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The predictive effects of Fintech-ESG dynamic interdependence: A global perspective on Cleantech energy transition risk

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ABSTRACT

Fintech plays an instrumental role in advancing global ESG objectives, leveraging a more inclusive, transparent, and accountable financial system. Our paper explores the occurrence of dynamic linkages between Fintech and ESG across various dimensions, examining how the strength of their interconnectedness drives the energy transition towards clean technology. Using daily data from 31st May 2018 to 1st August 2024, we apply a time-varying parameter robust Granger causality method coupled with quantile technique to provide the first attempt in the literature on the dynamic causal patterns between the strength of Fintech-ESG connection and Cleantech energy transition risk (CETR). We find asymmetry in the connectedness across different quantiles, with Fintech sectors acting primarily as shock transmitters, while most ESG indexes are receivers. The 2022 Russia-Ukraine conflict reduces the connectedness between Fintech and ESG, with minimal effects on spillover direction. Our results show a heterogeneous response to shocks in developed markets, while developing ones tend to react more homogeneously. Additionally, we find strong evidence of a time-varying causal relationship between Fintech-ESG connectedness and CETR, with the conflict exacerbating asymmetry, especially at the lower quantile. Recent trends suggest a modest resurgence in this connection, signalling a re-emergence of the Fintech-ESG connection influence on CETR. The impact of extreme events tends to taper-off over time, suggesting that the prolonged conflict-driven market environment may have stabilized sufficiently to restore Fintech's role in promoting ESG initiatives, thereby supporting the ongoing transition to clean technology.

1. Introduction

Financial technology (Fintech) can empower investors, via leveraging technologies such as blockchain, artificial intelligence, and big data, with both depth and breadth of informed decisions (Zhao et al., 2024; Henriques and Sadorsky, 2025), and can facilitate green finance, and democratize access to sustainable investments (Madaleno et al., 2022; Duan et al., 2024; Wen et al., 2024). Fintech possesses the potential to drive a more sustainable, ethical, and inclusive financial system, aligning economic growth with the global need for social and environmental responsibility (Gao et al., 2024).

Furthermore, the organisational commitment to sustainable energy, particularly within the environmental dimension, aligns with Sustainable Development Goal (SDG) 7, which advocates for sustainable and modern energy for all. This commitment can be further strengthened by adopting Fintech mechanisms to facilitate the transition, in alignment with SDG 9, which focuses on fostering innovation and building resilient infrastructure. These interconnected goals emphasize the need to harmonize environmental responsibility (Ren et al., 2023) with Fintech progress (Chaklader et al., 2023), ensuring that societal well-being (Zhou and Wang, 2024) and ecological balance are prioritized in pursuing long-term global sustainability (Hasan et al., 2024) through clean technology (Cleantech) innovations (Jensen et al., 2020). This paper addresses an emerging gap in the literature by exploring whether the deepening of Fintech-ESG relationship, specifically the strong co-moving pattern under extreme conditions, impacts the risk associated with the Cleantech energy transition.

To assess the impact of Fintech–ESG connectedness on Cleantech energy transition, it is first necessary to establish whether such a relationship exists. Confirming this linkage then enables us to proceed further and examine its implications for the Cleantech energy transition. A recent study by Ding et al. (2024) denotes that Fintech development

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motivates corporate Environmental, Social, and Governance (ESG) activities, boosts corporate ESG practices by alleviating financial constraints, and increases stakeholders' attention, thus prompting firms, particularly those listed on stock markets, to strategically engage in ESG initiatives (see, Kim et al., 2025). In addition, Fintech innovations can influence ESG outcomes through multiple channels: distributed ledger technologies enhance transparency and accountability in reporting, alternative finance widens access to sustainable capital, future payments improve efficiency in green financial transactions, and democratized banking fosters broader inclusion in ESG-oriented investment. These mechanisms suggest that Fintech not only encourages firms to adopt ESG practices but also shapes the broader financial environment in which such practices take place, see Table 1.

Previous research has largely concentrated on ESG indexes within specific regions, such as the US and China, or classified them by market development stage, distinguishing between developed and emerging markets (see, Jiang et al., 2023; Ding et al., 2024; Gao et al., 2024; Bouteska et al., 2025; Hu et al., 2025; Zhu et al., 2025). However, far fewer studies have simultaneously considered both geographical segmentation and the stage of economic development. This study employs all eight S&P ESG LargeMidCap indexes, categorized by region and stage of development: Europe Developed ESG, Middle East and Africa Developed ESG, Asia Pacific Developed ESG, North America ESG, Europe Emerging ESG, Latin America Emerging ESG, Middle East and Africa Emerging ESG, and Asia Pacific Emerging ESG. This segmentation allows us to investigate how Fintech mechanisms interact with ESG dynamics in heterogeneous contexts. Developed markets (e.g., Europe, North America, Asia Pacific Developed, and Middle East and Africa Developed) are generally characterized by mature regulatory frameworks, advanced financial ecosystems, and higher ESG disclosure standards, which may amplify the governance and transparency benefits of Distributed Ledger and Democratized Banking innovations. By contrast, emerging markets (e.g., Europe Emerging, Latin America Emerging, Middle East and Africa Emerging, and Asia Pacific Emerging) often face constraints in financial inclusion and capital access, where Alternative Finance and Future Payments could play a more significant role in facilitating sustainable investment. This dual segmentation provides a novel lens to examine regional spillover effects, offering insight into whether Fintech drivers of ESG performance differ systematically between developed and emerging economies.

Undoubtedly, the dual focus allows us to move beyond firm-level studies and instead capture how Fintech innovations shape ESG outcomes across regions with distinct geographical characteristics and stages of economic development. By adopting standardized and widely recognized indexes, we ensure comparability and transparency, thereby providing novel cross-market evidence on the ESG–Fintech nexus that has been overlooked in prior research (see, Albert et al., 2025, for a discussion). This approach not only highlights the heterogeneity in the diffusion of Fintech and ESG practices but also uncovers regional asymmetries that are critical for investors, regulators, and policymakers. In doing so, our study bridges the gap between fragmented regional or firm-level analyses and the need for a more integrated global perspective on sustainable finance and digital transformation.

