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Revisiting the Role of Technology Shocks in Climate Change-Stock Markets Nexus: Renewable and Non-Renewable Energy Stocks Perspective

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Growing investor awareness of climate-related risks to their portfolios has created a new perspective. There is now a widespread belief that investors who creatively apply novel technologies are better positioned to both protect the environment and withstand the impacts of climate change. Thus, we hypothesize that technology can moderate the effect of climate change on stock performance. Utilizing a GARCH-MIDAS model, we show results that give credence to technological innovation as an effective means to moderate the volatility effect of climate change in stock markets. We confirm the robustness of this finding for both renewable and non-renewable stocks.

I. Introduction

Climate risks, including extreme weather, changes in climate policy, technological innovation, and market mood, affect asset valuations in sectors like energy. Climate change poses direct physical risks to investments, which can reduce asset values, production capabilities, and overall business operations. It is indisputable that technological progress has improved over time and is expected to impact economic and financial factors greatly. However, despite the claim that technology shocks have a different effect on the value of existing assets and growth opportunities, existing studies on the economic impact of technological developments mainly focus on the role of technology in the growth process (see Kogan & Papanikolaou, 2014; Kung & Schmid, 2015). Sharma & Narayan (2022) recently investigated the predictability of stock return volatility by technology shock, providing evidence that global technology shock is a time-varying predictor of stock returns.

Moreover, research focusing on investors' concerns regarding climate change risks has recently suggested that investors with innovative ideas for utilizing emerging technologies are more likely to sustain the environment and, by extension, maximize returns from their investments in financial assets. However, while acknowledging the possibility of utilizing technologies to moderate the impact of climate change on financial stocks has been recently validated in the context of real estate equity (see Salisu et al., 2023) and conventional stocks (see Penzin et al., 2024), the extent

to which such a moderating role of technology holds for the energy sector of the stock market has remained unexplored. As a result, the main contribution of this study to the literature is to revisit the systematic risk of climate change in stock returns with an extended analysis of the moderating role of technology in the energy stock market from the viewpoint of renewable and non-renewable energy stocks.

To begin with, non-renewable energy (fossil fuels) such as coal, natural gas, and oil have been proven essential to promoting the rapid development of the global economy. However, they also lead to a rapid expansion of global warming, pollution, and disasters (Awodumi & Adewuyi, 2020). These environmental issues have awakened the world to the need to turn to renewable energy sources, which are aligned with the targets of the Paris Agreement on climate change. Thus, having an adequate and veritable understanding of the comparative performance of renewable and non-renewable energy stocks amid climate-related risk is crucial for investors who want to be informed about which energy stocks are relatively more resilient to climate change, to form their portfolio strategy around it.

Therefore, this study explores whether technologies, particularly those aimed at reducing greenhouse gas emissions, moderate or induce the volatility consequences of climate change differently for renewable and non-renewable energy stocks. This innovation was motivated by the view that technological advancement will lead to reduced greenhouse gas emissions, a reduction in demand for fossil

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fuels, and, by extension, lower investment in non-renewable energy stock compared to renewable energy stock. Thus, we hypothesize that technology will play a moderating role in the volatility consequence of energy stocks, but differently for renewable and non-renewable energy stocks. Essentially, we show results that give credence to technology as being capable of moderating shocks due to climate change in the volatility of renewable energy stocks, compared to the moderating effect of technology on the volatility consequence of climate change in non-renewable energy.

II. Data and Methodology

A. Data and preliminary results

Data used in this study are mixed daily and monthly samples of energy stocks, climate change series, and environmental-based technological indices. The daily frequency data consists of renewable (*RE*) and non-renewable (*NRE*) energy stocks, while the monthly frequencies include temperature anomalies, which serve as a proxy for climate change, and the FTSE Environment Technologies Index, which acts as a proxy for technological innovation. The renewable energy (*RE*) and non-renewable energy (*NRE*) stocks are measured in terms of the S&P Global Clean Energy (SPGTCLN) and FTSE 350 Oil & Gas Index, respectively. The data for the alternative energy series and the technological innovation index are obtained from investing.com, while the climate change data is based on temperature (*TEMP*) anomalies reported regularly by the National Aeronautics and Space Administration (NASA) and the Goddard Institute for Space Studies (GISS).

The summary statistics reported in [Table 1](#), which cover the period from February 2012 to July 2024, indicate that renewable energy stocks have higher average returns compared to non-renewable energy stocks during the same period. The mean statistics also indicate that climate change, measured in terms of percentage change in temperature (*TEMP*) anomaly, and technological shock (*TS*), measured in terms of percentage change in the technological index, have positive average values during the period considered. The standard deviation statistic, measuring the dispersion of the series from their mean levels, shows that *NRE* is more volatile than *RE*. However, while the skewness statistic is negative for *RE*, *NRE*, and *TS* but positive for *TEMP*, the kurtosis statistic, on the other hand, is consistently leptokurtic for all the series.

