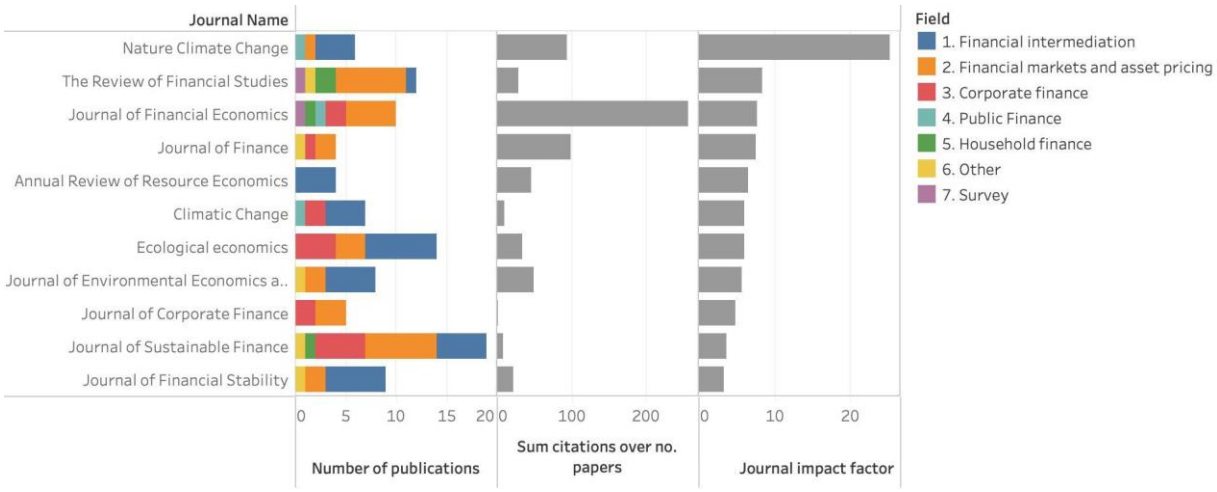

Figure 3: *The figure shows the number of publications in our database of climate finance literature by journal, the ratio of the sum of their citations and the number of papers in each*

journal and the journal latest impact factor. Published papers between 2010 and 2022. Journals ranked by 2021 impact factor.

Topics of Study

In terms of issues discussed by climate finance papers, *there are two large clusters of work,* broadly in (a) financial intermediation and banking; and (b) financial markets and asset pricing. There are smaller bodies of work in corporate and household finance. We hand-coded the primary topics of each paper and, in figure 4, show the breakdown of the work. Around 38% of the papers are on financial intermediation and around 30% on financial markets. Fewer papers are focued on corporate finance, public finance or household finance topics. There is an identifiable European/US tilt to the work, with authors at European institutions more likely to work on intermediation topics and American authors to work on financial markets. The financial intermediation work is further divided in two streams discussing (a) financial policies for supporting the low carbon transition through the financial system (e.g., green prudential regulation, green monetary policy) and (b) assessing the impacts of climate change on financial stability. The latter stream mostly involves climate stress testing or discussions around the impact of climate change on the financial system. The branch of literature on financial markets largely focuses on asset pricing in the context of climate change. It covers a vast array of asset classes, but also investigates how markets react to climate events, how changing investors' expectations affect stock prices, and how climate risks can be hedged.

