In the Race to Net-zero: A Fund Flow Investigation

Louisa Chen and Koji Takahashi

Abstract

How are capital markets driving the green transition? This study investigates the response of US energy equity mutual funds and ETFs to climate change risks between 2006 to 2022. We observe a time-varying shift in investment from brown to green energy funds, primarily driven by growing climate concerns. At the macroeconomic level, green fund flows act as a hedge against climate risk shocks by reducing brown fund flows and contributing to the stabilization of stock markets and industrial production growth. The pace of the transition from brown to green energy funds is closely linked to US government climate policies, where a fast net inflow into green (brown) funds enhances (weakens) stock market return and IP growth.

Keywords: Green and brown fund flows. climate change risks. evolving transition. pace of transition.
JEL codes: G11, G23, Q43, Q54.

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1. Introduction

Climate change is characterized by long-term shifts in global climate patterns, most importantly rising global temperatures due to greenhouse gas emissions from the extraction and burning of fossil fuels (Bolton et al. 2020). Global warming has accelerated since 2010 (Hansen et al., 2025)To limit global warming to 1.5°C, greenhouse gas emissions will need to be reduced by 45 percent by 2030 and reach net zero by 2050, as stated in the Paris Agreement. This commitment has prompted the international community to pledge increased financial investments towards climate action and sustainable development.[1] However, critical questions remain: What is the recent state of capital market progress with respect to climate investing? Do investors respond more strongly to imminent policy-related climate risks than to the threat of physical climate change itself? And how does the speed of the energy transition impact capital markets and economic growth? These are the key questions we seek to address in this study.

Climate change poses systemic risks to economies and financial systems, significantly impacting economic activities (e.g., Litterman, 2020). Since the pioneering seminal works of Nordhaus (1977, 1992), extensive research has explored the economic implications of climate change. However, the finance aspect - including pricing, hedging, and investor attitudes towards climate risks - has only recently garnered attention (see Giglio et al., 2021 for reviews). Within this emerging field, the main focus has been on the pricing and hedging of climate risk (e.g., Ardia et al., 2023), while investment decisions and the resulting trading activities have received less attention.

Capital markets play a critical role in mitigating climate risk through directing capital towards sustainable green investments and away from carbon-intensive industries. Green transition is more urgent than ever, as climate change is an accelerative process in the sense that exceeding certain climate tipping points could lead to catastrophic and irreversible impacts (Dangendorf et al., 2019; Bolton et al., 2020). However, the limitations of current technology and the reliance of existing business models on fossil fuels pose severe challenges, as a rapid energy shift could substantially increase energy system costs, potentially halting GDP growth and employment (Hafner et al., 2021; Victor, 2019).

As predicted by the equilibrium model in Pástor et al. (2021) (PST model, hereafter), there is a shift in investment flows from brown firms to green firms due to the latter's relatively lower cost of capital. Green firms achieve a lower cost of capital for three main reasons: investors exhibit a preference for green assets ('green taste'); greener assets provide a hedge against climate risks, resulting in a lower climate beta; and if climate conditions worsen unexpectedly, brown assets tend to lose value relative to green assets, caused by factors such as new regulations that penalize brown firms.

[1] See, for example, World Economic Forum (2024) at https://www.weforum.org/stories/2024/10/alliance-of-ceo-climate-leaders-cop29/.

We focus on the net inflows of energy equity mutual funds and ETFs domiciled in the US between 2006 to 2022.[2] We proceed the analysis in three steps. Firstly, we examine how green and brown energy fund flows respond to climate change risks over time, considering the signs, magnitude, non-linearity, and the speed of responses. In line with the existing literature, we utilise two types of climate risk measure. The first is the MeCCO climate change news index, which tracks climate change news published in highly circulated US newspapers. This index captures public concerns to both policy-related transition risks and physical climate risks. This type of news-based climate risk measure has been commonly used in recent finance literature (e.g., Engle et al., 2020). The second climate risk measure is the Intergovernmental Panel on Climate Change (IPCC) temperature anomaly. Rising global temperatures are closely linked to other climate change variables, such as carbon dioxide emissions, sea level rise, and weather events like droughts and storms (Solomon et al., 2009; Cazenave and Llovel, 2010; Diffenbaugh et al., 2017), which represent many of the physical risks associated with climate change.

In the second step, we simulate the potential impact of green energy investments in curbing brown energy investments and mitigating the adverse effects of climate risk shocks on stock markets and industrial production (IP) growth. Finally, we apply an advanced time-varying model to examine the broader implications of the pace of transition from brown to green investments for the performance of the US stock market (S&P500 index) and industrial production growth as indicators for the wider economy.

We adopt Paul's (2020) vector autoregressive model (VARX), where the structural climate risk shock is exogenous to the economic system and the impulse responses are time dependent.[3] This approach is motivated by two key aspects of climate change. First, climate change and its associated risks are regarded as external factors influencing economic outcomes. at least in the short term (Bansal and Ochoa, 2011; Carleton and Hsiang, 2016). Second, scientific studies find that climate change has accelerated over the past three decades (e.g., Nerem et al., 2018; Dangendorf et al., 2019), and policy shifts between political regimes may introduce structural breaks in time series data. Hence, a time-varying approach is suitable to capture the nonlinear dynamics of climate change and its economic impacts.

[2] We use green and brown energy mutual funds and ETFs as a proxy for green and brown investments in the context of a low-carbon transition. Energy plays a crucial role in economic growth, with the majority of energy production still reliant on fossil fuels, making up around 82% of the global primary energy supply in the last four decades (IEA, 2016, in https://www.iea.org/energy-system/fossil-fuels#programmes). To move the global economy towards a low-carbon path, a crucial step is to reform the energy sector by shifting fossil fuels to renewable sources (UNFCCC, see https://unfccc.int/cop28).

[3] We adopt the VARX model developed by Paul (2020) and adjust the codes that is published at http://www.pascalpaul.de/replication-codes-varx/

We start from a constant parameter VARX to establish an initial intuition, followed by a time-varying parameter VARX to detect any nonlinear patterns in the responses. The endogenous variables in the VAR system include green and brown fund flows, S&P500 index returns, the VIX (volatility index of the S&P500), and US industrial production (IP) growth. Green and brown energy equity funds are identified based on portfolio names and holdings using the Lipper database. Green (brown) fund flows are defined as the percentage of total net inflows relative to the total fund value for the sample green (brown) funds on a monthly basis.

The results from the constant parameter VARX show that MeCCO climate news shocks significantly raise net inflows into green funds while dampening those into brown funds and other economic variables over the sample period from 2006 to 2022. Consistent with this finding, the time-varying VARX reveals a significant time-dependent pattern in the impulse responses of these variables over the examination period from 2015 to 2022.[4] Notably, the response of brown fund flows has become progressively more negative over time, whereas the response of green fund flows follows an inverse U-shaped pattern, peaking in 2020 before declining slightly toward 2022.

Within the 9-month response horizon, the cumulative impulse response of brown fund flows declines each month before stabilizing, while green fund flows continue to rise, emphasizing the momentum in the investment shift. Meanwhile, MeCCO climate news shocks significantly weaken stock market performance and IP growth, with the adverse impact intensifying over time toward 2022. Our result suggests that broad climate change concerns, encompassing both transition and physical climate risks, have boosted investment shifts from brown to green energy in recent years. Our finding supports the prediction of the PST model, showing the increasing scale of transition towards sustainable investments.

Interestingly, temperature anomaly shocks – the proxy for many of the direct physical risks of climate change - drive a gradual increase in green fund investments over time, yet they do not cause divestments in brown funds. In fact, brown funds may even see a delayed recovery in flows following such shocks. This implies that brown fund investors are more inclined to mitigate near-term transition risks, as captured by the MeCCO climate news index, which stem from potential government interventions. However, they are less motivated to address the physical risks posed by climate change itself, as reflected in temperature anomalies.

Our finding is consistent with Stroebel and Wurgler (2021), who surveyed 861 finance academics, professionals, public sector regulators, and policy economists on climate finance topics. They identify

[4] The training sample data from 2006 to 2014 is used to calibrate the prior distributions of parameters for the time-varying VARX.

regulatory risk as the top climate risk for businesses and investors over the next five years, but they view physical risk as the top risk over the next 30 years. We also find that no other economic variables (i.e. VIX and industry production growth) are significantly affected by temperature anomaly shocks, except S&P500 return. For this reason, we use the MeCCO climate news index in the remainder of the analysis due to its significant impact on all endogenous variables.

We further constrain the estimated coefficients of green fund flows to zero in the time-varying VARX and recalculate the impulse responses. We find that, when green fund flows do not respond to climate news shocks, the response of brown fund flows to climate news shocks becomes increasingly negative over the 9-month response horizon from 2015 to 2022. Similarly, heightened adverse effects are observed in S&P500 return and volatility, as well as in industrial production growth. This finding emphasizes the important role of green investments in addressing climate change.

Then, we follow the methodology outlined in the literature (e.g., Ball, 1994) and define the speed change of fund flows as the difference of the p^{th} period cumulative impulse responses (CIRs) between the two consecutive calendar months, as estimated in the previous time-varying VARX. We find that the speed change of green and brown fund flows evolves in opposing directions. Visually, the increase (decrease) in net inflows into green (brown) funds coincides with the upheaval in the US changing stance on the Paris Agreement. Indeed, our regression analysis shows that the US climate policy uncertainty Index, which tracks changes in US climate policy, significantly slows green fund flows while accelerating brown fund flows. This highlights the pivotal role of government climate policies in driving the rate of progress in energy transition.

Using the estimated cumulative impulse response (CIRs) from the time-varying VARX, we also observe that the pace of net inflows into green funds in response to climate news shocks is strongly and positively correlated with S&P500 return and industrial production (IP) growth. Conversely, the pace of net inflows into brown funds has the opposite effect, particularly on IP growth. This finding may signal that the US stock market and economic growth are capable of accommodating the current pace of energy transition.

We conduct several robustness tests on our findings. These include an alternative approach for identifying green funds based on the E-rating element of the fund's ESG rating, as well as controlling for the influence of oil prices, inflation, and extreme events within the sample. The results of these robustness tests in each case demonstrate qualitative consistency with the main findings.

Our study makes three important contributions to the literature. First, we contribute to the theoretical literature by identifying a time-varying shift from brown to green energy fund investments. This transition is primarily driven by broad climate concerns, especially US government climate policies, and is less influenced by physical climate change risks, which do not seem to encourage divestment from brown

funds. Second, we contribute to the empirical literature by analyzing the hedging capabilities of green investments against climate risk shocks. Specifically, we demonstrate their role in reducing brown investments and stabilizing both stock markets and economic growth. Finally, we contribute to the ongoing debate on the pace of the brown-to-green energy transition. Our empirical findings reveal that government climate policies play a significant role in accelerating the shift from brown to green energy investments. Most importantly, we assess whether US stock markets and economic growth have been able to accommodate this pace of transition in recent years.

Our study is related to recent developments in the theoretical climate finance literature. This body of research suggests that the presence of climate risk can increase market values of green firms while reducing that of brown firms, thereby driving a shift in real investments from brown to green firms (Ambec & Lanoie, 2008; Freeman, 1984; and Pástor et al., 2021). Recent empirical studies have documented a significant increase in flows into green energy ETFs compared to traditional energy ETFs from 2009 to 2019, especially following the Paris Agreement (Reboredo and Otero, 2021), as well as investors' preference for mutual funds with lower climate-related transition risks or higher sustainability ratings (Ammann et al., 2019; Hartzmark and Sussman, 2019; Reboredo and Otero, 2021; Ceccarelli et al., 2023). While this body of research primarily examines investment flows from a static perspective or explores the relationship between environmental performance disclosures and investment flows, our study diverges by focusing on the evolving patterns of sustainable investment transitions, their pace, and their implications for capital markets and economic output.

Our study is also related to the growing literature that examines the adverse economic impacts of climate change (e.g., Dell et al., 2014; Nordhaus, 2019; and Batten et al., 2020). A detailed literature review will be presented in the following section.

The remainder of the paper is structured as follows: Section 2 provides a review of the related literature. Section 3 outlines the sample data and methodology employed. Sections 4 and 5 present the results of the VARX analysis and the speed of transition analysis, respectively. Section 6 discusses the findings from the robustness tests. Finally, Section 7 summarizes the key findings and discusses their policy implications.