Given the high-frequency dynamics of the energy stocks under consideration, also presented in [Table 1](#) is the *F*-statistic from the autoregressive conditional heteroscedasticity (ARCH) test and the *Q*-statistic/*Q*-square-statistic from the Ljung-Box autocorrelation test. These tests provide substantial evidence of conditional heteroscedasticity and autocorrelations in both *RE* and *NRE* return series. This, among other things, validates the robustness of our analysis, as this preliminary analysis supports the appropriateness of our chosen estimating technique in the subsequent section.

B. Methodology

In addition to the energy stock series and the climate change and technology variables being sampled at different frequencies, the significant presence of ARCH and autocorrelation effects in the return series of the energy stocks motivates our preference for the GARCH-MIDAS model as the most appropriate approach in the context of this study. The preference for this model hinges on its ability to utilize data at their natural frequencies, thus averting the loss of information that typically arises when data is aggregated into a single uniform frequency. Equation (1) through to Equation (3) are the generic representation of the GARCH-MIDAS model following the procedure of Engle et al. (2013).

$$r_{i,t} = \mu + \sqrt{\tau_t} \times h_{i,t} \varepsilon_{i,t} | \Phi_{i-1,t} \sim N(0, 1), \forall i = 1, \dots, N_t \quad (1)$$

$$h_{i,t} = (1 - \alpha - \beta) + \frac{(r_{i-1,t} - \mu)^2}{\tau_i} + \beta h_{i-1,t} \quad (2)$$

$$\tau_i^{(r\omega)} = m^{(r\omega)} + \theta^{(r\omega)} \sum_{k=1}^K \phi_k(\omega_1, \omega_1) X_{i-k}^{(r\omega)} \quad (3)$$

Equation (1) is the mean equation, while Equations (2) and (3) are the short-run and long-run segments of the conditional variance of the GARCH-MIDAS model. Among the parameters of interest is (μ) in the mean equation, denoting the unconditional average returns to be captured separately for the renewable and non-renewable energy stocks. Following the GARCH (1.1) process, the short-run component of the conditional variance segment of GARCH-MIDAS is captured by the parameters α and β , expressed as ARCH and GARCH effects, which are conditioned to be positive and/or at least zero ($\alpha > 0$ and $\beta \geq 0$) and summing to less than unit ($\alpha + \beta < 1$). With respect to the long-run component of the conditional variance denoted (τ_i) in Equation (3), it helps incorporate the exogenous variable or realized volatility when no exogenous factor is being considered. Other parameters of interest are $(r\omega)$ and (m) , with the former measuring the outcome of the implementation of a rolling-window framework that allow the secular long-run component to vary monthly, while the latter denotes the long-run component intercept. The slope coefficient (θ) measures the predictive power of climate change (*TEMP*) on the volatility dynamics of the alternative energy stocks under consideration. To capture the moderating role of technological shock in the climate change-energy stock nexus, we employ principal component analysis (PCA) to obtain a combined factor of *TEMP* and *TS*, forming an alternative exogenous factor in the GARCH-MIDAS-X model. Moreover, the described weighting scheme, $\phi_k(\omega_1, \omega_2) \geq 0, k = 1, \dots, K$ is expected to sum to one for the model's parameters to be identified.

III. Results

The main innovation in the study hinges on the moderating role of technology in the volatility effect of climate change in renewable and non-renewable energy stocks. However, for the sake of comparison, we begin our empirical analysis with the model excluding the role of technology. The GARCH-MIDAS estimates in [Table 2](#) show that, in

Table 1. Preliminary results

	Daily Energy Stock Returns		Climate Change and Technology Shock	
	Renewable (RE)	Non-Renewable (NRE)	TEMP	TS
Summary Statistics				
Mean	0.0112	0.0014	0.9034	0.2500
Std. Dev.	1.4636	1.7057	0.2031	3.4230
Skewness	-0.3703	-0.4744	0.5853	-3.0607
Kurtosis	10.9740	20.9287	3.3469	25.3989
No. Obs.	3236	3236	149	149
Frequency	Daily		Monthly	
Start	02/02/2012		February, 2012	
End	17/07/2024		July, 2024	
Conditional Heteroscedasticity & Autocorrelation tests				
ARCH(10)	82.1609***	57.4970***		
ARCH(20)	43.9341***	51.4965***		
ARCH(30)	30.0960***	40.8282***		
Q(10)	81.056***	43.903***		
Q(20)	107.52***	62.492***		
Q(30)	119.69***	78.377***		
Q ² (10)	1865.4***	944.37***		
Q ² (20)	2183.3***	1672.0***		
Q ² (30)	2307.7***	1841.4***		

The reported figures are F-statistics for the ARCH test and Ljung–Box Q-statistics for the autocorrelation test. Both tests are considered at three different lag lengths ($k = 10$, $k = 15$, and $k = 20$). ***, **, and * indicate the rejection of the null hypothesis at the 1%, 5%, and 10% levels of significance, respectively.

addition to the realized volatility shock, the changing climate induces the volatility dynamics of both renewable and non-renewable energy stocks. However, we find the effect of volatility as a consequence of climate change to be relatively higher for renewable energy stock returns compared to non-renewable energy stock returns. This may be connected to the fact that an increase in climate change leading to higher demand for renewable energy is expected to result in more investment in renewable energy stocks, thus increasing volatility, while the reverse is expected to hold for non-renewable energy. Our findings underscore the importance of understanding and adapting to the changing dynamics of the energy market, particularly in the face of climate change. We find that the sum of $(\alpha + \beta)$ at 0.95 in the model with renewable energy stocks is relatively lower compared to 0.99 in the model with non-renewable stocks, suggesting that the short-term energy stock returns have the highest level of persistent volatility in the case of non-renewable energy compared to renewable energy.