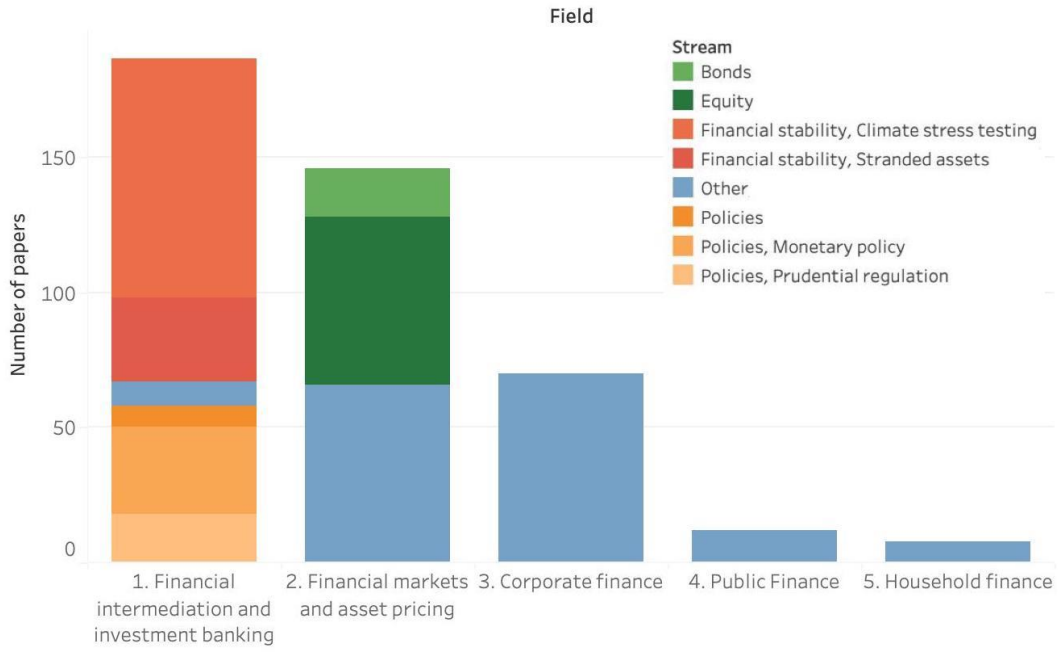

Figure 4: *The figure shows the share of the climate finance literature interest in different issues broken down from an institutional perspective. All published and unpublished paper from 2010 to 2022.*

We will use the institutional view reported above to frame a selection of some of papers in this space. We highlight the diversity of topics and methods as well as the increasing relevance of these issues for academic finance.

3. A selected review of climate finance research

We do not attempt to exhaustively survey the field, but refer the reader to Giglio et al. (2021) and Hong et al. (2020). In this selective review of the major streams above, we touch on some points relevant to academics, practitioners, and policy-makers. The papers we discuss cover themes that have been highlighted by previous surveys of financial economists, policy makers, and investors (e.g., Stroebel & Wurgler, 2021), in particular three key aspects: i. that markets might under-estimate climate related risks, especially long-term physical risks ii. Increasingly, environmental policy risk might be one of the main concerns and drivers of change of investors, and iii. corporate and household activities are emerging, in terms of measurement and action, as climate change moves from the scientific realm of using global data to the social science realm of using enterprise and household data.

Financial intermediation

A first strand of climate finance literature focuses on the exposure of the financial system to climate-related risks and the potential repercussions on economies and societies. As discussed above, climate change risks include both transition or physical risks. Transition risks are financial risk which might arise from a revaluation of assets following a shift towards a clearner economy - e.g., policy, technology). Physical risks are the impacts of increasing frequency and severity of weather events - e.g., floods, storms, droughts (FSB, 2020). Increasing evidence shows that financial institutions might be susceptible to abrupt climate shocks, from both risks. This literature examines how the financial system might be an enabler of the ecological transition required to prevent global warming through policies by central banks and financial supervisors.

Caldecott et al. (2021) discuss the concept of *stranded assets* in the context of climate change, defined as "assets that have suffered from unanticipated or premature write-downs, devaluations, or conversion to liabilities". They discuss the transmission channels of climate related risks and the possible effects on societies, economies, and the financial system. They also review the growing central banks and supervisors' responses, including climate disclosure and stress testing[6].

Jung and Engle et al. (2021) develop a *climate stress testing* methodology to assess the resilience of the financial system. They estimate the exposure of financial institutions (beta) to a stranded asset portfolio and calculate an expected capital shortfall conditional to a stressed climate scenario (provided by the Network for Greening the Financial System). They find that some banks might be particularly exposed to these risks and argue that climate change might be a systemic risk for the financial system[7].

This issue has also drawn a growing interest from disciplines outside of traditional finance. Battiston et al. (2017) use *complexity economics* methods, such as network analysis, to extend climate stress testing to the possible contagion effects among interconnected financial institutions. They use granular information about European Union (EU) banks, investment firms and pension funds to calibrate their model. They also provide a novel sectorial classification of economic activities sensitive to climate related risks (Climate policy relevant

[6] Other similar literature includes Monasterolo (2020); van der Ploeg & Rezai (2020)

[7] Some studies from regulators and financial supervisors include Alogoskoufis et al. (2021); Bolton et al. (2020); Litterman, 2020

sectors). They find that the EU financial system could be exposed to climate related risks, but also that the indirect losses arising from overlapping exposures might magnify these effects[8]

The changing attitude of the financial system towards climate change might also lead to a re-orientation of financial flows which might affect the real economy and how financial regulation might be a tool to address carbon externalities. Oehmke & Opp (2022) discuss whether a financial regulator with a broader mandate might prevent financial instability and foster the green transition through differentiated capital requirements. In particular, they discuss the merits of *green supporting factors* (lower capital requirements for green loans) and a *brown penalising factors* (higher capital requirements for polluting loans). They make use of a model of banking capital requirements regulation and a policy maker with a broader mandate to address global warming. They find that these tools might be effective in preserving the stability of the financial system (or externalities that manifest inside the financial system), but they have little ability to foster green investments, addressing the global warming externality (or externalities that manifest outside the financial system).