Despite the emerging literature on the impact of Fintech on ESG, the impact of their interaction on Cleantech energy transition risk remains an unexplored area, which is the primary focus of our study. Building on the climate-transition risk channels identified by Acharya et al. (2025) that technological breakthroughs enable renewables to serve all sectors, anticipated carbon taxes, and restrictions on fossil-fuel capacity, the Fintech–ESG synergies can crucially shape these mechanisms (see, Albert et al., 2025; Hu et al., 2025). Specifically, Fintech-driven innovations in green financing, distributed-ledger carbon markets, and AI-based climate analytics can accelerate capital reallocation towards renewables, thereby increasing the probability and speed of technological breakthroughs that lower future energy prices (see, Mehmood et al., 2025). At the same time, Fintech platforms that enhance carbon-pricing transparency and automate compliance, such as blockchain-enabled carbon credit trading (Kim and Huh, 2020), can magnify the impact of anticipated carbon taxes and drilling restrictions, thereby discouraging new fossil-fuel exploration while boosting the valuation of renewable energy firms as reflected in ESG indexes. These dynamics directly mirror our model's heterogeneous firm-level responses, where incumbents, new fossil entrants, and renewable producers face distinct incentives under transition risk (see, Hong et al., 2024). Consistent with the theoretical mechanism of Acharya et al. (2025), the strength of Fintech–ESG integration becomes a key determinant of cleantech transition risk. As such, when the linkage is weak, the channels of technological breakthroughs, anticipated carbon taxes, and drilling restrictions are unlikely to transmit meaningfully to energy prices or firm valuations. However, when the linkage is strong, it can causally accelerate cleantech breakthroughs and induce sharper adjustments in energy prices and valuations, thereby impacting the transition risks highlighted in Acharya et al. (2025) framework. In light of these theoretical considerations, our study offers the first attempt in the literature to empirically examine the impact of the strength of Fintech-ESG connectedness under extreme conditions on Cleantech energy transition risk.

Additionally, we investigate whether external factors, such as the 2022 Russia-Ukraine military conflict, which caused significant disruptions not only in Europe but also in the global energy sector, affect these impacts (Mubarik et al., 2024; Younis et al., 2024). In fact, persistent uncertain environment is not often conducive to innovation climate, because greater uncertainty forces firms to 'reserve' resources for tough times and negotiate current challenges by planning for the future. This implies that firms are likely to scale back or delay subsequent investments in innovative technologies (Agarwal et al., 2025). In particular, the 2022 Russia–Ukraine conflict constitutes a profound exogenous shock to global energy and financial systems (see, Boubaker et al., 2023; Maneejuk et al., 2024, for a discussion). By simultaneously elevating energy security concerns, disrupting capital markets, and increasing cyber and policy risks, the military conflict alters the economic environment in which Fintech facilitates ESG investment and Cleantech deployment. Therefore, if the strength of the Fintech–ESG relationship governs the Cleantech energy transition, a shock of the magnitude of the Russia–Ukraine conflict is likely to reshape the

Table 1
Fintech proxies and their potential impact on ESG outcomes across regions.

Fintech proxy	ESG dimension most affected	Mechanism of impact	Regional relevance
Distributed Ledger	Governance (G) & Environment (E)	Enhances transparency in ESG reporting, enables carbon tracking and green bond verification.	Critical for emerging markets with weak monitoring systems.
Alternative Finance	Social (S) & Environment (E)	Provides funding for Cleantech startups and inclusive projects via P2P and crowdfunding.	Strong role in regions with underdeveloped banking systems.
Future Payments	Environment (E) & Social (S)	Reduces costs of green transactions, accelerates retail adoption of sustainable investment products.	Global relevance across developed and emerging markets.
Democratized Banking	Social (S) & Governance (G)	Expands access to financial services, fosters inclusive participation in ESG investments.	Important for both developed (innovation diffusion) and emerging (financial inclusion) regions.

Note: Authors' synthesis.

Cleantech energy transition prospects. Hence, another objective of this paper is to investigate whether the strength of Fintech–ESG connectedness influences Cleantech energy transition risk under heightened uncertainty, particularly amid the 2022 Russia–Ukraine conflict.

To sum up, this study makes a notable contribution to the existing literature by revealing whether, and if so, how the strength of Fintech-ESG connectedness under extreme conditions affects Cleantech energy transition risk. First, to examine the strength of the Fintech–ESG relationship, it is essential to establish if such a relationship exists. We therefore begin by testing for linkages between Fintech and ESG indexes, analysing the spillovers effects and considering the often-overlooked segmentation of ESG indexes by geographical region and stage of economic development. In fact, Meira et al. (2023) determine the existence of regional heterogeneity across ESG pillars. In particular, they find that governance dimension varies markedly across regions, whereas the environmental and social pillars remain closely intertwined, exhibiting similar risk–return characteristics and strong correlations. Another study by Qureshi et al. (2025) discovers that ESG investments and energy-sustainability indicators are less pronounced and consistent in emerging markets. Our study further extends this body of knowledge by examining these impacts through the lens of Fintech-ESG connectedness. Second, our study addresses the gap in understanding how ESG regional indexes respond to shocks originating from different segments of the Fintech industry by explicitly examining four key sectors: Future Payments, Distributed Ledger, Democratized Banking, and Alternative Finance. This sectoral decomposition enables us to capture heterogeneity within Fintech itself (see, Naysary and Shrestha, 2024, for a discussion). Such heterogeneity may influence Cleantech energy transition risk differently across regions and, in some cases, may reveal no significant link at all. Thus, a central aim of our study is to identify whether and where these links exist, thereby clarifying the regional and developmental conditions under which Fintech–ESG interactions affect the Cleantech energy transition risk. Third, we expand our analysis into a time-varying framework to examine the causal relationships between Fintech-ESG connectedness and Cleantech energy transition risk employing a time-varying parameter robust Granger causality (TVP-GC) method of Rossi and Wang (2019) coupled with the quantile technique of Ando et al. (2022). This approach pinpoints periods of causality and non-causality between Fintech–ESG connectedness and Cleantech energy transition risk, while accounting for potential instability in their relationship under varying conditions. Last but not least, we explore how the 2022 Russia–Ukraine conflict affects the dynamics of these relationships, assessing how the strength of their interconnectedness shapes the Cleantech energy transition during a period of military conflict. Robustness checks confirm our baseline results.

The structure of the paper is as follows. Section 2 reviews the literature, Section 3 discusses the methodology, Section 4 overviews the data, Section 5 provides a discussion of the empirical results, Section 6 performs robustness checks, and Section 7 concludes the study.