2. Literature review

The growing concern over the environmental impact of traditional energy production and its contribution to global warming is likely to drive increased investment in clean and renewable energy (Climent and Soriano, 2011). According to stakeholder theory, firms have a responsibility to create value for all stakeholders (Freeman, 1984). In this context, green energy firms could achieve better financial performance compared to brown energy firms, as they may have lower costs and higher profits (see a review in Ambec and Lanoie, 2008). This perspective is further supported by Pástor et al. (2021), who

integrate climate betas into a traditional equilibrium asset pricing model, alongside market betas and investor preferences. Their model reveals that greener firms exhibit lower climate betas than brown firms, resulting in a reduced cost of capital and higher market valuations. This dynamic encourages a shift in investment from brown to green energy firms. Empirical studies, such as Choi et al. (2020) and Engle et al. (2020), provide additional evidence that brown assets generally carry higher climate betas compared to green assets, reinforcing the financial advantages of investing in sustainable energy firms.

Recent empirical research has linked climate change to financial markets. While most of the studies focus on the impact of climate risk on asset prices,[5] others have examined its influence on investment flows. For example, Reboredo and Otero (2021) demonstrate that investments in green energy ETFs are higher relative to traditional energy ETFs between 2009 and 2019, particularly following the Paris Agreement. Additional research indicates that mutual fund investors tend to favor funds with lower climate-related transition risks or higher sustainability ratings. Additional research indicates that mutual fund investors tend to favor funds with lower climate-related transition risks or higher sustainability ratings (Ammann et al., 2019; Hartzmark and Sussman, 2019; Reboredo and Otero, 2021; Ceccarelli et al., 2023).

A related literature has explored how to hedge climate risk with low carbon footprint assets that may or may not sacrifice financial returns A related strand of literature investigates strategies for hedging climate risk using low-carbon footprint assets, exploring whether such investments compromise financial returns (e.g., Andersson et al., 2016; de Jong and Nguyen, 2016; Trinks et al., 2018; Boermans and Galema, 2019; Monasterolo and de Angelis, 2020).

A large body of literature models and estimates climate change's effects on economic outcomes. These studies typically begin with assumptions about future emissions, the magnitude and pattern of global warming, and other potential dimensions of climate change. Using a variety of methodologies, researchers then translate these climate-related factors into economic consequences. Climate change is widely understood to influence agricultural and industrial productivity, energy demand, economic growth, labor efficiency, and political stability. These impacts could lead to substantial financial losses, diminished wealth, and a decline in GDP (see Dell et al., 2014; Bansal et al., 2016; Batten et al., 2020; Nordhaus, 2019 for reviews). Empirical studies demonstrate that abnormal temperatures and other climate-related phenomena heighten economic risk, adversely affecting firms' earnings and equity valuations. Over time, these factors exert an increasingly negative impact on equity prices (Bansal et al., 2016 a, b; and Hugon and Law, 2019).

3. Data and methodology

[5] See, for example, Ardia et al., 2023, Alekseev et al. (2024); Ardia et al. (2022); Bernstein et al. (2022); Bolton and Kacperczyk (2021); Flammer (2021); Ho (2022); Hong et al. (2019); Painter (2020); Pástor et al. (2022); Schlenker and Taylor (2021); Giglio et al. (2021); Hong et al. (2020); and Pástor et al. (2021).

3.1 Data

3.1.1 Fund flows

Our data on mutual funds and ETFs is from Lipper. We construct a sample of equity energy mutual funds and ETFs through the following procedure. First, we identify funds and ETFs that are categorized within the energy and utilities sectors, domiciled in the US, denominated in USD, and primarily invest in global equities. Following recent literature (see, for example, Martí-Ballester, 2019; and Lantushenko et al., 2020), we classify these funds into green energy funds (REs) and brown energy funds (BEs). Green energy funds are those that a) include at least one of the following keywords in the fund name: *clean, fossil free, renewable, zero carbon, low carbon, green energy, free crude oil, sustainable*, and b) allocate more than 50% of their assets to firms in the oil and gas production sector or the oil equipment services and distribution sector. Brown energy funds, on the other hand, are those that invest more than 50% of their assets in firms categorized within the oil and gas production sector or the oil equipment services and distribution sector.[6]

The final sample comprises 417 green funds and 371 brown funds (at the share class level).[7] Over the sample period, the number of green funds ranges from 70 to 358, while the number of brown funds ranges from 82 to 195. On average, there are 143 green funds per month, with an average assets under management (AUM) 0.18 billion USD per fund. In comparison, the average number of brown funds is 112 per month, with an average AUM 0.39 billion USD per fund. In addition, the monthly average size of non-green and non-brown funds is 0.69 billion USD per fund. Overall, the size of green funds is smaller than those of brown fund as well as non-green and non-brown funds. In terms of performance, green funds achieve an average monthly return of 0.53%, while brown funds yield 0.30%. Non-green and non-brown funds, meanwhile, have an average monthly return of 0.56%.

We aggregate the net inflows[8] and market value (AUM) of green energy funds on a monthly basis and calculate green energy fund flows (green fund flows, hereafter) as the percentage of aggregate net inflows relative to the aggregate fund value within each month.[9] Brown energy fund flows (brown fund flows, hereafter) are defined in the same manner. Figure 1(a) illustrates the trends in green and brown fund flows over the sample period. Visually, green fund flows consistently exceeded brown fund flows after 2017.

[6]Drawing on existing literature, it is reasonable to assume that investors adjust their allocations between brown and green energy funds based on the proportion of green assets held within the fund at the time when they investment. This assumption remains valid regardless of whether the funds are actively or passively managed, or whether they primarily invest in brown firms with the objective of transitioning those firms toward more sustainable practices.

[7] The remaining 27142 funds are considered non-green and non-brown funds.

[8] Fund flows in Lipper are calculated by subtracting fund performance.

[9] In this paper, "fund flow" refers to net inflow of the fund unless specified otherwise.

This pattern suggests that the Paris Agreement, an internationally recognized climate change treaty that took effect on November 4, 2016, may have played a role in driving increased investment in green energy.

3.1.2 Climate change news index and economic variables

Climate change is a complex phenomenon that encompasses various dimensions of risk. In the existing literature, these risks are typically categorized as transitional risk and physical risk. Transition risk pertains to potential threats posed to certain business models due to regulatory measures aimed at reducing emissions and promoting the transition to a low-carbon economy. Physical risk, on the other hand, refers to the direct consequences of climate change, such as extreme temperatures and rising sea levels, which can cause significant damage to businesses and households (Engle et al., 2020; and Jung et al., 2023).

A widely used approach to assessing climate risk involves textual and narrative analyses of climate change-related news. This approach quantifies the intensity of climate change news coverage in newspapers, websites, and other media sources, including topics such as natural disasters, global warming, international summits, and climate policy. Given their comprehensive coverage of climate-related topics, news-based climate risk measures are regarded as indicators of investor attention to both physical and transitional climate risks (Engle et al., 2020;Choi et al., 2020; Faccini et al., 2023; Ardia et al., 2022; 2023; Kölbel et al., 2024; Li et al., 2024).

For example, Engle et al. (2020) introduce two news-based climate risk indices: the *WSJ Climate Change News Index* and the *CH Negative Climate Change News Index*. The former is derived from climate-related news in the *Wall Street Journal (WSJ)*, while the latter is constructed by analyzing negative climate change news from over 1,000 media outlets. A key assumption in their study is that, in the context of climate change, "no news is good news." [10] However, these indices are only available up to 2018 and do not cover our entire sample period. As a result, we adopt the conceptual framework of Engle et al. (2020) and use the MeCCO Climate Change News Index as an alternative measure in our analysis.

The MeCCO index monitors highly circulated newspapers in the US, compiling data from archives accessed through the Nexis Uni, Proquest and Factiva databases via the University of Colorado libraries. The index identifies relevant articles containing the terms ‘climate change’ or ‘global warming’ and calculates the total number of articles each month in each region, normalized by the number of

[10] The authors find that the performance of climate risk-hedging portfolios remains consistent, regardless of whether they are designed to hedge against the WSJ Climate Change News Index or the CH Negative Climate Change News Index.

newspapers searched during that month.[11] We transform the MeCCO index into logarithmic values for our analysis.

Physical risk is commonly measured by indicators such as rising temperatures and extreme weather events, especially the former is a key indicator of climate change in both scientific and economic research (e.g., Cachon et al., 2012;Zivin and Neidell, 2014;Burke et al., 2015). Continuous rising temperatures signify higher climate risks, which can disrupt normal business operations (Zivin and Neidell, 2014,2018), increase production costs (Huynh et al., 2020), and reduce industry earnings (Addoum et al., 2020, 2023). Warmer temperatures are also closely linked to other climate change variables, such as carbon dioxide emissions, sea level rise, and weather events like droughts and storms (Solomon et al., 2009; Cazenave and Llovel, 2010; Diffenbaugh et al., 2017), highlighting the physical risks associated with climate change.

Hence, the second climate risk measure we apply is the Intergovernmental Panel on Climate Change (IPCC) temperature anomaly - the HadCRUT5 Land and Marine Temperature Anomaly for the Northern Hemisphere (Temp_Anomaly, hereafter). This time series is calculated as grids of monthly anomalies relative to the 1961–1990 baseline. Notably, the value of this measure has remained above zero since 2000, indicating that temperatures above the historical average have become the norm during this period.

While the Temp_Anomaly index is naturally exogenous to financial markets and the economy (at least, no simultaneous influence), we regard the MeCCO index as exogenous as well, given its broad coverage of news outlets beyond just *The Wall Street Journal*.[12] Nonetheless, to ensure the exogeneity of the climate risk measures, the series of climate risk measures – both the MeCCO and Temp_Anomaly indices - are projected onto the three lags of the endogenous variables in the VAR system ($\boldsymbol{y}_t$). The residuals from this projection are then used as the exogenous climate risk measures (z_t), ensuring that z_t is uncorrelated with $\boldsymbol{y}_t$ and not serially correlated. Details of this estimation will be described in Section 4.1.

Figure 1(b) illustrates the MeCCO climate change news index and Temp_Anomaly index from December 2006 to November 2022. While both indices show an upward trend, particularly after 2010, some divergence is evident during certain periods. For instance, significant declines in the Temp_Anomaly during 2007 and 2020 are not mirrored in the MeCCO index. The correlation between the two indices over the sample period is 0.46, suggesting that the MeCCO index may capture a broader range of climate concerns, including both transition and physical risks. In contrast, the Temp_Anomaly serves as a more specific measure of climate risk, primarily reflecting physical risks.

[11] For more details on index construction, please refer to the MeCCO website.
[12] The news outlets include the *Washington Post, Wall Street Journal, New York Times, USA Today* and *Los Angeles Times*.

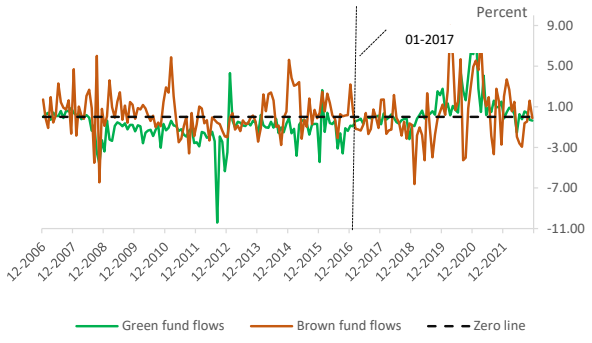
The daily data of the S&P500 index and VIX as well as monthly data of the US consumer price index are from WRDS. The monthly data of US industry production and APSP crude oil index are from the website of the Federal Reserve Bank of St. Louis. For the endogenous variables in the VARX model, we use the last day of the month S&P500 index logarithm return (SP500 return, in percentage) and VIX (index level) as the monthly inputs. Industry production growth (IP growth) and oil return are the monthly percentage change of the initial time series. Inflation is the monthly percentage change of the US consumer price index. All the time series are stationary according to the Augmented Dickey–Fuller unit-root test. A summary definition of the variables is presented in Appendix A. The following Table 1 shows their summary statistics and correlation matrix.