Papoutsi & Piazzesi, et al. (2021) discuss these issues through the lenses of monetary policy. In their empirical analysis they find that the ECB corporate purchase program favors firms with high GHG emissions because of the structure of the bond market and the methodology used by the ECB for maintaining its objective of market neutrality. They argue that monetary policy is inherently tilted towards polluting firms, but a Central Bank can construct a portfolio which minimises climate related risks, increasing risk premia for polluting firms. In this regard, they argue that *green monetary policy* initiatives discussed in related literature might seem less unconventional than initially thought, as central banks already have implicit stances on the environmental risks of their holdings[9]. However, Hansen (2021) argues that although the independence of central banks might seem appealing for fighting climate change, this could lead to dangers such as harming reputation and hampering independence of central banks, but also distract attention from implementing first-best environmental policies such as carbon taxation.

Financial markets and asset pricing

A second large portion of the financial economics literature on climate change discusses empirical and theoretical issues about the pricing of climate related risks in financial markets. This literature investigates whether these risks are priced in equity markets, but also in other asset classes such as bonds, options, and real estate. The papers use various methods and provide different theories underlying why and how climate risk pricing might manifest itself.

Bolton and Kacperczyk (2021) investigate whether financial markets price climate related risks by looking at the cross section of stock returns and firms carbon emissions. They consider all three scopes of carbon emissions (as defined by the GHG protocol[10]) and three variables: the

[8] Other similar literature: includes Battiston et al. (2021); Dietz et al. (2016); Monasterolo et al. (2019); Vermeulen et al. (2021)

[9] Other similar literature includes Campiglio et al. (2018); Dafermos et al. (2018); Monasterolo (2020); Campiglio & Van der Ploeg (2021)

[10] WBCSD & WRI in the GHG protocol classify corporate carbon emissions in three scopes. Scope 1 emissions pertain to "Direct GHG emissions [that] occur from sources that are owned or controlled by the company". Scope 2 emissions are defined as "GHG emissions from the generation of purchased electricity consumed by the company". Scope 3 emissions are "all other indirect emissions […] as a consequence of the activities of the company, but occur from sources not owned or controlled by the company"

total level of emissions, the year-on-year change and the emission intensity (defined as carbon emissions over sales). They find a statistically significant *carbon premium* related to the absolute level in carbon emissions. They also find a relationship with the year year-on-year change in emissions, but not with the emission intensity. They argue that financial markets are pricing the risk of higher CO_2 emissions, not only in industries targeted by investors for divestment (e.g., fossil fuels)[11] This analysis is further extendended in Bolton & Kacperczyk (2023) .

Hsu et al. (2022) theorise the causes of an environmental pollution premium. They first show empirically that a portfolio short of firms with high toxic emissions intensity and long of firms with low toxic emissions intensity (high-minus-low) yields statistically significantly positive returns. They then construct a general equilibrium model where future firms' profits depend on a regime shift in environmental regulation. They assume that if the policy maker tightens environmental regulation the profitability of firms with high toxic emissions intensity declines more than low toxic emissions. They argue that the environmental pollution premium might be explained by firms' exposure to an environmental policy uncertainty and the *policy regime shift* risk.

In contrast, Pástor et al. (2021) theorise that investors hold green stocks not only because they seek to hedge climate related risks, but also for *non-pecuniary motives* (i.e., preferences for positive environmental impact). They discuss this result in a CAPM framework with a three funds separation: a risk-free asset, a market portfolio and an "ESG" portfolio. Investors with strong preferences for green assets deviate from the market portfolio and tilt their investments towards the "ESG" portfolio. In a CAPM framework, green (brown) stocks have negative (positive) alpha, but green (brown) stocks have also a positive (negative) exposure (beta) to an "ESG factor". A strengthening of ESG concerns leads to green stocks outperforming brown stocks. However, they argue that in equilibrium green assets show lower *expected returns* than brown ones, but, if ESG concerns change unexpectedly, green assets might show g*reater realised* returns than brown ones. In Pástor et al. (2022) they test empirically their theoretical predictions constructing a Green-Minus-Brown portfolio which explains the recent outperformance of green stocks in US stock markets.[12]

Investors' environmental preferences might appear more clearly in the green bonds markets. Baker et al. (2022) provides a review of US green municipal bonds and find that they show a *premium* compared to similar traditional bonds, yielding 5 to 9 bp difference. They theorise that investors non-pecuniary preferences are the underlying driver of the green premium. They also argue that green bonds tend to have more concentrated ownership. In contrast, Flammer (2021) does not find that corporate green bonds trade at a premium compared to traditional bonds. She argues that investors are not willing to sacrifice returns for positive social outcomes, but that firms issue green bonds to signal credible environmental commitments. In an event study, she finds that stock prices respond positively to green bond issues with statistically significant cumulative abnormal returns following the announcement. Firms also improve their environmental score after the issuance.

A related issue discussed in this literature is hedging. Due to the increasing climate related risks, investors may wish to hedge against such negative outcomes. Engle, Giglio et al. (2020) construct a dynamic hedging portfolio against news about climate change. They use textual

[11] Other literature in this space includes Ilhan, Sautner, et al. (2021); Ramelli et al. (2021); Wagner et al. (2018)
[12] Other literature in this space includes Pedersen et al. (2021); Riedl & Smeets (2017); Zerbib (2022)

analysis of newspapers' climate news to develop a *climate news index*. They use it to construct a *"*mimicking*"* portfolio that is negatively exposed to the index and shows positive returns following negative innovations in the index. Alekseev et al. (2021) expands some of these concepts introducing a quantity-based approach for mutual funds.