2. Literature review

The integration of ESG principles into Fintech has gained increasing scholarly attention, with consensus that Fintech can both advance and complicate sustainable finance (De Lucia et al., 2020; Mejia-Escobar et al., 2020; Macchiavello and Siri, 2022; Qureshi et al., 2025). At the organisational level, challenges persist in embedding ESG into business models. Non-financial firms and startups often fall short of translating ESG commitments into practice (Alkaraan et al., 2022), while financial institutions struggle to balance rapid Fintech innovation with sustainability goals (Mejia-Escobar et al., 2020). Although artificial intelligence (AI) and related technologies offer tools for ESG risk assessment and financial decision-making, concerns remain about accountability and transparency (Jabeur et al., 2023). In particular, at the regulatory level, effective Fintech–ESG integration depends heavily on institutional frameworks. The EU's "Digital Finance Action Plan" exemplifies efforts to embed sustainability in digital finance (Macchiavello and Siri, 2022), but diffusion is uneven, reflecting disparities in incentives, supervision, and compliance mechanisms (De Lucia et al., 2020; Mejia-Escobar et al., 2020). These organisational and regulatory dynamics are crucial because ESG indexes are constructed from the aggregated performance and disclosures of constituent firms (Baldini et al., 2018). Thus, inconsistencies in ESG adoption, reporting, and Fintech implementation at the firm level can directly influence index composition, weighting, and cross-regional comparability. Despite these advances, little is known about how the ESG–Fintech relationship varies across stages of economic development. Most existing studies are conceptual or region-specific, leaving open the question of whether developed and developing markets exhibit systematically different ESG–Fintech dynamics. It is also important to note that ESG indexes themselves are not tradable instruments but rather benchmark indicators that reflect the sustainability performance of firms within a specific region or sector (Pagano et al., 2018). This distinction is essential for interpreting index movements as representations of underlying firm behaviour rather than direct investment vehicles.

Corporate ESG initiatives have gained significant momentum worldwide (Reber et al., 2022), driven by active regulatory measures but passive market forces (Agliardi et al., 2023). Incorporating ESG criteria into portfolio strategies has consistently demonstrated a reduction in portfolio risk, underscoring the risk mitigation benefits inherent to ESG-focused investment management (Imran et al., 2024). The risk mitigation hypothesis in corporate social performance (CSP) also corroborates this, presenting evidence such as higher equity capital costs and elevated idiosyncratic risk for companies with lower CSP (Miletkov and Staneva, 2025). Firms with stronger CSP generally experience reduced costs of debt, fewer capital constraints, and lower idiosyncratic risks, fostering a more favourable risk profile (Liston-Heyes and Ceton, 2009; Koh et al., 2014). Additionally, firms with value-oriented characteristics tend to exhibit higher average ESG ratings (Joliet and Titova, 2018), contrasting with growth and momentum stocks, which typically show lower ESG ratings. For instance, Europe's advanced adoption of ESG practices is shown to lead more efficient pricing of ESG information in European markets (Amel-Zadeh and Serafeim, 2018). Consequently, U.S. value investors stand to benefit significantly from integrating ESG factors, potentially reducing risk while enhancing return potential (Van Duuren et al., 2016). In response, governments worldwide are urging industries to actively invest in clean technology innovation (Cifrino, 2023), develop green patents that support environmental protection (Fabrizi et al., 2018), and accelerate the transition to renewable energy sources (Dong et al., 2024). These firm-level shifts in ESG performance and disclosure are directly captured in ESG indexes, where the weighting of firms with stronger ESG metrics tends to stabilize index volatility and enhance long-term return predictability (Ferdous et al., 2025). Therefore, understanding how organisational behaviour shapes these underlying metrics is essential for interpreting ESG index trends as indicators of market-level sustainability.

Sustainability information has become increasingly relevant to investors assessing Fintech firms (Gao et al., 2024), reflecting the pivotal role finance is expected to play in advancing a sustainable economic paradigm (Edmans and Kacperczyk, 2022). This shift offers significant growth opportunities for Fintech companies that can strategically align with the SDG values (Ding et al., 2024), boosting their long-term cash flow projections and enhancing market competitiveness (Giakoumelou et al., 2024). Several research findings suggest that the use of Fintech can help improve the sustainable performance of firms (Zhou and Wang, 2024; Hu et al., 2025). Wu et al. (2024) determine that Fintech promotes corporate green transformation in China. A further study by Liu et al. (2025) confirms this by showing that Fintech can significantly enhance corporate ESG performance in China by dismantling information barriers, optimizing investment structures, and fostering green innovation. Since ESG indexes aggregate firm-level data, such Fintech-induced improvements in transparency, disclosure quality, and ESG scoring accuracy can translate into measurable changes in index values. Therefore, Fintech adoption not only affects firm behaviour but also refines the informational efficiency and interpretability of ESG indexes at regional and global levels. Intriguingly, Merello et al. (2022) find that the sustainability profile of Fintech companies can substantially boost stakeholder attention as engagement in green practices has a negative impact on their market value in the US. Although the impact of Fintech on ESG is generally found as positive, the results remain somewhat mixed (see, Trotta et al., 2024, for a discussion). As investors factor in regulatory and technological risks in their capital allocation, they anticipate that Fintech firms will be accountable for the ESG implications of their services and products (Galeone et al., 2024).

As observed, the existing literature has highlighted the impact of Fintech on ESG regional indexes, however, most studies have focused on a single dimension of the Fintech sector. Only a few studies have explored multiple dimensions of the Fintech industry (see, Abakah et al., 2023; Asl and Jabeur, 2024; Naysary and Shrestha, 2024, for a discussion). Our paper, therefore, investigates how ESG regional indexes respond to shocks from various Fintech dimensions (Future Payments, Distributed Ledger, Democratized Banking, and Alternative Finance) and aims to identify the primary Fintech driver for each ESG market based on their geographical location and stage of development. By explicitly linking firm-level ESG and Fintech behaviours to the construction and interpretation of ESG indexes, this research bridges the micro–macro divide, showing how corporate sustainability and innovation patterns aggregate into market-level sustainability indicators. Furthermore, given that ESG indexes serve as non-tradable benchmarks rather than investment assets, understanding their movements requires attention to the underlying firm-level drivers and their aggregated influence on sustainability trends.

A parallel stream of research claims that Fintech can mitigate agency problems (Akhtar, 2025) and leverage greater revenues (He et al., 2023), thereby helping mitigate the regressive revenue-generating effects of uncertainty. Since the Cleantech energy transition is central to the world's objective of achieving NetZero in the coming decade (Van den Heuvel and Popp, 2023), there are prevalent transitional challenges in moving from traditional pollution-intensive technology platforms to Cleantech. Extant literature on innovation diffusion has already established that a new technology is always costly (Pástor and Veronesi, 2009) and hence, the fast-paced diffusion of a new (environmental) technology, apart from its desired sustainability effects, also means that firms that steadfastly adopt this costly new technology face a short-term rise in costs, a solution they surmise can help mitigate long-term reputational and survival costs (Comin and Hobijn, 2010). Popp (2002) determines that environmental taxes and regulations promote the development of new technologies, which reduce the long-term costs of pollution control. Such technological advancements induce transition risks, which could make fossil fuel assets unprofitable (Hansen, 2022). Nonetheless, different assets experience varying exposures to these risks (Zadeh and Romagnoli, 2024). For instance, coal companies might suffer from transition risks, whereas renewable energy firms could benefit. These variations in firm-level exposure and adaptation strategies ultimately feed into ESG index behaviour, as sectors and firms with higher transition readiness contribute to stronger index resilience against environmental policy shocks. Given the diverse risk exposures of different assets, a key challenge for climate finance research is whether the Fintech-ESG connectedness impacts the energy transition risk at the technology level.