Panel A of Table 1 indicates that the average green fund flows are negative over the sample period, whereas it is positive for brown fund flows. The limited investment in green energy before 2017 - prior to the implementation of the Paris Agreement - significantly lowers the sample average. Panel B of Table 1 reveals a strong and positive correlation between green fund flows and the MeCCO and Temp_Anomaly climate risk indices, particularly with the former. In contrast, this relationship is much weaker for brown fund flows. This preliminary analysis suggests that climate risk may encourage green fund investments but does not appear to deter brown fund investments.

Figure 1. Green fund flows, brown fund flows and climate risk indices

This figure plots the monthly green fund flows, brown fund flows, and the two climate risk indices - the MeCCO climate change news index and Temp_Anomaly index from 2006M12 to 2022M11. All variables are defined in Section 3.

(a) Green and brown fund flows



(b) Climate risk indices

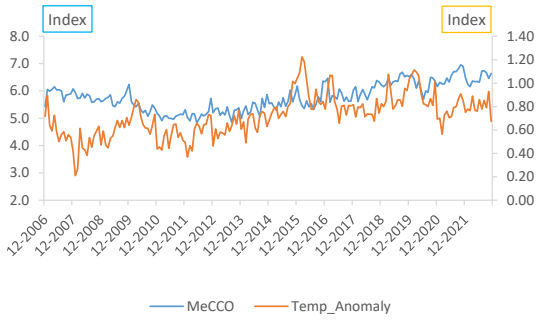


Table 1. Summary statistics

All variables are defined in Section 3.1.

Panel A*. Summary statistics*

	Obs	Mean	Median	Std. dev.	Min	Max
Green fund flows (%)	192	-0.44	-0.50	1.88	-10.40	8.58
Brown fund flows (%)	192	0.31	0.06	2.30	-6.62	8.96
SP500 rerturn (%)	192	0.14	0.26	1.43	-8.93	4.60
VIX (Index)	192	20.42	17.82	9.14	9.45	68.51
IP growth (%)	192	0.03	0.12	1.36	-13.20	6.28
MeCCO (Index)	192	5.78	5.73	0.50	4.84	6.96
Temp_Anomaly (Index)	192	0.72	0.72	0.17	0.21	1.22
Oil return (%)	192	0.27	1.68	9.72	-50.68	29.28
Inflation (%)	192	0.20	0.19	0.40	-1.92	1.37

Panel B. *Correlation matrix*

	Green fund flows (%)	Brown fund flows (%)	SP500 rerturn (%)	VIX (Index)	IP growth (%)	MeCCO USA (Index)	MeCCO NA (Index)	Oil return (%)
Brown fund flows	0.25							
SP500 rerturn	0.11	0.15						
VIX	-0.03	0.12	-0.39					
IP growth	0.10	-0.17	0.17	-0.32				
MeCCO	0.48	0.05	0.01	0.05	-0.06			
Temp_Anomaly	0.24	0.02	0.09	-0.18	-0.05	0.44		
Oil return	0.19	0.03	0.15	-0.17	0.38	-0.02	-0.11	
Inflation	0.24	0.12	0.23	-0.24	0.23	0.13	-0.04	0.61

3.2 Methodology

In this section, we describe Paul's (2020) vector autoregressive model (VARX) adopted in our analysis. This model can estimate the impulse responses of fund flows and US market indicators in both constant and time-varying manner, where the structural climate risk shocks are exogenous to the economic system. This model is suitable for our analysis for two reasons. First, the response of green and brown fund flows to climate risk shocks may exhibit nonlinear characteristics. Scientific studies have documented an accelerating climate change over the past three decades. For example, both empirical studies and climate model projections demonstrate that global mean sea level has been rising faster since 1993 (see Nerem et al., 2018; and Dangendorf et al., 2019), and the risk premium associated with carbon dioxide emissions on equity prices is variable over time (Alessi et al., 2021). Reports from the IPCC and private scholars also suggest that the impacts of climate change are likely to be nonlinear and cumulative (IPCC, 2014[13], 2018[14]; and Nordhaus, 2019). In addition, policy changes between political regimes can lead to structural breaks in time series data. For instance, a Democratic administration might emphasize increased spending and environmental regulations, whereas a Republican administration may prioritize tax cuts and deregulation. These shifts may introduce non-stationarity, as the economic conditions before and after such changes may follow different processes.

[13] See https://unfccc.int/topics/science/workstreams/cooperation-with-the-ipcc/the-fifth-assessment-report-of-the-ipcc

[14] See https://www.ipcc.ch/sr15/download/

The second reason is that climate risk is exogenous to economic outcomes in the short term. Although it is widely acknowledged that human activities, such as carbon emissions, contribute to current climate change, climate change and its associated risks are regarded as external factors influencing economic outcomes in the near term. (Bansal and Ochoa, 2011; and Carleton and Hsiang, 2016).

The VARX model is presented below.[15] Assuming the general structural form of $\boldsymbol{y}_t$ evolves as follows:

$$Hy_t = C_0 + C_1 y_{t-1} + \cdots + C_k y_{t-k} + \epsilon_t, \tag{1}$$

where H and C_k are conformable coefficient matrices, ϵ_t is an $n \times 1$ vector of structural shocks. y_t is an $n \times 1$ vector of endogenous variables at month t, defined as follows:

$$\boldsymbol{y}_t \equiv [\text{GE}, \text{BE}, \text{SP500 return}, \text{VIX}, \text{IP growth}]', \tag{2}$$

where GE and BE represent the monthly green and brown fund flows respectively, SP500 return is the logarithm return of the S&P500, VIX is the S&P500 implied volatility index, and IP growth is the US industry production growth. All variables are defined in the previous section. Multiplying each side of the equation (1) by H^{-1}, we obtain the following equation:

$$y_t = B_0 + B_1 y_{t-1} + \cdots + B_k y_{t-k} + \mu_t, \tag{3}$$

where $\mu_t = H^{-1}\epsilon_t$ collects the impulse vectors of the shocks.

Assume that the interest lies in the identification of impulse responses to one of the structural shocks, denoted by $\epsilon_{1,t}$, the residual in the above model can be rewritten as:

$$\mu_t = s\epsilon_{1,t} + S\epsilon_{2,t}, \tag{4}$$

where s is the impulse vector associated with $\epsilon_{1,t}$ and the $(n-1) \times 1$ vector $\epsilon_{2,t}$ collects all other structural shocks. The contemporaneous *relative* impulse response of some other variable i in y_t with $i \neq j$ is defined as:

$$r_{ij} = \frac{s_i}{s_j}, \tag{5}$$

where s_i indicates the i^{th} element of vector s.

Now we consider an exogeneous instrument variable z_t and assume that z_t is correlated with the structural shock of our interest, $\epsilon_{1,t}$, and uncorrelated with the remaining structural shocks. Instead of using z_t as an instrument of $\epsilon_{1,t}$, we directly introduce it in the VAR model as an exogenous variable as follows:

[15] For more detailed information about the model and its validity, please refer to the original paper by Paul (2020).

$$y_t = \tilde{B}_0 + \tilde{B}_1 y_{t-1} + \cdots + \tilde{B}_k y_{t-k} + \tilde{A} z_t + \tilde{u}_t, \quad (6)$$

where $\tilde{A}$ is an impact vector for z_t, tildes are used to distinguish variables and coefficients from the notations. In this context, z_t is the climate risk index and $\epsilon_{1,t}$ is a climate risk shock. Then, the contemporaneous *relative* impulse response to shock $\epsilon_{1,t}$ is given by:

$$\widetilde{r_{iJ}} = \frac{\widetilde{A_i}}{\widetilde{A_J}}, \quad (7)$$

where the estimated $\widetilde{A_i}$ and $\widetilde{A_J}$ with $i \neq j$ are two elements in $\tilde{A}$.

In the following section, we first estimate the constant parameter VARX model, as specified in equation (3), to gain initial intuitions. Then we proceed to estimate the time-varying parameter VARX model given by:

$$y_t = B_{0,t} + B_{1,t} y_{t-1} + \cdots + B_{k,t} y_{t-k} + A_t z_t + u_t, \quad (8)$$

t=1, …, T.

where $B_{0,t}$ is an $n \times 1$ vector of time-varying intercepts and $B_{j,t}$ for $j \in \{1, \ldots, k\}$ are the $n \times n$ time-varying coefficient matrices with respect to the lagged endogenous variables. A_t is the $n \times 1$ vector of time-varying coefficients of the exogenous variable z_t. z_t is linked to the structural shock $\epsilon_{1,t}$ as follows:

$$z_t = \gamma \epsilon_{1,t} + \eta_t,$$

$E(\eta_t y_t) = 0$ and $\eta_t \sim N(0, \sigma_\eta)$.

Additionally, we define B_t as a vector that stacks all coefficients in the VAR model including the exogeneous variable z_t, and assume that B_t follows a driftless random walk as follows:

$$B_t = B_{t-1} + \nu_t$$

Assume that the innovation terms follow a jointly normal distribution with mean zero, and the variance-covariance matrix is a block diagonal as follows:

$$\nu = Var \begin{bmatrix} u_t \\ \nu_t \end{bmatrix} = \begin{bmatrix} \Omega & 0 \\ 0 & \varrho \end{bmatrix},$$

where Ω and ϱ are positive definite matrices.

The contemporaneous *relative* impulse response is given by:

$$\widetilde{r_{t,iJ}} = \frac{\widetilde{A_{t,i}}}{\widetilde{A_{t,J}}}. \quad (9)$$

4. Response of fund flows and economic indicators to climate risk shocks

In this section, we present the results obtained by using two climate risk indices – the MeCCO climate change news index (MeCCO) and Temp_Anomaly index.

4.1 Climate risk measured by MeCCO

4.1.1 Constant VARX

We start with a constant parameter VARX as defined in equation (3) to gain insight into the responses of fund flows and the US economy to climate risk shocks. The estimation in equation (3) consists of the following specifications. Firstly, the lag length $k = 3$ is chosen based on AIC. Secondly, the series of MeCCO climate news index is projected on the 3 lags of $\boldsymbol{y}_t$, and residuals from this projection are used as the exogenous variable z_t, ensuring that z_t is not correlated with $\boldsymbol{y}_t$ and is not serially correlated, as required by Paul (2020). Thirdly, the size of the shock is normalized to match the initial fall in the industry production growth to a 1SD climate risk shock – z_t, as calculated in the previous step. Lastly, the credibility intervals are computed using a residual-based moving block bootstrap. [16]

Figure 2 presents the cumulative impulse responses of green and brown fund flows, SP return and IP growth as well as the *impulse response* of VIX[17] to a MeCCO climate news shock. The median response is shown, along with 68% and 90% credibility intervals. The sample period ranges from December 2006 to November 2022.

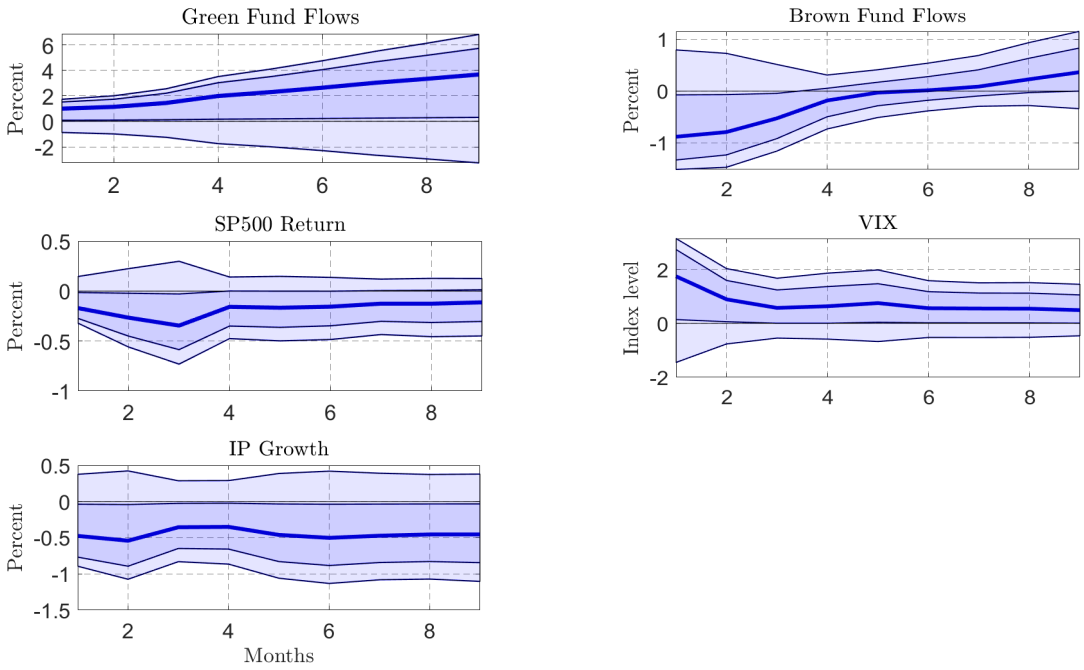
As shown in Figure 2, within the 68% credibility intervals, green fund flows exhibit an immediate increase of 1.01% following a climate news shock. The cumulative impulse response (CIR) continues to rise, reaching 3.72% after 9 months. In contrast, brown fund flows experience a significant initial decline of -0.89% immediately after the shock, eventually recovering to 0.37% after 9 months, though at a lower level of significance. The stark difference in the responses of green and brown fund flows to the climate news shock aligns with the predictions of the PST model.