One of the peculiar features of climate change is its high *uncertainty*, especially about future physical damages. Barnett et al. (2020) apply decision theory and asset pricing methods to investigate optimal climate policy under uncertainty about future damages induced by global warming. They use the social cost of carbon to explore the sensitivity to three components of uncertainty: risk (uncertainty within the model), ambiguity (uncertainty across the models) and misspecification. The show that the social cost of carbon increases if uncertainty is accounted for by an ambiguity-averse policy maker[13].

Future and present risk of extreme weather events damages might also be material for assets' valuations. Hong et al. (2019) investigate whether stock markets *efficiently* discount such risks focusing on drought and food stocks. They use an index which measures drought intensity and rank different countries in quintiles depending on their vulnerability to drought. They investigate whether a portfolio sorting between the countries in the top and bottom quintile of vulnerability generates excess returns. They find that the drought vulnerability ranking forecasts excess returns suggesting that financial markets underreact to climate related risks. They argue the predictability of excess returns is a sign of market inefficiency in pricing the increasing risks brought by global warming[14].

Corporate finance and institutional investors

Corporations and institutional investors seem to be paying increasing attention to climate change. They are increasingly aware of the risks arising from either transition to net zero emissions or from global warming. Institutional investors increasingly engage with firms to consider climate related risks and generally support, together with regulators, broader climate-related disclosure. This literature oftentimes leverages surveys of corporate management and institutional investors, but also uses novel approaches such as natural language processing.

Sautner et al. (2023) discuss how corporate management and investors are increasingly concerned about climate change. They use machine learning methods and *earnings calls* transcripts to construct an index about the share of discussion focused a set of keywords related to climate change, as a proxy of firms' exposure to climate related risks. They find that the utility sector is the most exposed in terms of risks, and opportunities, but also other sectors are exposed such as transportation and construction. They argue that their measure predicts real outcomes such as green patenting and green tech growth.[15]

Institutional investors are particularly concerned with climate change risks. Krueger et al. (2020) survey *institutional investors* in order to understand whether they consider climate related risks in their investment process. They find that, although climate related risks are ranked after more traditional risks, investors deem them material, with 40% of respondents

[13] Other literature discussing similar issues include Ackerman (2019); Daniel et al. (2019); Lemoine (2021); Weitzman (2011)

[14] Similar literature in this space includes Alok et al., 2020; Bansal et al., 2019; Choi et al., 2020; Schlenker & Taylor, 2021

[15] Addoum et al. (2020); Barker & Eccles (2018); Bartram et al. (2022) discuss the real effects of climate change on corporates

reporting expectations of temperature increasing above the Paris alignment target of 2°C. The survey also highlights that uncertainty is the greatest challenge to managing climate related risks and most respondents having developed management tools such as portfolio carbon footprint and scenario analysis. Most investors report preferring to *engage* with the firms they hold rather than divest[16].

Investors are also increasingly demanding greater climate related disclosure. Ilhan, Krueger, et al. (2021) document in a survey that a large share of institutional investors considers *climate disclosure* important and that more disclosure is required. 79% of investors deem it as important as traditional financial disclosure and one-third deem it more important. They also use data of firms' ownership and disclosure from the Carbon Disclosure Project (CDP) to test the relationship between firms' owners and climate disclosure. They find that firms report more about climate if investors are in countries that require a stewardship code, in countries that have more environmental norms, and if held by universal owners.

Corporate disclosures and promised actions to combat climate change might be questionable. Bingler et al. (2022) use machine learning methods to assess firms' TCFD climate disclosure. They find a small increase in the information disclosed by firms after the launch of TCFD recommendations arguing that most of the ambition of greater disclosure have not always matched the facts of more information. Dai et al. (2021) find that firms *outsource* part of their emissions in order to achieve their domestic objectives, exploiting foreign supply chains to artificially reduce their emissions rather than truly decarbonizing.

Corporations are also increasingly setting *net zero carbon emissions targets*. Bolton and Kacperczyk (2022) discuss the increasing commitments by firms to reduce their emissions in line with the Paris Agreement objectives. Oftentimes these pledges are taken as part of climate alliances or broader forms of cooperation that are increasingly becoming prominent in this space such as the Science Based Target Initiative (SBTi). However, the authors find that so far only the better positioned companies join these initiatives, as opposed to companies with hard-to-abate emissions. Similarly to climate disclosure and emissions outsourcing, corporates are not always genuinely interested in climate change, but might *greenwash* their activities in order to try to mitigate the risks emerging from changing investors and consumers tastes.