The analysis reveals that renewable energy-based models exhibit significant volatility induced by climate change, while non-renewable energy-based models are relatively less affected by this factor. Moving forward, we utilize the PCA technique to amalgamate the factors of *TEMP* and *TS*, enabling us to test the moderating role of *TS* in the nexus. Our analysis commences with the direct impact of *TS* on the volatility dynamics of *RE* and *NRE*.

Taking a closer look at [Table 3](#), we show that the slope coefficient pertaining to *TS* is consistently negative and

statistically significant, regardless of the energy stock's renewable or non-renewable nature. However, the potential of *TS* to directly mitigate the volatility of energy stocks is more pronounced in non-renewable energy. Conversely, technology's ability to moderate the volatility effect of climate change is discernible only in the case of renewable energy. Here, the magnitude of the slope coefficient on the interaction term is 0.0044%, compared to 0.0272% in [Table 2](#), where the slope coefficient measures the direct effect of climate change on the volatility of renewable energy stock. This finding is supported by Salisu et al. (2023) and Penzin et al. (2024), both of which confirm the effectiveness of technologies in moderating the impact of climate change on financial stocks. However, the magnitude of the slope coefficient for *NRE* is 0.0007% in both the models with and without interaction terms, indicating that technology has little or no moderating effect on climate change for non-renewable energy stock volatility.

IV. Conclusion

Motivated by the increasing concern of investors about the vulnerability of their investments to climate-related risks, and the belief that investors with innovative ideas for utilizing emerging technologies are more likely to sustain the environment, and by extension, be resilient to climate change, we hypothesize that technology can moderate the effect of climate change on stock performance. Our research findings are crucial in informing investors about the potential impact of climate change on their investments.

Table 2. GARCH-MIDAS estimates without the role of technology

	μ	α	β	θ	w	m
Renewable Energy-based Model						
RV	0.00040* (0.0002)	0.1473*** (0.0128)	0.7635*** (0.0196)	0.1994*** (0.0095)	5.0081*** (1.2416)	0.0056*** (0.0009)
TEMP	-0.00007 (0.0004)	0.0502*** (0.0129)	0.9005*** (0.0270)	0.0272*** (0.0036)	4.9998*** (0.0488)	0.0011*** (0.0001)
Non-Renewable Energy-based Model						
RV	0.0004* (0.0002)	0.1473*** (0.0128)	0.7635*** (0.0196)	0.1994*** (0.0095)	5.0081*** (1.2416)	0.0056*** (0.0009)
TEMP	0.0002 (0.0002)	0.0707*** (0.0037)	0.9196*** (0.0049)	0.0007** (0.0003)	17.229* (10.32)	0.0003*** (0.0000)

The parameter μ is the unconditional mean, while α and β are the ARCH and GARCH terms. The parameter θ is the slope coefficient, while w and m are the adjusted beta polynomial weight and the long-run constant term, respectively. The values in parentheses are the standard errors of the parameter estimates, while ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Table 3. GARCH-MIDAS estimates with the role of technology

	μ	α	β	θ	w	m
Renewable Energy-based Model						
TS	0.0003 (0.0002)	0.0807*** (0.0066)	0.9115*** (0.0069)	-0.0027*** (0.0010)	35.135*** (12.321)	0.0003*** (0.0000)
TEMP_TS	0.0003 (0.0002)	0.1020*** (0.0079)	0.8863*** (0.0079)	0.0040* (0.0022)	2.1678** (1.1029)	0.0003*** (0.0000)
Non-Renewable Energy-based Model						
TS	0.0003 (0.0002)	0.0713*** (0.0069)	0.9152*** (0.0056)	-0.0270*** (0.0046)	1.2872*** (0.1231)	0.0004*** (0.0000)
TEMP_TS	0.0002 (0.0002)	0.0705*** (0.0037)	0.9198** (0.0048)	0.0007** (0.0003)	16.693* (10.035)	0.0003*** (0.0000)

The parameter μ is the unconditional mean, while α and β are the ARCH and GARCH terms. The parameter θ is the slope coefficient, while w and m are the adjusted beta polynomial weight and the long-run constant term, respectively. The values in parentheses are the standard errors of the parameter estimates, while ***, **, and * indicate statistical significance at the 1%, 5%, and 10% levels, respectively.

Using both renewable and non-renewable energy stocks, we employed the GARCH-MIDAS model to show results suggesting that technology's ability to moderate the volatility effect of climate change is particularly noticeable in the case of renewable energy. The implication is that technological innovation in green energy could play a crucial role

in stabilizing markets and fostering economic resilience in the face of climate challenges.

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