Turning to the economy, the climate news shock exerts a negative impact on both the stock market and industrial production. Specifically, the cumulative impulse response (CIR) of S&P500 return declines by -0.17% immediately after the shock and stabilizes at around -0.11% over a period of 9 months. The *impulse response* (*IR*) of VIX increases by 1.8 index point immediately after the shock, then stabilizes at around 0.4 index point over the same 9-month period. The CIR of industrial production growth remains at around -0.48% during this time frame. These findings align with the theoretical prediction made by

[16] All the time series involved in the estimation are stationary and exhibit no serial correlation.
[17] The remainder of the paper will present the *impulse response* for VIX (level) rather than cumulative impulse response.

Nordhaus (2019).

Figure 2. Impulse response to an MeCCO climate news shock within a constant parameter VARX
This figure illustrates the cumulative impulse responses to an exogenous MeCCO climate news shock, estimated from a constant-parameter, 3-lagged VARX model based on equation (3), except for VIX which is plotted as an *impulse response.* The responses are normalized to match the initial decline in IP growth from a 1 SD climate news shock. The median response is displayed, along with 68% and 90% credibility intervals. The sample period spans from December 2006 to November 2022. All variables are defined in Section 3.



4.1.2 Time-varying parameter VARX

As discussed in Section 3.2, financial markets and the broader economy may respond to climate risk shocks in a non-linear manner. To address this issue, we estimate the VARX model with time-varying parameters as defined in equation (8). Following the methodologies of Primiceri (2005) and Paul (2020), we calibrate the prior distributions using a training sample spanning eight years (2006M12 - 2014 M12). The remaining portion of the sample (2015M1 - 2022M11), referred to as the examination period, is used to estimate the time-varying impulse responses. Based on the OLS estimates of a constant parameter VARX model using the training sample, the mean and variance of B_0, scale matrix and degrees of freedom for the inverse-Wishart prior of Ω and ϱ are set to be:

$$B_0 \sim N\left(\hat{B}_{OLS}, 6 \times V\left(\hat{B}_{OLS}\right)\right),$$
$$\Omega \sim \text{IW}(I_n, n+1),$$
$$\varrho \sim IW\left(k_\varrho^2 \times \tau \times V\left(\hat{B}_{OLS}\right), \tau\right), \quad (10)$$

where $\hat{B}_{OLS}$ is the OLS point estimates from the training sample with a variance of $V\left(\hat{B}_{OLS}\right)$, $\tau = 97$ (months) is the size of the training sample, k_ϱ is the prior belief about the amount of time variation in B_t set at 0.02.[18] The simulation of the model is based on 5000 iterations of the Gibbs sampler, and the first 4000 are discarded for convergence.

To ensure the reaction to the same-size shock $\epsilon_{1,t}$ over time, we normalize the response of IP growth to -20 basis points at the beginning of the examination period (2015M4), giving a particular value of $\bar{z}$ the instrument to achieve this response. That said, $\bar{z} = (-0.2)/\bar{A}_{2015M4}$, where $\bar{A}_{2015M4}$ is the estimated posterior mean for IP growth at time 2015M4. The same variation $\bar{z}$ is then used to obtain contemporaneous impulse responses for other variables in 2015M4 or any subsequent period. Figure 3 presents the cumulative impulse responses (CIRs) of the time-varying VARX with a 9-month response horizon from 2015M4 to 2022M11.[19]

As shown in Figure 3, the impulse responses of the time-varying parameter VARX are consistent with those of the constant parameter VARX (Figure 2) in terms of the signs of the responses, except that the CIR of brown fund flows remains negative in the 9-month response horizon during the examination period.[20] Most importantly, Figure 3 demonstrates the changing impulse responses over time. For green fund flows, the contemporaneous impulse response to climate news shocks increases steadily, peaking in 2020. Its cumulative impulse response (CIR) also shows a consistent upward trend over the 9-month response horizon during the same period. In contrast, the contemporaneous response of brown fund flows becomes more negative toward the end of 2022, while its CIR continues to decline over the 9-month response horizon during the examination period.

To simplify, Figure 4 depicts the time-varying cumulative impulse responses (CIRs) of green and brown fund flows at selected response horizons during the examination period.[21] At the 3-, 6-, and 9-month horizons following the climate news shock, the CIRs of green fund flows remain positive and exhibit an upward trend over time. This increase is particularly pronounced from 2017 to 2020, though

[18] Primiceri (2005) indicates the sensitivity of results to k_Q. Setting a lower value of k_Q decreases the time variation in the coefficients B_t, resulting in less time variation of the impulse response. Setting a higher value of k_Q works the opposite way. Hence, we experiment with different prior values for $k_Q = \{0.01,\ 0.03\}$, and our conclusions remain consistent.

[19] Figure B.1 of Appendix B presents the credibility intervals for a selected period - 2020M1, as an example.

[20] Note that the magnitude of the CIRs differs between Figures 2 and 3 because of the time-varying assumptions of $\bar{z}$ in the estimation.

[21] See Appendix G for the credibility interval of CIRs.

the rate of growth has slowed in more recent years. This coincides with important changes to US climate policy – the government formally left the Paris Agreement in November 2020, after announcing that decision in June 2017, then rejoined in February 2021. In addition, higher CIRs are also observed at longer response horizons, suggesting the momentum in the net inflows of green funds following the climate news risk shock. On the contrary, the CIRs of brown fund flows show an opposite pattern. Our findings imply that increasing attention to climate risk among investors has driven a significant shift toward sustainable energy investments over the past decade, a trend that is sure to be further influenced by US government climate policies.

Regarding the stock market and industrial production (IP) growth, Figure 3 reveals that, in response to climate news shocks, the contemporaneous reaction of the S&P500 return remains negative throughout the examination period (2015M4 - 2022M11), with its cumulative impulse response (CIR) displaying an inverse U-shaped pattern over the 9-month response horizon during the same timeframe. The impulse response (IR) of stock market volatility, as measured by the VIX, spikes sharply by approximately 1.2 to 1.4 index points immediately following a shock, before declining and stabilizing at a lower but still positive level in the subsequent months. The overall response of the VIX intensifies toward the end of 2022. These trends show that climate risk has increasingly exerted a negative influence on stock market performance in recent years. Similarly, the CIR for industrial production (IP) growth follows a comparable pattern and carries analogous implications to that of the S&P500 return.

To summarize, our findings align with recent literature, which suggests that increased climate risk increases the prices of green energy while reducing its volatility (Dutta et al., 2023). Our findings also support the argument that investing in decarbonized indices allows long-term passive investors to hedge against climate risk without sacrificing financial returns (Andersson et al., 2016). From a macroeconomic perspective, green investments can mitigate climate uncertainty and enhance financial stability (Cepni et al., 2022; and Yousaf et al., 2022). In addition, our findings resonate with the principles of green growth theory, which has gained widespread recognition among national and international organizations. Since the 2012 Rio+20 Conference on Sustainable Development, policymakers have increasingly focused on transitioning energy systems from brown energy sources (e.g., coal, oil, and gas) to green energy sources (e.g., wind, solar, and biofuel), as advocated by institutions such as the OECD, the United Nations Environment Program, and the World Bank.

Figure 3. Time-varying impulse responses to an MeCCO climate news shock

This figure shows the time-varying cumulative impulse response of green fund flows, brown fund flows, S&P500 return and IP growth, as well as the *impulse response* of VIX to an exogenous climate news shock (MeCCO) using equations (8) and (9). Prior $k_Q = 0.02$. All variables are defined in Section 3. *y*-axis: percentage or index level. *x*-axis (left): months. *x*-axis (right): years.

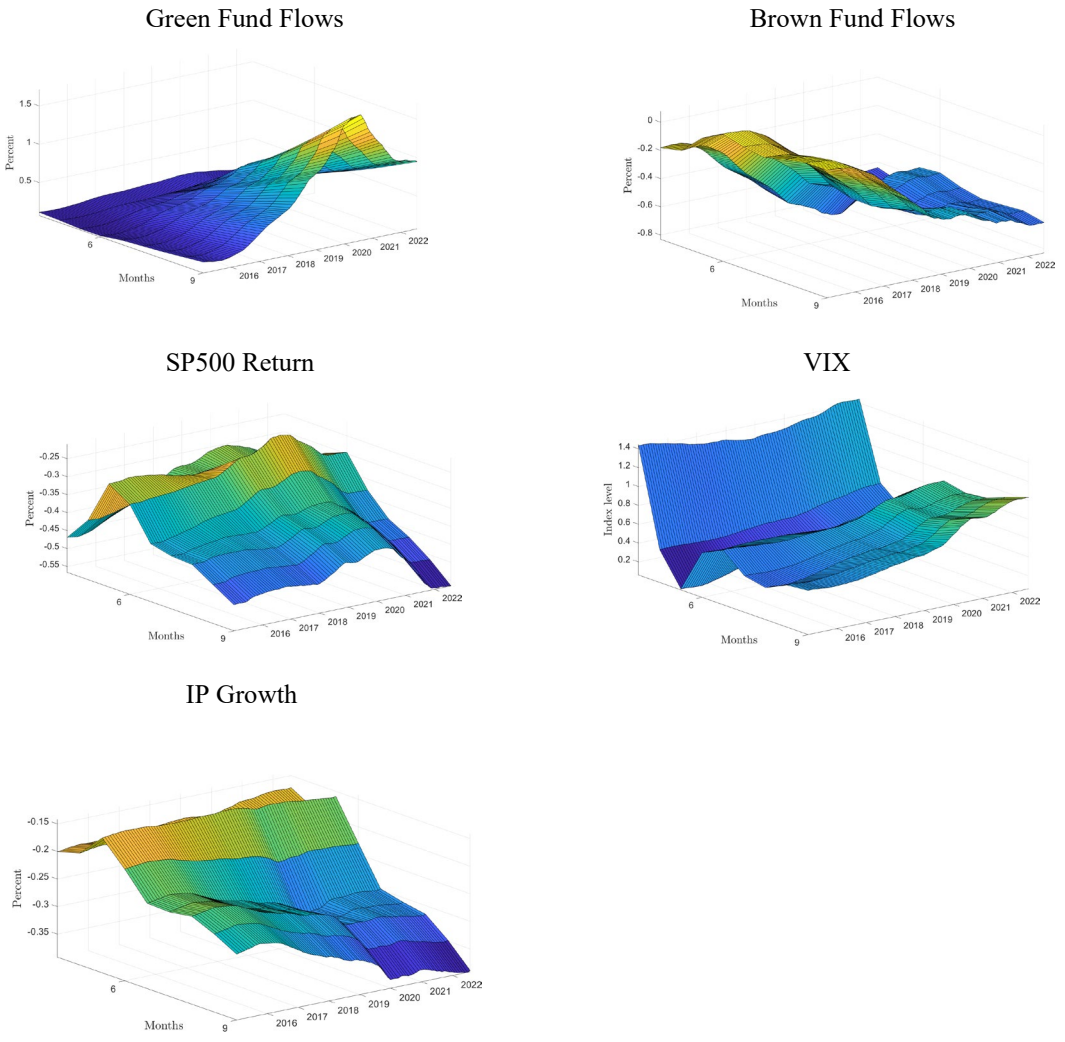
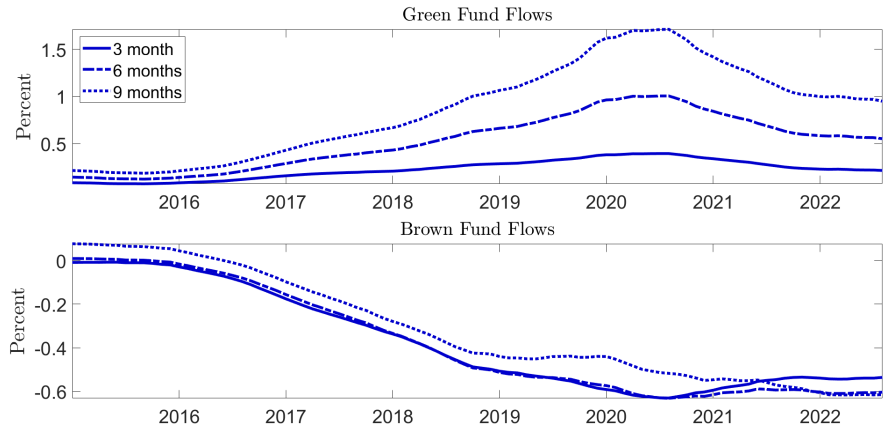


Figure 4 Time-varying impulse response of fund flows to an MeCCO climate news shock at different horizons

This figure shows the time-varying cumulative impulse response of green and brown fund flows to an exogenous MeCCO climate news shock at the 3-, 6- and 9-month impulse response horizons using equations (8) and (9). The definition of the variables and the estimation approach are described in Figure 3.