3. Methodology

3.1. Connectedness measures based on QVAR method

Following Wang et al. (2024a), we adopt the connectedness measures developed by Diebold and Yilmaz (2012); Diebold and Yılmaz (2014) with their Quantile Vector Autoregressive (QVAR) extension proposed by Ando et al. (2022), our study examines the existence of dynamic linkages between ESG and Fintech at different quantiles, λ, of the distribution. Thus, an infinite order vector moving average (MA) process at time t is transformed from a stationary QVAR(λ, q) as:

$$z_{t,\lambda} = \zeta_\lambda + \sum_{k=1}^{q} \Gamma_{k,\lambda} z_{t-k} + \eta_{t,\lambda} = \varphi_\lambda + \sum_{i=0}^{\infty} \Omega_{i,\lambda} \eta_{t-i,\lambda} \tag{1}$$

where $\lambda \in [0,1]$, q is the lag length, $z_{t,\lambda}$ is m-dimensional dependent variables vector, ζ_λ are φ_λ are vectors of intercepts, $\Gamma_{j,\lambda}$ is a $m \times m$ lag coefficients matrix, $\eta_{t,\lambda}$ is a $m \times 1$ vector of error disturbances, $\Omega_{i,\lambda}$ is a $m \times m$ matrix of MA lag coefficients.

To address the ordering issue of Cholesky factorization, we follow the methods of Koop et al. (1996) and Pesaran and Shin (1998) which are insensitive to variable ordering (Jena et al., 2022). Hence, the generalized forecast error variance decomposition (GFEVD) is denoted as:

$$\Psi^{g}_{i\leftarrow k,\lambda}(H) = \frac{\sum(\lambda)^{-1}_{kk} \sum_{h=0}^{H-1} \left(e_i'\Omega_{h,\lambda} \sum(\lambda) e_k\right)^2}{\sum_{h=0}^{H-1} \left(e_i'\Omega_{h,\lambda} \sum(\lambda) \Omega_{h,\lambda}{}' e_i\right)} \tag{2}$$

where e_i is a vector of value 1 for the i-th element and 0 otherwise, H is the forecast horizon. Following Ando et al. (2022), $\widetilde{\Psi}^{g}_{i\leftarrow k}(H)$ normalizes the unscaled GFEVD, i.e., $\Psi^{g}_{i\leftarrow k,\lambda}(H)$, such as:

$$\widetilde{\Psi}^{g}_{i\leftarrow k,\lambda}(H) = \frac{\Psi^{g}_{i\leftarrow k,\lambda}(H)}{\sum_{k=1}^{m} \Psi^{g}_{i\leftarrow k,\lambda}(H)} \tag{3}$$

where $\sum_{k=1}^{m} \widetilde{\Psi}^{g}_{i\leftarrow k,\lambda}(H) = 1$ and $\sum_{i,k=1}^{m} \widetilde{\Psi}^{g}_{i\leftarrow k,\lambda}(H) = \text{m}$. We then define four connectedness measures:

$$TO_{\bullet\leftarrow i,\lambda}(H) = \sum_{k=1, i\neq k}^{m} \widetilde{\Psi}^{g}_{k\leftarrow i,\lambda}(H) \tag{4}$$

$$FROM_{\bullet\rightarrow i,\lambda}(H) = \sum_{k=1, i\neq k}^{m} \widetilde{\Psi}^{g}_{i\leftarrow k,\lambda}(H) \tag{5}$$

$$NET_{i,\lambda}(H) = TO_{\bullet\leftarrow i,\lambda}(H) - FROM_{\bullet\rightarrow i,\lambda}(H) \tag{6}$$

$$TCI_\lambda(H) = \frac{\sum_{i,k=1, i\neq k}^{m} \widetilde{\Psi}^{g}_{i\leftarrow k,\lambda}(H)}{m-1} \tag{7}$$

$TO_{\bullet\leftarrow i,\lambda}$ refers to the impact of variable k on variable i at quantile λ. $FROM_{\bullet\rightarrow i,\lambda}$ is the impact of i on k at quantile λ. The sign of the $NET_{i,\lambda}$ value, either negative or positive, determines if i is a net transmitter or net recipient of the spillover, respectively. TCI_λ is the overall average connectedness.

The Bayesian Information Criterion (BIC) determines the lag length of 1 for the QVAR model via which are estimated the connectedness measures at $H = 1$. To address a possible time variation, a 40-days rolling-window approach is adopted (see, Farid et al., 2022; Zhou et al., 2024, for details). The choice of a 40-day window is motivated by the need to capture high market turbulence and short-term variability, and is further supported by prior studies in the literature (see, Lintilhac and Tourin, 2017; Wang et al., 2025).

3.2. TVP-GC approach

To examine whether the strength of the connectedness between Fintech and ESG has impact on Cleantech energy transition risk, we follow Wang et al. (2024a) by utilizing the TVP-GC method of Rossi and Wang (2019), which offers a significant advantage over traditional causality tests as it accounts for instabilities (Harrison et al., 2023).

Considering the time span of our study including intensive changes in energy-related policies, such as European Green Deal, ESG Disclosure Simplification Act of 2021, Inflation Reduction Act of 2022, in stock markets, such as the COVID-19 pandemic, the 2022 Russia–Ukraine conflict, and the 2023 Israeli-Hamas conflict, and in financial technology, such as FTX collapse and Microsoft CrowdStrike glitch, the TVP-GC method enables a more robust examination of time-varying causal relationships compared to standard tests (see, Akyildirim et al., 2022). The TVP-VAR model is defined as:

$$z_t = \theta_{1,t}z_{t-1} + \theta_{2,t}z_{t-2} + \ldots + \theta_{q,t}z_{t-q} + u_t \tag{8}$$

where $z_t = [z_{1,t}, z_{2,t}\ldots, z_{m,t}]'$ is a $m \times 1$ vector, $\theta_{k,t}$ are functions of time-varying coefficient matrixes, $k = 1, 2, \ldots q$, and u_t represents idiosyncratic shocks with serial correlation and heteroscedasticity. Hence, the null hypothesis is defined as CETR (TCI) does not Granger cause TCI (CETR), $H_0 : \Phi_t = 0, \forall t = 1, 2, \ldots T, \Phi_t \subset (\theta_{1,t}, \theta_{2,t}, \ldots, \theta_{q,t})$. TCI is the total connectedness index at a given quantile λ, as estimated by Eq. (7), and determines the strength of the connectedness between the ESG and Fintech, and CETR denotes the Cleantech energy transition risk. The BIC determines the lag length, q. Following the esteemed research practices, a standard trimming parameter of 0.10 is used.