Household finance

The effects of global warming can go beyond corporate and investors. Choi et al. (2020) examine whether the salience of global warming affects retail investors' beliefs, and in turn stock market prices. They find that people search keywords related to global warming on Google more frequently when their city is impacted by abnormally higher temperatures. They also find that in such periods, firms listed in the local stock exchange and more exposed to a transition to net zero emissions display lower returns. They use stock ownership data to argue that *retail investors* are the ones reacting to higher temperature rather than institutional investors, which do not sell systematically stocks in warmer periods.

Financial and *climate literacy* might also affect investments in green stocks. Anderson & Robinson (2021) investigate if households' environmental values impact their investment choice. In a survey of Swedish households' pro-environmental values and their pension plan

[16] Related studies include Bauer et al., 2021; Broccardo et al., 2022; Dyck et al., 2019; Gantchev et al., 2020; Gantchev & Giannetti, 2021; Hartzmark & Sussman, 2019

decisions, they find that people with strong environmental values are not more likely to hold green stocks, although people more financially literate are likely to hold ESG-labelled funds. They argue this is because people who are more environmental engaged are less likely to be interested in investment decisions and that the complexity of determining whether an investment is green or not prevents people from investing in green assets.

Nevertheless, households could be greatly affected by the growing frequency and magnitude of extreme weather exacerbated by climate. Baldauf et al. (2020) assess whether expectations about future climate change impact current valuations of *residential real estate* assets. They use granular data about future climate damages, populations beliefs about climate change and house prices. They find that dwellings in areas with strong climate "believers" and projected to be "underwater" show statistically lower prices, as opposed to areas with climate "deniers". However, in general, Bernstein et al. (2019) and Murfin & Spiegel (2020) do not find differences in the prices of houses projected to be impacted by sea level rise.

4. What are the implications for thought leadership — in research and the classroom — by financial economists?

Financial economists have long been pioneers in advancing powerful concepts: irrelevance theorems that sharpen our understanding of the factors that affect valuation; principle-based valuation models, such as the capital asset pricing model; or engineering-based valuation models, including option pricing models. We have popularized these concepts by teaching them for the past half century, so that every MBA will recognize the acronyms DCF, WACC, M&M, and CAPM. As we sit in the first half of the so-called decisive decade, where we are likely to exceed the planet's maximum carbon budget to contain global warming to 1.5° C, what concepts and tools do we need to develop and socialize in our finance research and curricula? We suggest six directions to consider:

- Make externalities visible through disclosure
- Value externalities—alongside of traditional financial valuation approaches
- Develop a heightened appreciation for a wider range of risks and uncertainty
- Consider the implications for work-horse economic and finance models and approaches
- Conduct timely and independent research on emissions incentives, promises, and actions
- Acknowledge the limitations of fundamental frameworks in light of massive and profound externalities

Make externalities visible through disclosure

The first two recommendations begin with the recognition of the scale of the externalities that are producing profound climate change impacts on economies, societies, and the planet. A first recommendation is to make externalities visible by advancing our work on measuring and disclosing GHG emissions of nations, firms, plants, and households. While recognizing that disclosure may be imperfect and costly, financial economists should call for complete disclosure of GHG emissions—and through their research, recommend better ways to collect, disclose, and report this data. For example, financial economists are helping to sharpen GHG reporting protocols by considering how to attribute emissions to firms and products. Without adequate data on emissions, we will not be able to conduct meaningful research—nor create management systems, incentives, or rules to drive new behavior

Value the externalities—alongside of traditional valuation approaches

Over the past decades, financial economists have developed and popularized various approaches to value firms and projects. DCF valuation of private costs and benefits is core to most finance courses. We generally do not teach students how to calculate the *social* implications of *private* projects. Given the enormous scale of the externalities imposed by GHG emissions, a first step would be to teach students to routinely calculate GHG emissions of firms and projects, apply the social cost of carbon (SCC) or other measures to these emissions, and calculate the firms' or projects' climate change impacts. This process would have many benefits, including: (a) creating a ready use for emissions disclosures; (b) sensitizing students to the social implications of private wealth creation; (c) encouraging scrutiny of social cost of carbon estimates or alternatives; (d) putting social costs on the same footing as private benefits; and (e) permitting consideration of not only future but also past externalities. A more elaborate approach would be to include not only GHG externalities, but also other externalities and impacts, as proposed by the Impact Weighted Accounts (IWA) approach (Serafeim et al., 2019).

We will need to help students develop judgment to carefully model these social costs. On GHG emissions, do we consider direct (scope 1) or indirect (scopes 2 and 3) emissions or something else altogether? In the spirit of studying marginal impacts, what is avoidable if the project were (not) to go ahead? There are a variety of SCC estimates depending on which outcomes we include, the geographic boundaries of the externalities considered, and the discount rate we employ. What is the appropriate SCC? These rich and substantive discussions parallel those around estimating cash flows and discount rates. By simply making the externalities regularly visible—in every case study, every valuation, every homework assignment, every exam—students will be forced to confront the planetary implications of corporate decisions. Systemically measuring externalities also helps students prepare for when/if carbon taxes are imposed or firms systemically include the cost of carbon in their managerial accounting analyses.