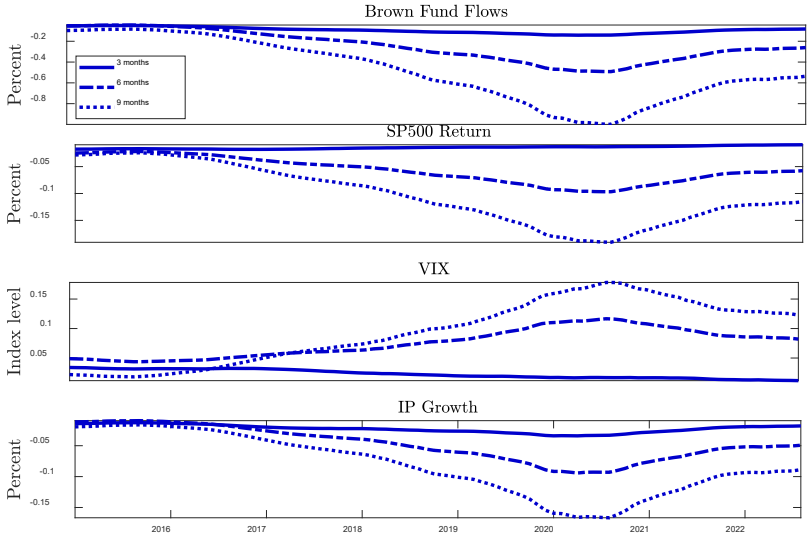
4.1.3 Time-varying parameter VARX with green fund flows restriction

In this section, we examine the hedging potential of green energy investments against climate risk, as reflected in brown fund flows and broader economic indicators. We assume that green fund flows remain unresponsive to such shocks within the time-varying VARX framework. This is achieved by constraining the estimated coefficients of green fund flows to zero in the time-varying VARX model as estimated in the previous section. That said, we set $B_{t,1,GE} = \cdots = B_{t,k,GE} = 0$ and $A_{t,GE} = 0$. Following this adjustment, we recalculate the impulse responses for brown fund flows, S&P500 return, the VIX, and industrial production (IP) growth.

Figure 5 illustrates the differences in the cumulative impulse responses (CIRs) between the models with unrestricted and restricted time-varying parameters. Specifically, the CIRs of brown fund flows and the impulse responses (IRs) of the VIX become more positive in reaction to climate news shocks, while the CIRs of S&P500 return and IP growth turn more negative. This suggests that, in the absence of green fund investments, brown fund investments could rise, and both the stock market and industrial production would experience more pronounced adverse effects from climate news shocks. Green energy investments seemingly play a critical role in curbing brown energy investments and stabilizing the US economic indicators during periods of heightened climate risk.

Figure 5. The difference in the responses to an MeCCO climate news shock between the restricted and unrestricted time-varying VARX

This figure shows the difference in the cumulative impulse responses of brown fund flows, S&P500 return and IP growth, as well as the *impulse responses* of VIX across various response horizons between the restricted and unrestricted time-varying VARX models. In the restricted VARX model, the estimated time-varying coefficients B_1, B_2, B_3 and A_t of green fund flows in the VARX system - as estimated in Section 4.1.2 - are constrained to zero, while the unrestricted VARX model, estimated in Section 4.1.2 and depicted in Figure 3, retains these coefficients without restriction.



4.2 Climate risk measured by Temperature Anomaly

We use Temperature Anomaly (Temp_Anomaly) as a measure of climate risk and re-estimate the constant and time-varying VARX models. Figures 6 and 7 present the results. While all the five endogenous variables exhibit time-varying responses to Temp_Anomaly shocks, both figures indicate that only the responses of green fund flows and S&P500 return are predominantly significant at the 68% credibility level.

Within the time-varying framework, Figure 7 and Figure B.2 of Appendix B demonstrate that temperature anomaly shocks significantly influence green fund flows at the 90% credibility intervals. The contemporaneous response of green fund flows shows an upward trend from 2015 to 2022. Over a 9-month response horizon, the cumulative impulse response (CIR) peaks at 22% in late 2020. In contrast, the response of brown fund flows is initially negative and largely insignificant. However, over a longer horizon (i.e., 2 months after the shocks), the response turns positive and becomes significant at the 68% credibility level, with the 9-month CIR reaching 11% by late 2020.

Figure 6. Impulse response to a Temp_Anomaly shock within a constant parameter VARX

This figure shows the cumulative impulse responses to an exogenous Temp_Anomaly shock using a constant parameter 3-lagged VARX model of equation (3), except for VIX which is plotted as an *impulse response.* The responses are normalized to match the initial decline in IP growth from a 1 SD Temp_Anomaly shock. The median response is displayed, along with 68% and 90% credibility intervals. Temp_Anomaly is IPCC Land and Marine Northern Hemisphere Temperature Anomaly (HadCruT5). The sample period spans from December 2006 to November 2022. All other variables are defined in Section 3.

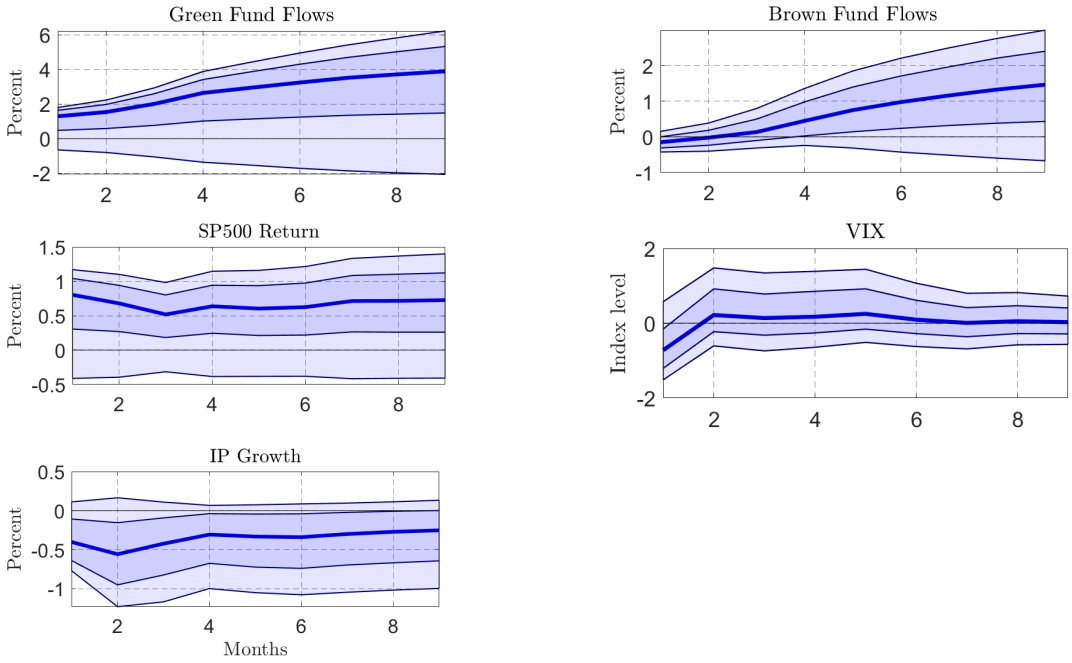
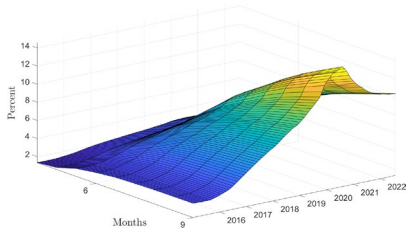


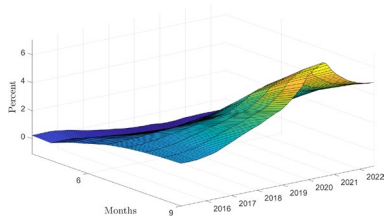
Figure 7. Time-varying impulse responses to a Temp_Anomaly shock

This figure shows the time-varying cumulative impulse response of green fund flows, brown fund flows, S&P500 return and IP growth, as well as the *impulse response* of VIX to an exogenous Temp_Anomaly shock (HadCRUT5) using equations (8) and (9). Prior $k_Q = 0.02$. Temp_Anomaly is IPCC Land and Marine Northern Hemisphere Temperature Anomaly (HadCruT5). All other variables are defined in Section 3. *y*-axis: percentage or index level. *x*-axis (left): months. *x*-axis (right): years.

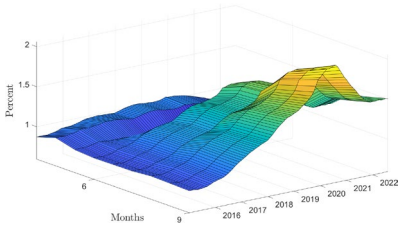
Green Fund Flows



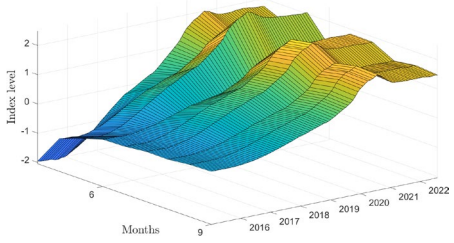
Brown Fund Flows



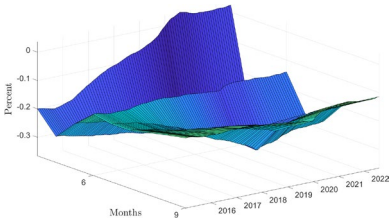
SP500 Return



VIX



IP Growth



In contrast to the findings in the previous section, where MeCCO climate news shocks significantly encourage green fund flows and discourage brown fund flows, climate risks associated with temperature anomalies only stimulate green fund flows. Temperature anomaly shocks do not lead to divestment from brown funds, nor do they affect stock market stability or our measure of IP growth. Apparently, investors are more inclined to mitigate imminent transition risks, as captured by MeCCO climate news (reflecting government intervention and policy shifts), rather than direct physical risks from climate change itself, as captured by temperature anomalies.

Our findings align with recent literature. For instance, Stroebel and Wurgler (2021) survey 861 finance academics, professionals, public sector regulators, and policy economists on climate finance topics. They identify regulatory risk as the top climate risk to businesses and investors over the next five years, but they view physical risk as the top risk over the next 30 years. Similarly, Faccini et al. (2023) found that among the four Reuters news-based climate change risk measures related to natural disasters, global warming, international summits, and US climate policy, only the climate-policy factor is priced into US stocks.

Other economic factors also exhibit time-varying responses to temperature anomaly shocks. Over the 9-month response horizon, the average impact on S&P500 return increases from 2015 to 2022, rising from 1.1% to 1.5% within the 68% credibility intervals. In contrast, the responses of VIX and IP growth remain largely insignificant at the 68% credibility level, although the adverse effect of VIX increases slightly over the same period. These results suggest that temperature anomalies do not exert a substantial negative impact on the US stock market and economic output.