3.3. TVP-SVAR-SV approach

The above methods are effective for detecting causal links and quantile-dependent dynamics, yet they fall short of assessing how the Fintech–ESG nexus actually shapes Cleantech energy transitions, including the sign of the effect and its potential evolution across different periods. To reflect this, we follow the approach by Feng et al. (2023) to adopt the time-varying parameter structural vector autoregression model with stochastic volatility (TVP-SVAR-SV) model that combines the TVP-VAR method of Primiceri (2005) with the stochastic time-varying volatilities based on the innovations of Nakajima (2011). The benefit of using TVP-SVAR-SV model is that it captures any potential nonlinear time-varying relations between variables. Following Nakajima (2011), a SVAR model is defined as follows:

$$Ay_t = \varphi_1 y_{t-1} + \ldots + \varphi_s y_{t-s} + \nu_t \tag{9}$$

where y_t is a 2×1 vector of observed variables, $y_t = [\text{TCI}_t, \text{CETR}_t]$, $t = s+1, \ldots, T$, A is a 2×2 is a lower-triangular parameter matrix, $\varphi_1, \ldots, \varphi_s$ are 2×2 coefficient matrixes, ν_t is a 2×1 structural shock with $\nu_t \sim N(0, \Sigma\Sigma)$, Σ is a 2×2 dimensional diagonal matrix. The Eq. (9) can be rewritten in reduced form SVAR model:

$$y_t = G_1 y_{t-1} + \ldots + G_s y_{t-s} + A^{-1}\Sigma\epsilon_t \tag{10}$$

where $G_i = A^{-1}\varphi_i$, $i = 1, \ldots, s$, $\epsilon_t \sim N(0, I_2)$. Following Nakajima (2011), stacking the elements in the rows of the G_i's to form $\beta(2^2 s \times 1$ vector), the Eq. (10) can be rewritten as:

$$y_t = Z_t\beta + A^{-1}\sum \epsilon_t \tag{11}$$

where $Z_t = I_k \otimes (y'_{t-1}, \ldots, y'_{t-s})$ and $\otimes$ is the Kronecker product. By incorporating the time factor into Eq. (11), the TVP-SVAR-SV model is:

$$y_t = Z_t\beta_t + A_t^{-1}\sum_t \epsilon_t \tag{12}$$

where β_t, A_t, and Σ_t are all time-varying, the lower-triangular matrix for A_t is recursive identification for the VAR system (see, Nakajima, 2011, for details). Eq. (12) is qualified as the observation equation of the TVP-SVAR-SV model (Feng et al., 2023; Zhong et al., 2023). Following Nakajima (2011), the parameters are assumed to follow a random walk process:

$$\begin{cases} \beta_{t+1} = \beta_t + \nu_{\beta t} \\ \alpha_{t+1} = \alpha_t + \nu_{\alpha t} \\ h_{t+1} = h_t + \nu_{ht} \end{cases} \tag{13}$$

where $h_t = (h_{1t}, \ldots, h_{nt})'$ and $h_{jt} = log\sigma_{jt}^2, j = 1, 2.$

$$\begin{cases} \beta_{s+1} \sim N(\mu_{\beta_0}, \Sigma_{\beta_0}) \\ \alpha_{s+1} \sim N(\mu_{\alpha_0}, \Sigma_{\alpha_0}) \\ h_{s+1} \sim N(\mu_{h_0}, \Sigma_{h_0}) \end{cases} \tag{14}$$

The correlation pattern of the model's shocks is captured by the block-diagonal variance–covariance matrix:

$$\begin{pmatrix} \epsilon_t \\ \nu_{\beta t} \\ \nu_{\alpha t} \\ \nu_{ht} \end{pmatrix} \sim N\left(0, \begin{pmatrix} I & 0 & 0 & 0 \\ 0 & \Sigma_\beta & 0 & 0 \\ 0 & 0 & \Sigma_\alpha & 0 \\ 0 & 0 & 0 & \Sigma_h \end{pmatrix}\right) \tag{15}$$

where Σ_β, Σ_α and Σ_h are diagonal matrixes, and I denotes the identity matrix.

The estimation of the TVP-SVAR-SV model is carried out within a Bayesian framework using the Markov Chain Monte Carlo (MCMC) method. Consistent with Boufateh and Saadaoui (2021), the prior distributions for the i^{th} diagonal elements of the covariance matrixes are specified as $(\Sigma_\beta)_i^{-2} \sim Gamma(40, 0.02)$, $(\Sigma_\alpha)_i^{-2} \sim Gamma(4, 0.02)$, and $(\Sigma_h)_i^{-2} \sim Gamma(4, 0.02)$. Following Primiceri (2005), the posterior inference is conducted via the Gibbs sampling algorithm, wherein the initial 1000 iterations are discarded as the burn-in and 10,000 subsequent draws are retained for parameter estimation.

4. Data

To evaluate the quantile connectedness between Fintech and ESG, we use daily data for the period from 31st May 2018 to 1st August 2024. The starting date is dictated by the data availability, and more precisely, data for Distributed Ledger, one of our proxies for Fintech. As a matter of fact, Distributed ledger technology is a foundational element of fintech and an essential component of the clean energy and ESG finance landscape. In particular, it enables decentralized energy trading, the tokenization of carbon credits, and transparent ESG data verification (see Cao et al., 2025), making it an indispensable part of our analysis. As a proxy for Fintech, our study considers all four Standard & Poor (S&P) Kensho Fintech indexes: Future Payments, Distributed Ledger, Democratized Banking, and Alternative Finance (see, Abakah et al., 2023; Asl and Jabeur, 2024). These indexes, which have a global scope, track the performance of companies leading the way in the Fintech revolution (Naysary and Shrestha, 2024). As such, our study offers a clearer view on the impacts of different Fintech dimensions on ESG, and determines any variations among them. As a representative of ESG, our study employs the S&P ESG LargeMidCap indexes, which act as indicators for stocks that fulfil sustainability performance standards. More precisely, we consider a broad range of S&P ESG LargeMidCap indexes split by region and stage of development. In fact, we consider all eight S&P ESG LargeMidCap regional indexes: Europe Developed ESG, Mid-East and Africa Developed ESG, Asia Pacific Developed ESG, North America ESG, Europe Emerging ESG, Latin America Emerging ESG, Mid-East and Africa Emerging ESG, and Asia Pacific Emerging ESG.[1] Considering such a variety of ESG indexes allows us to explore the existence of heterogeneity in the Fintech impact on ESG across regions and its variation due to stage of country development. The Fintech and ESG data are obtained from Bloomberg (see Appendix A for series definitions).

To proxy the Cleantech energy transition risk, our study follows the existing literature by using the WilderHill New Energy Global Innovation Index (NEX) to reflect energy transition risk at the technology level

[1] The list of developed and emerging countries is available here: https://www.spglobal.com/esg/performance/indices/esg-index-family

(see, Guo et al., 2024). The index is created to track the progress of technological innovations for global climate change solutions, with all the companies included being involved in technological advancements aimed at reducing carbon emissions resulting in a positive environmental impact. The data for the Cleantech energy transition risk (CETR) index are from Bloomberg. All series are transformed into logarithmic returns.