Elinor Ostrom's Nobel-prize winning work on the tragedy of the commons will become an increasingly core element of our work (Ostrom, 1999). As we model the consequences, social discount rates and the social cost of capital will increasingly play a prominent role in our work. Our unit of analyses will have to not only consider individuals, organizations and financial markets, but also our social and planetary systems, melding our considerations of public and private welfare.

Develop a heightened appreciation for a wider range of risks and uncertainty

Finance centers around considerations of risk and return. Modern finance theory, through the notion of diversification, has focused primarily on non-diversifiable or systemic risk as the primary driver of returns and prices. While this remains a powerful concept, climate-related risks force us to ask which risks are systemic, to whom, and when.

The impending climate crisis will surely increase the amount of risk and uncertainty we face, both individually and collectively. Recent research and polls of market participants suggest that the range of climate risks may not yet be fully baked into prices and valuations (Stroebel & Wurgler, 2021). A recent survey of financial institutions shows that, although most firms recognize climate risks, climate risk management is still in its early stages of development (GARP, 2022). Through our work, we can help financial institutions understand how to better

measure and manage these risks. Practitioner are adopting a broader consideration of risks, and so too must we—or we risk becoming increasing irrelevant.

Systematically work through implications for work-horse models

The models we use and teach in finance are the product of decades of refinement, and this long-term familiarity may give us an unwarranted sense of comfort. Yet, climate change should make us far less comfortable with many of these models—and research is beginning to explore how we may need to tweak our business-as-usual approaches. We not only need to help make clearer the impact of corporate decisions on the planet, but also the impact of planetary or policy choices on firms in the form of physical and transition risks.

- Standard DCF approaches often use "terminal values" which assume well-behaved cashflows into the future. However, physical and transition risks may generate very poorly behaved futures, e.g., stranded assets, possibilities of substantial carbon prohibitions and taxes. For example, with stranded assets, terminal values may simply fail to materialize or become negative if there are remediation requirements. In some of the more extreme cases, long-dated investments may simply disappear if the economic bases of activity are fundamentally altered. For example, if we had to limit global warming to 1.5C by 2050 around 60% of oil and gas and 90% of coal could remain in the ground (Welsby et al., 2021).

- Standard valuation approaches look at expected values and well behaved distributions, but climate change forces us to consider a broader range and modality of outcomes. The finance toolkit must be expanded so that students and professionals are more comfortable with and conversant with scenario-based analysis. Climate science and models are primarily based on various transition paths or scenarios (e.g., consistent with temperature rises of 1.5° or 2.0° C degree post-industrial age). Long horizon analyses of firms and projects—as well as some short-horizon analyses—need students to master scenario-based modelling.

- Most standard economic models do not consider climate-change impacts, unlike Integrated Assessment Models (IAMs) which incorporate economic and planetary factors (e.g., Nordhaus (1992). IAMs are joint modelling frameworks of the economy, society and the environment which allow a broader economic policy assessment, including climate change. We are generally also much more comfortable with equilibrium outcomes, whereas planetary models are more likely to generate disequilibrium outcomes, especially if we trigger tipping points. The likelihood of less-rosy disequilibrium outcomes—moving us past dangerous tipping points—is rising. The implication of this, for economic models, is a recognition of the need to model scenarios, rather than expected outcomes; to think in terms of multimodal distributions vs well behaved distributions; to consider tipping points, perhaps in the form of jumps, more commonly. In general, we may lose some of the elegance and analytic simplicity of existing models as we are forced to adopt more computationally-complicated models that link economic outcomes and planetary outcomes more closely.

Conduct timely and independent work on emissions incentives, promises, and actions

While many listed firms have made some sort of Net Zero promise, MSCI—hardly an environmental activist group—estimates that the world's listed companies are on track to

contribute emissions consistent with a 2.9˚ warming outcome[17]. Academics can provide independent evidence-based research on the activities of firms, including tracking emissions promises vs. actions. Are reported emissions falling? If so, are they truly reduced or merely shifted up the supply chain or sold to less-public owners? There are many solutions suggested—from taxes, positive incentives for emissions reduction, outright bans and prohibitions, financial pressure, public pressure, collaboration by industry groups. What is the evidence—in the long and short run—about the effectiveness of these approaches?

Acknowledge the limitations of our fundamental economic frameworks in the face of massive and profound externalities

The First and Second Welfare Theorems hold that competitive equilibria can produce pareto-optimal outcomes—assuming full information, no externalities, and complete markets; and with appropriate redistribution. Yet, climate change induced externalities are profound; markets are incomplete in that future claims relating to these externalities are not traded; and the distribution of harm is so uneven that welfare redistribution is unlikely.

We believe in the power of competitive equilibria. While competition has been a powerful force—and while monopolies and concentration of power more problematic, we may need to re-consider the conditions under which collaboration among firms—to set standards, jointly commit to socially beneficial actions, to jointly stimulate demand for new climate solutions—may be optimal.