This finding is consistent with recent studies. For example, Addoum et al. (2023) find that extreme temperatures significantly affect earnings in approximately 40% of US industries, with some industries experiencing harm while others benefit. Notably, analysts and investors do not immediately react to observable intra-quarter temperature shocks. Similarly, Dell et al. (2012) and Felbermayr et al. (2022) document that extreme temperatures tend to negatively affect economic growth in low-income countries but do not have a robust, discernible impact on growth in rich countries. This may be because developed countries like the US can utilize precise weather forecasts and leverage advanced hedging and diversification capabilities provided by financial markets, resulting in a more weather-resilient economy.

Since temperature anomalies do not significantly drive a divestment from brown fund investments, nor do they affect financial market stability or industrial production growth, we utilize the MeCCO climate news index in the subsequent analysis to examine the speed of fund flows.

5. The speed of fund flows and climate risk

5.1 The speed of fund flows and its benefits

Transitioning to a green economy is a complex challenge. It requires large-scale transformations and investments in energy sectors, as well as changes in production and consumption patterns that are currently reliant on traditional energy. Recent research argues that a very rapid energy transition could lead to a substantial rise in energy system costs, potentially stalling GDP growth and employment, even when accounting for significant gains in energy efficiency. This has led to advocacy for a moderate energy transition (Hafner et al., 2021; Victor, 2019).

From this perspective, we hypothesize that accelerated investments in green funds will foster innovation, advance clean technologies, and encourage the development of sustainable infrastructure, thereby supporting economic growth. Conversely, a rapid divestment from brown funds may have detrimental economic consequences. To test this hypothesis, we analyze the sensitivity of changes in the speed (acceleration or deceleration) of fund flows to the stock market and economic output in response to the MeCCO climate change news index - a climate risk measure.

Considering the scale of the transition from brown to green investments is necessary for understanding the broader impact of the transition. If the shift remains small, its effect on the economy and stock market

will be minimal. As shown in Figure 8, the relative size of the total value of green funds to brown funds in our sample is between 0.23 and 1.40 with a mean of 0.53. While the total size of green funds is on average half that of brown funds, they overtake brown funds during two periods: one is during late 2006 and early 2007, and the other is during late 2020.

Figure 8. The relative size of green funds to brown funds

This figure illustrates the relative size of the total value of green funds compared to brown funds in our sample.



Following the conceptual approach of Ball (1994), we define the speed of fund flows as the level that the fund flows can research over a specific time after the climate news shock:

$$Speed_t^p = CIR\ Fund\ Flow_t^p,\ p \in [1,12], \quad (11)$$

where t is the calendar month of the sample 2015M4 – 2022M11, p is the p^{th} impulse response period, *CIR Fund Flow* is the cumulative impulse response (CIR) of green and brown fund flows to climate news shocks as estimated in the time-varying parameter VARX in Section 4.2.

We are interested in understanding how the pace of transition from brown to green investments impact both financial markets and output. To this end, we calculate the change in the speed of fund flows ($Fund\ flow\ speed\ change_t^p$) as the difference of the speed of fund flows ($Speed_t^p$) between two consecutive calendar months (t). This change in fund flow speed captures the evolving perception of climate risk among investors and their corresponding adjustments in asset allocation over time:

$$Fund\ flow\ speed\ change_t^p = Speed_t^p - Speed_{t-1}^p \quad (12)$$

Figure 9 illustrates the estimated changes in fund flow speed for green and brown funds in the third month following climate news shocks. The speed of green fund flows increased, indicating an acceleration, while the speed of brown fund flows decreased, reflecting a deceleration. Starting in late 2015, when the US joined the Paris Agreement, net inflows into green funds outpaced those into brown funds, a trend that

continued until November 2020, when the Trump Administration formally withdrew from the Paris Agreement. Following this withdrawal, brown fund flows accelerated and exceeded green fund flows until February 2021, when the Biden Administration took office and rejoined the Paris Agreement. Since then, the speed of green fund flows has once again risen, while the speed of brown fund flows has declined. This fluctuation in fund flow speeds appears to be closely tied to shifts in government climate policies.

Indeed, the regression results in Table 2 reveal that Gavriilidis' (2021) US Climate Policy Uncertainty Index, which measures the uncertainty of US climate policy, significantly reduces the change in green fund flow speed while increasing that of brown funds.

Figure 9. Changes in the speed of fund flows as responses to climate news shocks

This figure illustrates the changes in the speed of green and brown fund flows in the third month after the climate news shocks, as estimated in Section 4.1.2.

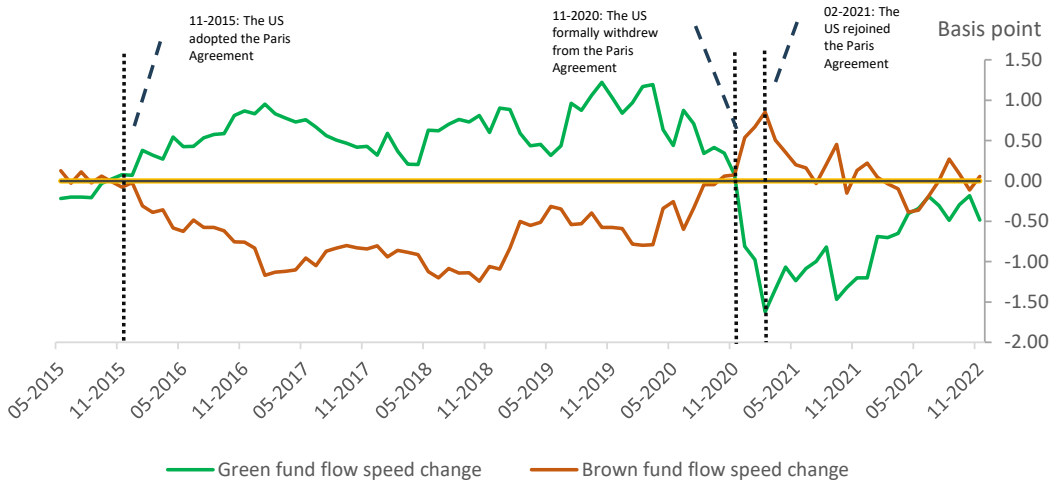


Table 2. The impact of climate policy uncertainty on changes in fund flow speeds

This table presents the impact of the US climate policy uncertainty on changes in the speed of green and brown fund flows. $Green\ (Brown)\ fund\ flow\ speed\ change_t^3$ is the difference in green (brown) fund flow speed between two consecutive calendar months, where green (brown) fund flow speed is the cumulative impulse response in the third month after the MeCCO climate new shock. *Climate Policy Uncertainty*$_t$ is the Gavriilidis' (2021) US Climate Policy Uncertainty Index. All other variables are defined in Section 3.

	Green fund flow speed change^3_t	Brown fund flow speed change^3_t
	(1)	(2)
Climate Policy Uncertainty$_t$	-0.006	0.004
	(0.00)***	(0.00)***
Constant	0.027	-0.022
	(0.00)***	(0.00)***
Adj-R^2	0.09	0.10
Sample size	91	91

It is crucial to understand how the pace of transitioning from brown to green investments relates to the performance of financial markets and economic output. To explore this relationship, we analyze the cumulative impulse responses (CIRs) of S&P500 return and industrial production (IP) growth by regressing them against changes in the speed of fund flows across 3- and 6-month impulse response horizons. We consider these longer timeframes because the transition in investments normally takes time to produce measurable economic effects. The results of this analysis are presented in Table 3.

Panel A of Table 3 reveals that, in response to a climate news shock, an acceleration (i.e., an increase in fund flow speed change) in green fund investments is strongly and positively associated with the cumulative impulse responses (CIRs) of S&P500 return and industrial production (IP) growth over both the 3- and 6-month response horizons. In contrast, accelerated brown fund investments are negatively and significantly correlated with IP growth, while showing a weaker relationship with S&P500 return. Although these results may indicate correlation rather than causation, they suggest that the US economy has been capable of accommodating the accelerated shift toward green investments in recent years.

We recognize that using the estimated cumulative impulse responses (CIRs) in the regression analysis has a limitation - it is subject to estimation errors. To provide a straightforward robustness check, we conduct the analysis using actual fund flow speeds, S&P500 return, and industrial production (IP) growth. We define the actual speed change of fund flows as the first difference of the actual green and brown fund flows. We then regress the actual S&P500 return and IP growth on the 3- and 6-month-lagged speed changes of green and brown fund flows, respectively. Albeit, this approach introduces a tradeoff: it becomes difficult to isolate the effects of climate news shocks from other fundamental shocks impacting the dynamic economy.

Panel B of Table 3 demonstrates that an actual acceleration (i.e., an increase in fund flow speed change) in green fund flows is positively associated with S&P500 return, though only at a 3-month lead time, and this relationship is marginally significant at the 10% level. Conversely, an actual acceleration in brown fund flows shows a negative association with S&P500 return at both 3- and 6-month lead times, with

strong significance at the 1% level. Notably, neither green nor brown fund flow accelerations exhibit a statistically significant relationship with industrial production (IP) growth. These results offer partial validation for the regression analysis conducted using the estimated data, as presented in Panel A of Table 3.

Table 3. The relationship between fund flows speed change, S&P500 return and IP growth

Panel A of this table presents the results of the regression analysis where the CIRs of S&P500 return and IP growth in the 3 and 6 months after a climate news shock are examined in relation to the changes in the speed of green and brown fund flows. The speed change in fund flows is defined by equation (12). The *CIR S&P500 return* and *CIR IP growth* are the cumulative impulse response of S&P500 return and IP growth to a climate news shock as estimated in Section 4.2. Panel B of this table presents the regression results of the *actual* speed change in green and brown fund flows on S&P500 return and IP growth. The *actual* speed change is the first difference of the fund flows between two consecutive months. *t* is the calendar month. *p*-values are in parenthesis. ***, ** and * indicates significance levels of 1%, 5% and 10%, respectively.

Panel A. *The relationship between green and brown fund flows speed changes to the CIR S&P500 return and CIR IP growth based on the estimated cumulative impulse responses (CIRs)*

	CIR SP500 return^3_t		CIR IP growth^3_t		CIR SP500 return^6_t		CIR IP growth^6_t	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Green fund flow speed change^3_t (b_1)	0.80		0.57					
	(0.00)***		(0.00)***					
Brown fund flow speed change^3_t (b_2)		-0.42		-0.60				
		(0.09)*		(0.00)***				
Green fund flow speed change^6_t (b_1)					1.31		0.20	
					(0.00)***		(0.00)***	
Brown fund flow speed change^6_t (b_2)						1.57		-0.40
						(0.17)		(0.04)**
t	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	(0.02)**	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
Constant	-0.29	-0.28	-0.15	-0.15	-0.44	-0.41	-0.24	-0.24
	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***	(0.00)***
Adj-R^2	0.38	0.23	0.27	0.17	0.31	0.10	0.80	0.77
Sample size	91	91	91	91	91	91	91	91

Panel B. *The relationship between green and brown fund flows speed changes to S&P500 return and IP growth based on the actual fund flows, S&P500 return and IP growth.*

	SP500 return$_t$	IP growth$_t$	SP500 return$_t$	IP growth$_t$
	(1)	(2)	(3)	(4)
Green fund flow speed change$_{t-3}$	0.10	0.04		
	(0.10)*	(0.48)		
Brown fund flow speed change$_{t-3}$	-0.13	0.02		
	(0.00)***	(0.57)		
Green fund flow speed change$_{t-6}$			-0.01	-0.02
			(0.87)	(0.68)
Brown fund flow speed change$_{t-6}$			-0.10	0.01
			(0.01)***	(0.79)
Constant	0.14	0.03	0.14	0.02
	(0.17)	(0.80)	(0.20)	(0.84)
Adj-R^2	0.06	0.01	0.03	0.01
Sample size	188	188	185	185

6. Robustness

6.1 Alternative identification of green funds

We use a different set of criteria to identify green energy funds while keeping the identification of brown energy funds unchanged. The alternative approach for identifying green energy funds is outlined as follows. First, we select green energy funds based on their names, the same as the initial identification as described in Section 3.1.1. To address potential concerns of "greenwashing," we retain only those funds whose average E score (the environmental component of the ESG rating[22]) is above the 75th percentile of all funds.[23] The average E score of fund *i* is calculated as following:

$$\bar{E}_{it} = \sum_{j \in F_{it}} \frac{Inv_{ijt} \times E_{jt}}{InvE_{it}} \tag{13}$$

where Inv_{ijt} is the amount of investment in firm *j* within fund *i* at month *t,* E_{jt} is the score of the environmental component of firm *j*'s ESG, $InvE_{it}$ is the total amount of investment in all firms invested within fund *i* for which the E score data are also available, the set of these firms is denoted as F_{it}.