Furthermore, the sample is divided into pre- and post-conflict announcement periods, using February 24, 2022, as the reference date when Russia invaded Ukraine, marking the beginning of the 2022 Russia-Ukraine military conflict (see, Zhou et al., 2024). Specifically, the pre-conflict period spans from May 31, 2018, to February 23, 2022, while the post-conflict announcement period extends from February 24, 2022, to August 1, 2024. By this means, our study is the first to determine shifts in the Fintech-ESG relationship, and their interactions with Cleantech energy transition risk, brought by the outbreak of the military conflict between Russia and Ukraine in 2022.

Figs. 1 and 2 present the time-series of Fintech and CETR returns, and ESG returns, respectively, over the full sample period. Referring to Fig. 1, it is noticeable that the Fintech industry shows a relatively stable trend prior to the onset of the COVID-19 pandemic. However, the industry experiences significant volatility after the early 2020s. In fact, Fig. 1 shows several vast spikes in the Fintech sector, particularly, in early 2020 and 2021, which denotes the fast technological adoption during crises, specifically, during the COVID-19 pandemic (Fu and Mishra, 2022). In the meantime, the volatility of the Fintech series seems to die out quickly after the first sizable spike in early 2020, however, a persistency of high volatility is evident after the second substantial spike in the series, during early 2021. This period overlaps with the outbreak of the Russia-Ukraine military conflict and the substantial effect it has had on the Fintech and Blockchain industries (Abakah et al., 2023). Similarly, the CETR index exhibits a sharp increase in volatility following the outbreak of the COVID-19 pandemic, which gradually subsided over time before rising again in early 2022, coinciding with the onset of the Russia–Ukraine conflict. Some ESG indexes display a similar pattern, as shown in Fig. 2, with noticeable volatility clustering around the onset of the COVID-19 pandemic and renewed spikes following the outbreak of the 2022 Russia–Ukraine military conflict, particularly for the North America ESG, Europe Emerging ESG, and Europe Developed ESG indexes. Notably, the ESG performance of European emerging markets exhibits a pronounced volatility spike following the outbreak of the military conflict, indicating heightened sensitivity to geopolitical and transition-related risks (see Deng et al., 2022). This event therefore serves as a natural structural breakpoint in our analysis. The observed similarity in patterns among certain Fintech, ESG, and CETR markets further supports the notion that the Fintech–ESG relationship intensifies during episodes of market turbulence, a dynamic we investigate further in the following sections.

Fig. 3 illustrates the correlation coefficients between Fintech and ESG series. It can be noted that the correlation between the variables is predominantly positive.[2] On one side, this finding suggests that Fintech companies that prioritize ESG factors are likely to attract more investors who are looking for responsible and sustainable business practices (see, Chen and Xie, 2022). On the other side, a positive correlation between Fintech and ESG promotes sustainability through innovation. As such, Fintech solutions can help achieve ESG goals, particularly in areas like sustainability and inclusion (Erel and Liebersohn, 2022). Additionally, fintech innovations can foster social inclusion by offering access to financial services for populations that are typically underserved. Moreover, the North America markets show the highest correlation between sustainability, represented by ESG, and different determinants of Fintech. Referring to the post-conflict announcement results, as provided in Panel B of Fig. 3, we notice a slight decrease in the strength of the Fintech-ESG relationship. However, correlation does not imply causation (Granger, 1988), which is a central question our study seeks to explore within the context of ESG and Fintech markets.

Table 2 shows the summary statistics of the monthly returns of Fintech and ESG. The results determine a negative mean return of −0.031 for Alternative Finance, while all other series exhibit a positive mean return during the pre-conflict period. Likewise, the only two series with a negative mean return, of −0.007 and − 0.092, in the post-conflict announcement period are the Mid-East and Africa Emerging ESG and Europe Emerging ESG, respectively. Hence, we can conclude that the mean return of Fintech and ESG series is mostly positive regardless of the sub-period. Further to that, the Fintech series exhibit a higher average volatility compared to the ESG markets. In fact, Distributed Ledger has the highest standard deviation, whereas the Asia Pacific Developed ESG has the lowest standard deviation in both periods. This finding is unsurprising, as investors frequently view Distributed Ledger technologies, commonly associated with blockchain and cryptocurrencies, as high-risk, high-reward opportunities, which tend to drive speculative investment behaviour. This speculation amplifies price swings as market sentiment can shift dramatically based on news, trends, or regulatory changes (see, Cucculelli and Recanatini, 2022). The results with respect to skewness and kurtosis suggest that the series distribution is close to non-normal, especially in the pre-conflict period. Last but not least, all series are found to be stationary.

5. Results and discussions

5.1. Preliminary analysis on the impact of Fintech on ESG

To determine whether Fintech affects ESG regional indexes, we conduct several tests. Firstly, we estimate a time-invariant regression model:

$$ESG_t = \beta_1 + \beta_2 Fintech_t + \epsilon_t \tag{16}$$

where ESG_t denotes the ESG regional indexes at time t, $Fintech_t$ corresponds to the proxies of Fintech at time t, ϵ_t is the disturbance term.[3]

Table 3 shows the outcomes from Eq. (16). One can notice that Fintech has a significant positive impact on ESG regional indexes regardless of the proxy type for Fintech and sub-period. This finding is significant from an investor's perspective, particularly for green investors, as investing in the Fintech industry may contribute to improved performance of ESG regional indexes. Although the impact of Fintech remains positive and significant at 1 % for all ESG markets regardless of their stage of development, the conflict has impact on the coefficients' magnitude. In fact, a decrease in the impact of Fintech on ESG regional indexes is observed, irrespective of the countries' stage of economic development or the choice of Fintech index, after the outbreak of the military conflict between Russia and Ukraine in 2022.

Reflecting on the Fintech proxies, it is evident that Democratized Banking has the greatest average impact on ESG regional indexes during the pre-conflict period, as shown in Panel A of Table 3. However, after the outbreak of the 2022 Russia-Ukraine military conflict, Future Payments emerges as the most significant average influencer on ESG regional indexes. In the meantime, Distributed Ledger has the smallest impact on ESG regional indexes among all Fintech indexes for both sub-periods. This finding aligns with the safe haven literature, which identifies cryptocurrencies as a hedge or safe haven against market risk during both pandemics (see, Khelifa et al., 2021; Ren et al., 2022; Duan et al., 2023; Enilov and Mishra, 2023; Huang et al., 2023) and a military

[2] The full results from correlation tests are provided in Appendix C.

[3] We use Newey and West's (1987) kernel-based HAC covariance estimator, coupled with Newey and West's (1994) automatic bandwidth selection, to account for potential autocorrelation and heteroskedasticity in the disturbance term.