A touchstone of modern economics is the consideration of marginal impacts. However, because of the scale of climate-related investments required, we will need to consider aggregate impacts as well as incremental impacts. Although there is disagreement among different studies, the scale of investment required to mitigate climate risk is significant, potentially up to around 4% of GDP per year (McCollum et al., 2018). These investments may require reductions in other spending and will have macro-economic and macro-social impacts. In effect, micro- and macro- analyses will blend together uneasily. Considering only marginal impacts of non-marginal investments might lead to biased appraisals of projects with qualitative and quantitative errors (Dietz and Hepburn, 2013). For example, the IMF estimated that the scale of the clean energy transition might significantly change relative prices of certain commodities such as copper, cobalt, lithium, nickel. These effects are not generally considered in marginal cost-benefit analysis.

A bedrock of modern finance is the time value of money: generally cash flows received in the future are worth less than cash flows today. This normal reasoning would value future lives—our grandchildren and beyond—as less valuable than us, which is a deeply morally fraught question. The ethical question of whether species other than humans or biodiversity have "value" is not easily reconciled with financial models. Since the early days of environmental economics this has been a controversial topic, but finance has not been able to respond with traditional frameworks (W. D. Nordhaus, 2007). More recently, the question of whether lives in different countries should be valued differently has become more prominent and newsworthy, as the US government's social cost of calculations use an economic-value approach.[18] Modeling approaches can have significant repercussions on our societies.

[17] See https://www.msci.com/zh/research-and-insights/net-zero-tracker

[18] For example, see https://www.vox.com/future-perfect/23449849/social-cost-carbon-value-statistical-life-epa

This is not a call to abandon centuries of careful economic analysis, but rather to modernize core economic theory with consideration of the profound implications of the externalities we face. The growing field of climate finance—and the growing cadre of researchers who are sensitive to these issues—is a cause for optimism and hope. Students of systems change hold that one of the most powerful levers for social change is to alter the way that people think and the paradigms they hold. (Meadows, 2008). The new perspectives which climate change forces us to consider may create new ideas to spur action

Conclusion

As we noted earlier, McKinsey has estimated that globally, we will need to spend $9.2 trillion annually to decarbonize our economies, an amount equal to half of global profits or a quarter of global tax receipts. Other work shows that these investments will produce positive economics returns, even before considering harder-to-quantify planetary benefits. These investments—and many more to adapt to the climate crisis—will involve virtually every financial decision maker: policy makers, corporations, and households. The neat dividing lines between public finance, corporate finance, and household finance will get blurred because the causes and consequences of investing revolve around a huge externality that has to date largely been ignored in financial calculations.

One of the core elements of academic finance over the past decades has been to refine our metrics for investment analysis, help us think more deeply about risk and return, and teach this material to students and practitioners around the world. The climate crisis provides a huge opportunity to showcase the contributions that financial economists have made and can make.

The field has already begun to move in this direction. We document a growing and evolving field of climate finance research from a quantitative and qualitative perspective. We see growth and the geographical expansion of this field, and also the increasing awareness of the importance of this issue for traditional finance with top journals and conferences beginning to cover climate finance issues more fully. We see a breadth of topics and interdisciplinarity of the field, so far welcoming many from related and further afield disciplines

Our brief qualitative review mostly discussed empirical work at the intersection of climate change and finance, but also some theoretical work. The empirical work has so far mostly focused on the asset pricing implications of climate change and quantified the potential exposure of the financial system to climate related risks. The theoretical work provided some preliminary theories on the pricing of instruments with different levels of exposure to climate related risks (e.g., carbon premium) or the assets using proceeds for green purposes (e.g., green premium). The review also discussed the growing interest from institutional investors and corporations in climate change, but also how households' finances might be impacted by global warming.

We offered some observations about directions that climate finance might take, and how it might influence our teaching and research in order to spur discussion, debate—and action. Future generations of finance professionals must be much more sensitive to this externality, and that sensitivity can begin with our teaching. We must use this inflection point to revisit some of our workhorse models and techniques, realizing that they may be less relevant in a period of profound uncertainty.

The development of the fields of economics and finance in the past centuries provided powerful frameworks that allowed societies to best allocate scarce resources. This work supported modern economies that have allow many people to thrive. But this thriving has come at a large expense to future generations and the planet, by exploiting a "free" externality: the naïve priviledge of emitting GHGs and profoundly affecting the climate and planet. We are confronted with evidence global warming in the form of destructive extreme weather and changing climate at different latitudes. As in the past, academic finance can provide clear thinking to support change in this decisive decade.