We use this sample of green energy funds to re-estimate the time-varying parameter VARX, incorporating the MeCCO climate news index. The results, presented in Appendix C, demonstrate a high degree of qualitative consistency with those reported in Section 4.1.2. The only difference is seen in brown fund flows, which exhibit a slightly altered trend – they initially respond negatively to the climate news shock in the first two months before reverting to a positive trend. However, the magnitude of this positive trend is approximately three times smaller than that observed for green fund flows overall.

6.2 Control for oil price

[22] The ESG data is available up to December 2021 at the time of data collection.

[23] See United Nations' definition of 'green washing' at https://www.un.org/en/climatechange/science/climate-issues/greenwashing.

Oil price movements are closely tied to investor sentiment and industries that are either directly or indirectly influenced by oil (see, for example, Hammoudeh et al., 2004; Qadan & Nama, 2018). This relationship is evident in our data, as the APSP crude oil index return has a correlation of 0.39 with brown fund flows. To isolate the influence of oil prices on brown energy investments, the brown fund flows series is projected on the APSP crude oil index return. The residuals from this projection are then used as the endogenous variable, representing "oil-free" brown fund flows. The results of the time-varying VARX analysis using these adjusted brown fund flows are presented in Appendix D, which demonstrates qualitative consistency with the findings in Section 4.

6.3 Control for inflation

Since early 2021, the US and many other major economies have experienced elevated inflation, which has significantly affected investment and economic growth. To account for the effects of inflation in our analysis, we include it as an endogenous variable and remove the VIX from the VARX model to preserve degrees of freedom in the estimation. The results, presented in Appendix E, demonstrate qualitative consistency with those discussed in Section 4.

6.4 Control for extreme events

The sample period spanning 2006 to 2022 encompasses extreme events, such as the 2008 global financial crisis and the 2020 pandemic. To ensure that our findings are not driven by these outliers, we winsorize the endogenous variables at the 5th and 95th percentiles and re-estimate the time-varying VARX model. The results, presented in Appendix F, exhibit qualitative consistency with those reported in Section 4.

7. Conclusion and policy implications

Climate change is an ongoing and rapidly accelerating phenomenon. In recent years, the global community has placed increasing emphasis on setting a target date to achieve net-zero emissions, often in alignment with the temperature goals outlined in the Paris Agreement. Understanding how financial investments have shifted toward a low-carbon economy over the past few decades, the pace of this transition, and its implications for financial markets and the broader economy is of paramount importance.

In this study, we investigate the net inflows into green and brown energy equity mutual funds and ETFs in response to climate risk shocks in the US over the last two decades. Our findings reveal that climate risks drive a shift from brown to green energy investments while negatively impacting stock market performance and industrial production growth. This shift is time-varying and largely influenced by broader climate concerns, such as US government climate policies, as captured by the MeCCO climate change news index. However, while the direct physical risk posed by climate change itself (proxied by the Temperature Anomaly) encourages green energy investments, it does not lead to divestment from brown energy. At the macro level, green investments serve as a hedge against climate news shocks by reducing brown

investments and contributing to the stabilization of financial markets and the broader economy.

Moreover, we find that the pace of the transition from brown to green energy investments is closely linked to government climate policies, notably exemplified by the US government's changing position on the Paris Agreement. Encouragingly, our results also indicate that, in recent years, the US stock market and economic growth have effectively adapted to this pace of sustainable energy transition. This is evidenced by the fact that a fast net inflow into green funds are associated with enhanced stock market performance and industrial production growth, whereas the opposite trend is observed for net inflows into brown funds.

Our findings provide valuable insights for stakeholders engaged in net-zero transition policy making. Clearly, investors' growing awareness and attitudes toward climate change have been reflected in financial markets where, as we have demonstrated, trading activities have increasingly shifted toward green investments. However, the journey toward a net-zero emissions economy is not without challenges. The pace of transition from brown to green fund investments slowed during the period from November 2020 to February 2021, coinciding with the US temporary withdrawal from the Paris Agreement. This suggests that the pace of the energy transition is significantly impacted by government climate policies.

Since our findings show that the pace of the energy transition is positively related to the US stock market performance and economic growth, a critical question arises: what is the maximum sustainable speed of transition an economy can achieve, considering feasible economic adjustments and technological advancements? With many countries committing to net-zero emissions by 2050, can individual nations achieve this target sooner while maintaining a balanced economic growth? Further research to identify the optimal speed of transition will undoubtedly be a complex endeavor. Additionally, another important question that merits further exploration is disentangling the effects of physical and transition climate risks and evaluating their time-varying impacts on economic activities.

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Appendices

Appendix A. Variable definitions

Green fund flows (%)	The percentage of the aggregate net fund inflow over the aggregate fund value within the month for green funds. Green funds are identified as mutual funds and ETFs that are within the industries of energy and utilities; domicile in the US, denominated in USD, and primarily invest in equities worldwide; the name of the fund include at least one of the following keywords: *clean, climate, fossil, renewable, carbon, green energy, sustainable*; the fund holds less than 50% of their assets in firms categorized in the oil and gas production sector or in the oil equipment services and distribution sector.
Brown fund flows (%)	The percentage of the aggregate net fund inflow over the aggregate fund value within the month for brown funds. Brown funds are identified as mutual funds and ETFs that are within the industries of energy and utilities; domicile in the US, denominated in USD, and primarily invest in equities worldwide; the fund holds more than 50% of their assets in firms categorized in the oil and gas production sector or in the oil equipment services and distribution sector.
SP500 rerturn (%)	The last day of the month S&P 500 logarithm return in percentage.
VIX (Index)	The closing price of the CBOE S&P500 Volatility Index.
IP growth (%)	The monthly percentage change of the US industry production.
MeCCO (Index)	The total number of articles containing the terms '*climate change*' or '*global warming*' published in highly circulated newspapers each month in the US divided by the number of newspapers searched
Temp_Anomaly (Index)	The Intergovernmental Panel on Climate Change (IPCC) temperature anomaly - the HadCRUT5 Land and Marine Temperature Anomaly for the Northern Hemisphere, calculated as grids of monthly anomalies relative to the 1961–1990 baseline.
Oil return (%)	The monthly percentage change of APSP crude oil index.
Inflation (%)	The monthly percentage change of the US consumer price index.
Climate policy uncertainty (Index)	Gavriilidis' (2021) measure of uncertainty related to climate policy, based on news from major U.S. newspapers. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3847388

Appendix B.

Figure B.1 Time-varying impulse responses to an MeCCO climate news shock for a selected period

This figure plots the cumulative impulse responses of green fund flows, brown fund flows, S&P500 return and IP growth, as well as the *impulse response* of VIX to an exogenous MeCCO climate news shock for 2020 M1, along with 68 percent and 90 percent posterior credibility intervals based on iterations of the Gibbs sampler. All variables are defined in Figure 3. *y*-axis: percentage or index level. *x*-axis: months.

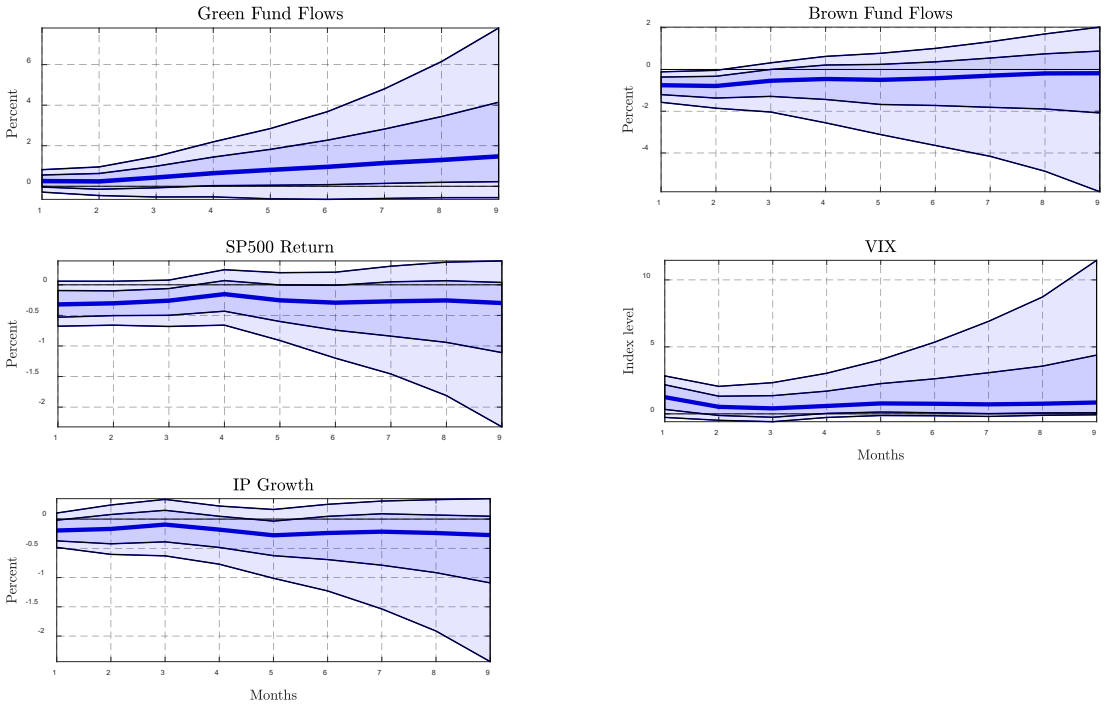
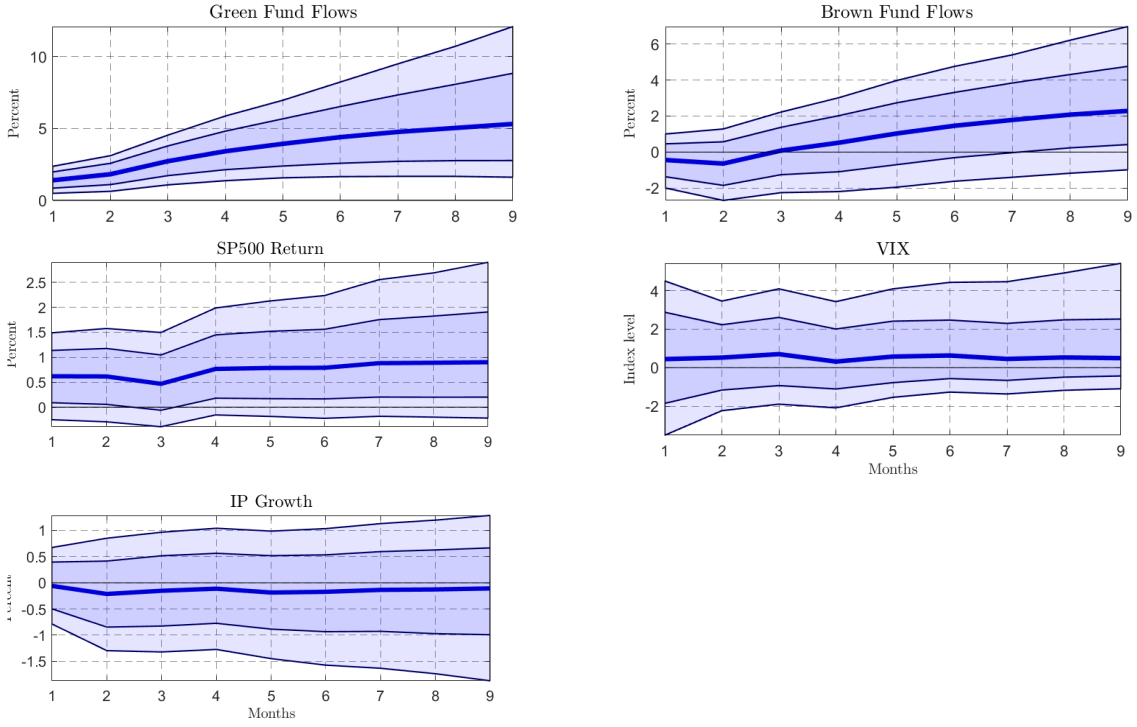


Figure B.2 Time-varying impulse responses to a Temp_Anomaly shock for a selected period

This figure plots the cumulative impulse responses of green fund flows, brown fund flows, S&P500 return and IP growth, as well as the *impulse response* of VIX to an exogenous Temp_Anomaly shock for 2019 M1, along with 68 percent and 90 percent posterior credibility intervals based on iterations of the Gibbs sampler. All variables are defined in Figure 3. *y*-axis: percentage or index level. *x*-axis: months.