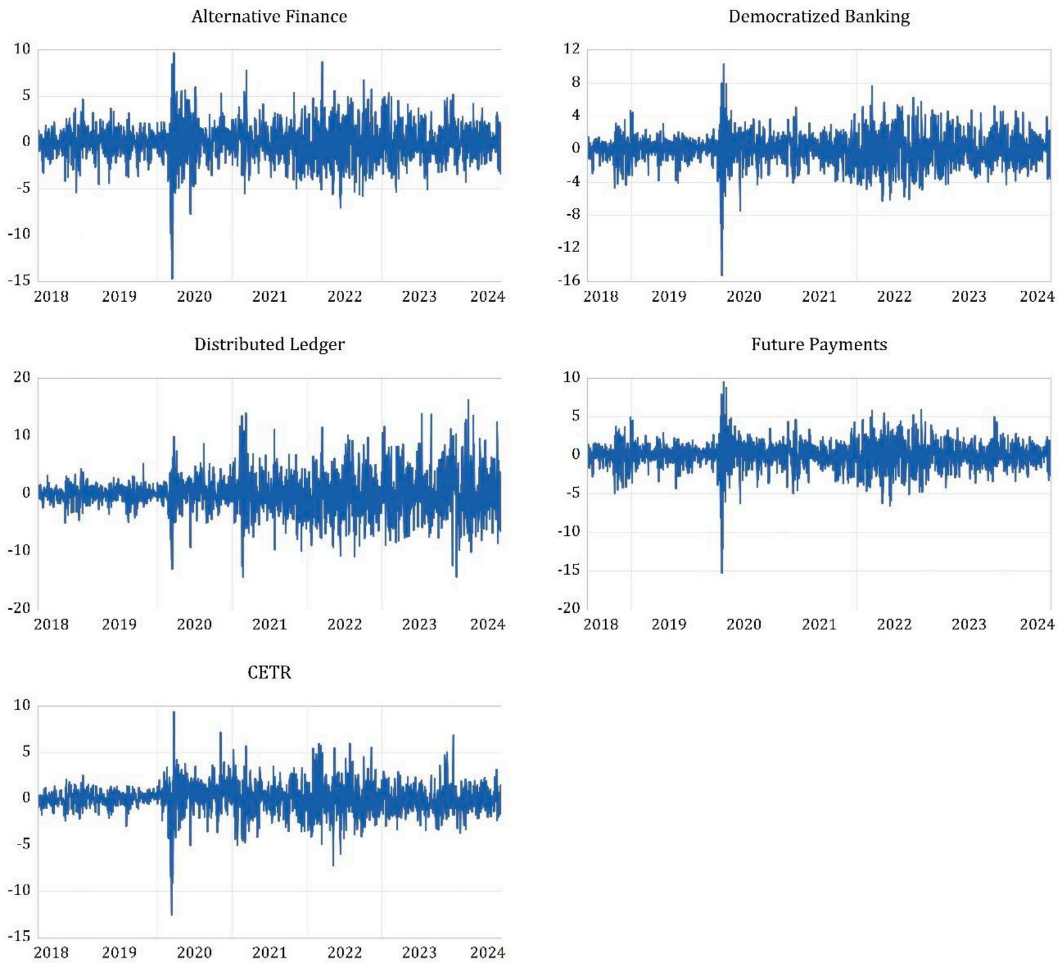


Fig. 1. Time-series graph of Fintech and CETR return series.

conflict (see, Abakah et al., 2023; Hsu et al., 2024; Rubbaniy et al., 2024). It is important to note that ESG indexes themselves are non-tradable benchmark indicators and cannot be directly used for diversification or hedging. Instead, investors achieve these benefits through index-tracking instruments such as exchange-traded funds (ETFs) or index mutual funds, which replicate the composition of ESG indexes to provide diversified and cost-effective market exposure. From an investor's perspective, ETFs and index funds are available on a regional basis, such as domestic, regional, or global markets, allowing investors to tailor their diversification and risk management strategies according to their geographic preferences and investment objectives.

Furthermore, the impact of Fintech is found to be the largest on the Latin America Emerging ESG regional indexes across all Fintech indexes but Distributed Ledger during the pre-conflict period. In fact, Distributed Ledger has the largest impact on the North America ESG regional indexes before and after the outbreak of the military conflict. Interestingly, all four Fintech indexes are found to have the greatest impact on North American ESG index following the commencement of the conflict.

The results in Table 3 show a consistently positive association between ESG performance and Fintech development across all regions, though the strength of this relationship varies over time and by geography. Before the conflict, North America exhibited the strongest ESG–Fintech linkages, particularly within the Distributed Ledger segment, and the second-highest coefficients across the remaining three Fintech categories. In contrast, developed European markets demonstrated comparatively weaker sensitivities, suggesting structural or regulatory differences in how ESG considerations are integrated into fintech innovation. Following the conflict, the relationship weakens globally, suggesting that geopolitical uncertainty and financial risk aversion constrained ESG-aligned Fintech activities (see, Gai et al., 2025), especially in regions more exposed to conflict-related disruptions. A possible explanation for this is that geopolitical uncertainty and heightened financial risk aversion may have disrupted the capital and innovation flows that previously supported ESG-aligned fintech initiatives (see, Wang et al., 2024b, for a discussion). In particular, the reduction is most visible in Europe and emerging markets, where financial ecosystems are more exposed to conflict-related shocks (Goel, 2025). Our findings indicate that although Fintech remains an important driver of ESG advancement, its effectiveness diminishes under geopolitical and macroeconomic stress, highlighting the importance of building more resilient ESG–innovation ecosystems.

To assess the differences across the two sub-periods, we conduct a Wald test on the interaction term from a pooled regression to formally compare slopes across the two stages and provide the results in Table 4. In 27 out of 32 cases the null hypothesis of slope equality is rejected, indicating a statistically significant change in the Fintech-ESG relationship after the 2022 Russia-Ukraine conflict outbreak.