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Appendix

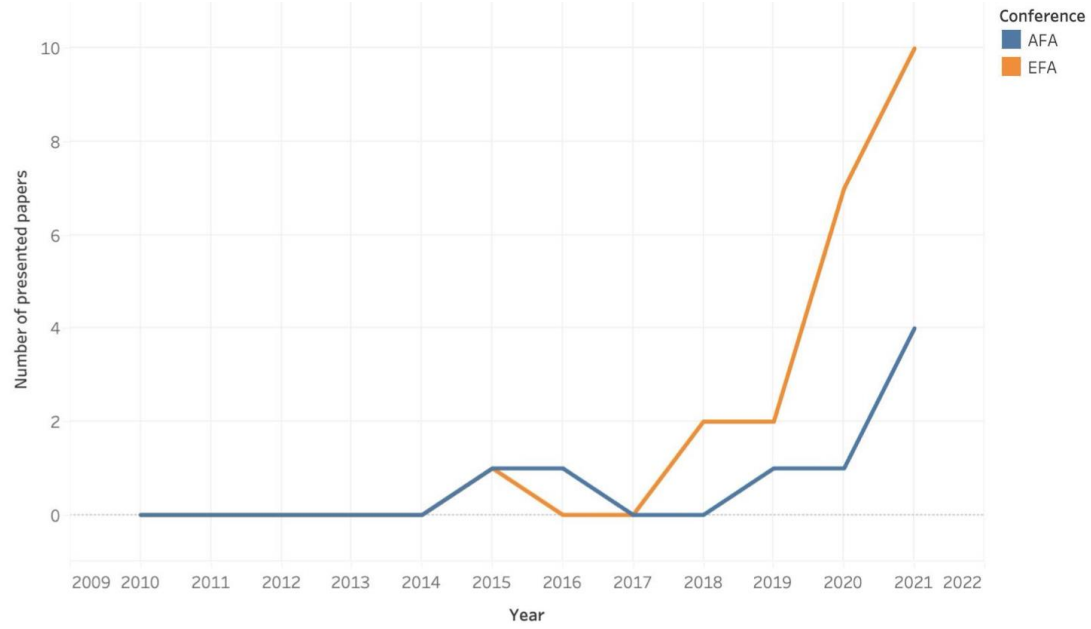

Figure A1: *The figure shows the number of climate finance papers discussed the American Finance Association (AFA) annual conference and European Finance Association (EFA) annual conference.*

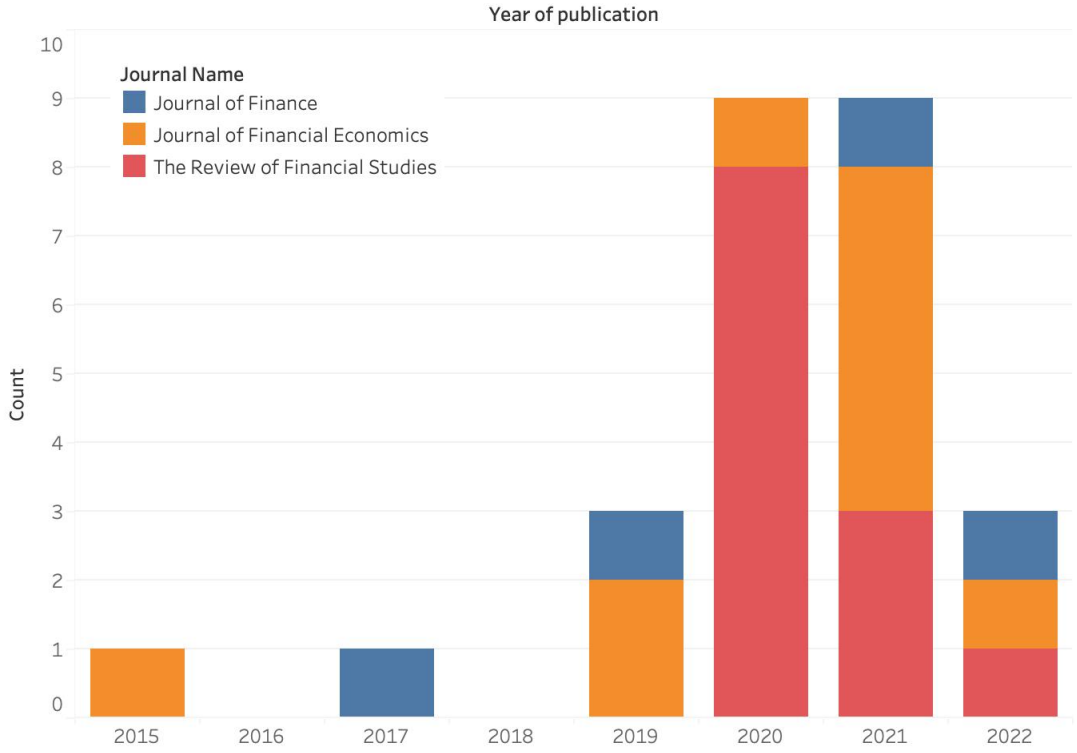

Figure A2: *The figure shows the number of climate finance published in three finance journals: Journal of Finance (JF), Journal of Financial Economics (JFE) and The Review of Financial Studies (RFS) through time. 2022 refers to mid- year figures.*