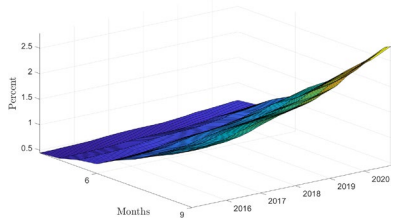


Appendix C. Alternative identification of green funds

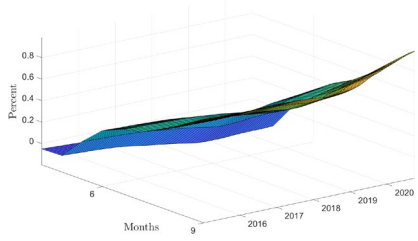
Figure C. Time-varying impulse response to an MeCCO climate news shock with an alternative identification of green funds

This figure displays the time-varying cumulative impulse response of green fund flows, brown fund flows, S&P500 return and IP growth, as well as the *impulse response* of VIX to an exogenous MeCCO climate news shock using equations (8) and (9) for the sample of 2015M1 – 2022M11. Prior $k_Q = 0.02$. Green funds are redefined in Section 6.1. Other variables are defined in Section 3. *y*-axis: percentage or index level. *x*-axis (left): months. *x*-axis (right): years.

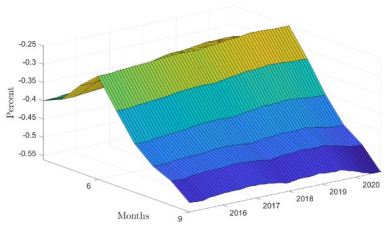
Green Fund Flows



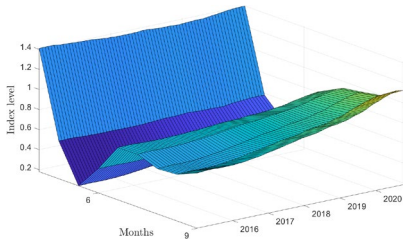
Brown Fund Flows



SP500 Return



VIX



IP Growth

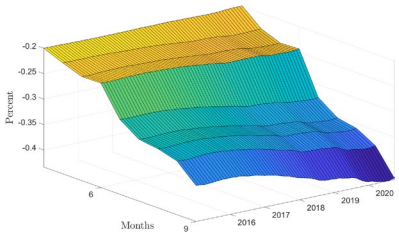
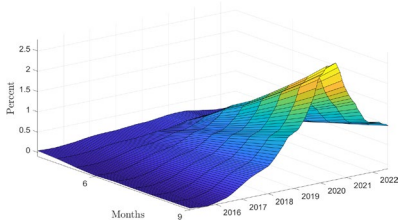


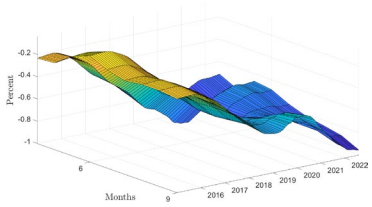
Figure D. Time-varying impulse responses to an MeCCO climate news shock by controlling oil price

This figure displays the time-varying cumulative impulse response of green fund flows, brown fund flows, S&P500 return and IP growth, as well as the *impulse response* of VIX to an exogenous MeCCO climate news shock using equations (8) and (9) for the sample of 2015M1 – 2022M11. Prior $k_Q = 0.02$. Brown fund flows is the residual from the projection of brown fund flows on crude oil return. Other variables are defined in Section 3. *y*-axis: percentage or index level. *x*-axis (left): months. *x*-axis (right): years.

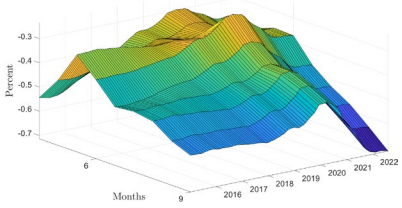
Green Fund Flows



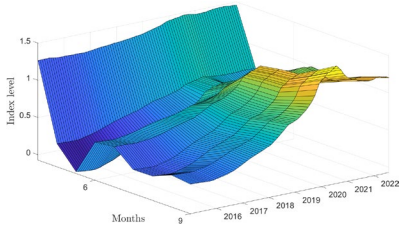
Brown Fund Flows



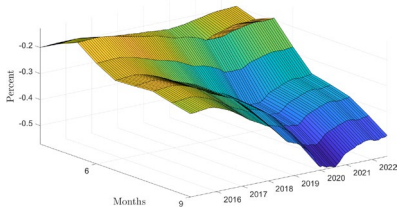
SP500 Return



VIX



IP Growth

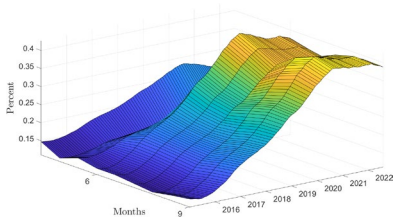


Appendix E. Robustness test by controlling inflation

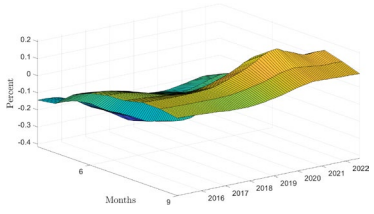
Figure E. Time-varying impulse responses to an MeCCO climate news shock by controlling inflation

This figure displays the time-varying cumulative impulse response of green fund flows, brown fund flows, S&P500 return, inflation and IP growth to an exogenous MeCCO climate news shock using equations (8) and (9) for the sample of 2015M1 – 2022M11. Prior $k_Q = 0.02$. All variables are defined in Section 3. *y*-axis: percentage or index level. *x*-axis (left): months. *x*-axis (right): years.

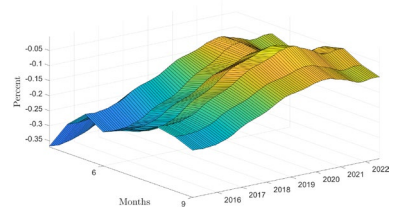
Green Fund Flows



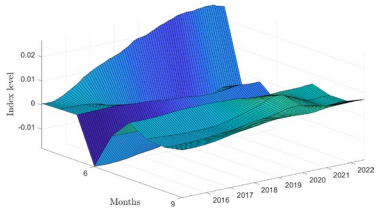
Brown Fund Flows



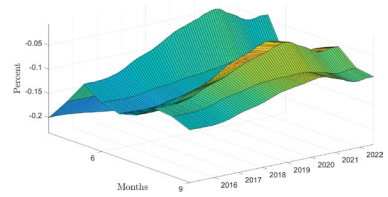
SP500 Return



VIX



IP Growth

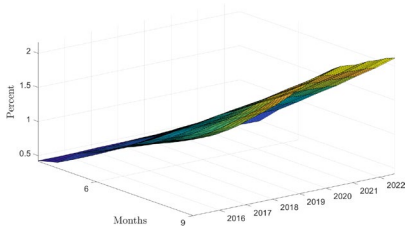


Appendix F. Robustness test by controlling extreme events

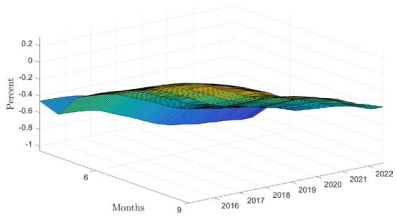
Figure F. Time-varying impulse responses to an MeCCO climate news shock by controlling extreme events

This figure displays the time-varying cumulative impulse response of green fund flows, brown fund flows, S&P500 return and IP growth, as well as the *impulse response* of VIX to an exogenous MeCCO climate news shock using equations (8) and (9) for the sample of 2015M1 – 2022M11. Prior $k_Q = 0.02$. All variables are defined in Section 3. The endogenous variables are winsorized at the 5th and 95th percentiles. *y*-axis: percentage or index level. *x*-axis (left): months. *x*-axis (right): years.

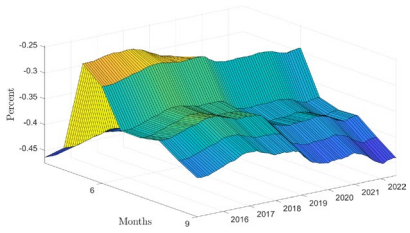
Green Fund Flows



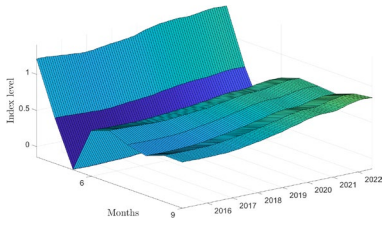
Brown Fund Flows



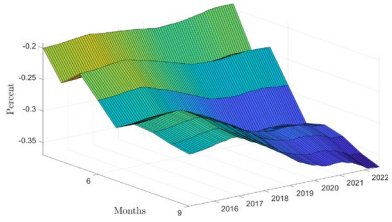
SP500 Return



VIX



IP Growth



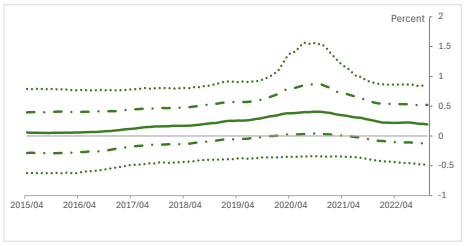
Appendix G. Credibility intervals of the cumulative impulse response (CIRs) for the baseline model

Figure G. Credibility intervals of the CIRs for the baseline model

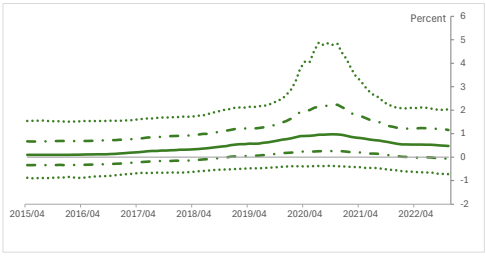
This figure presents the cumulative impulse responses (solid line) at the 3-, 6- and 9-month horizons to an exogenous MeCCO climate news shock for green (Panel A) and brown (Panel B) fund flows, along with 68 percent and 90 percent posterior credibility intervals based on iterations of the Gibbs sampler.

Panel A. *Green fund flows*

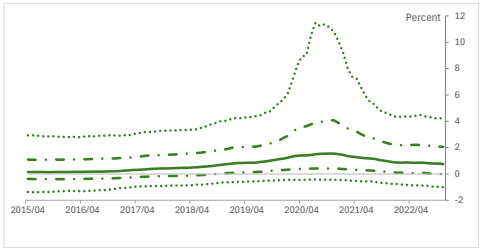
3-month



6-month

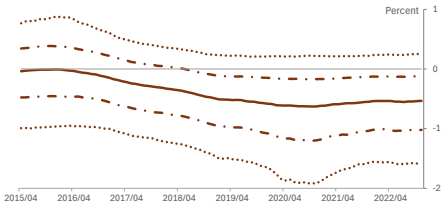


9-month

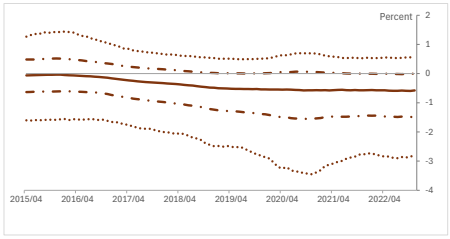


Panel B. *Brown fund flows*

3-month



6-month



9-month