The model in Eq. (16) does not account for the possibility that Fintech's influence on ESG regional indexes may change over time. Previous research has suggested that Fintech may have a time-varying effect on ESG regional indexes (see, Ding et al., 2024; Naysary and Shrestha, 2024). To overcome this limitation, we modify Eq. (16) to incorporate time-varying specifications:

$$ESG_{t,t+\omega} = \beta_{1,t+\omega} + \beta_{2,t+\omega} Fintech_{t,t+\omega} + \epsilon_{t,t+\omega} \quad (17)$$

where $ESG_{t,t+\omega} = ESG_t, ESG_{t+1}, \ldots, ESG_{t+\omega}$, $Fintech_{t,t+\omega} = Fintech_t$,

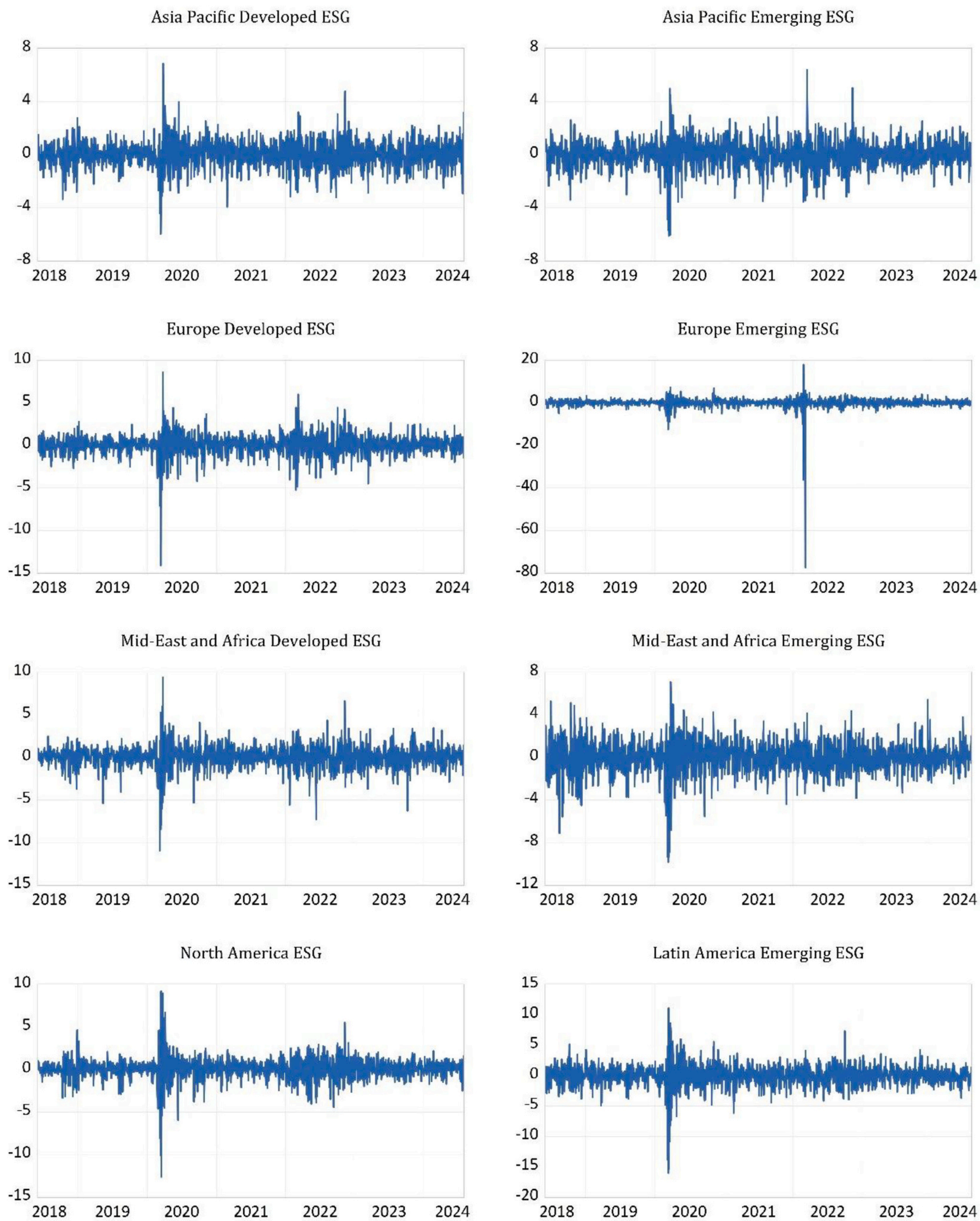


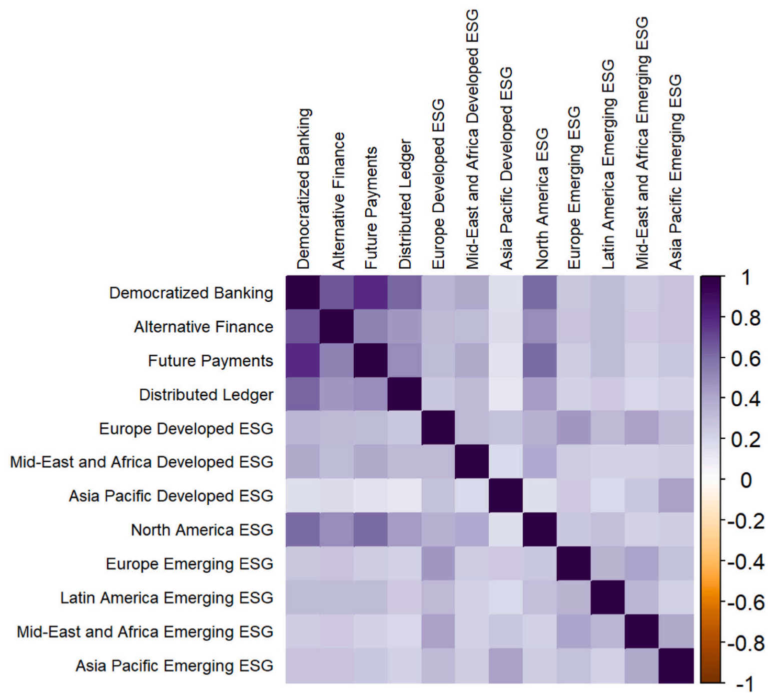
Fig. 2. Time-series graph of the ESG return series.

$Fintech_{t+1}, \ldots, Fintech_{t+\omega}$, ω is the rolling window size. Following the preceding studies, we set a 40-days rolling window (see, Wang et al., 2024a).

Table 5 presents the net time-varying intensity of the impact of Fintech on ESG regional indexes. The net time-varying intensity is calculated by subtracting the negative percentage frequency from the positive percentage frequency based on Eq. (17). As such, if the net time-varying intensity is positive, it denotes that Fintech has mostly a positive impact on ESG regional indexes, whereas if it is negative, then Fintech has predominantly an adverse influence on ESG regional indexes. Referring to the results in Table 5, we determine that Fintech has predominantly a positive impact on ESG regional indexes, irrespective of the proxy for Fintech, the ESG region, the countries' stage of economic development, or the sub-sample period. However, our findings note that the impact of Fintech on ESG regional indexes is not persistent over time. The only exeptions to that are North America ESG with Democratized Banking and Future Payments, for pre-conflict period and both levels of significance, and North America ESG with Democratized Banking, for conflict period and 10 % level of significance.

On top of that, some Fintech indexes have reduced their impact on ESG regional indexes, whereas others increase theirs, due to the outbreak of the conflict, as shown in Panels A and B of Table 5. As such, Alternative Finance is found to reduce its impact on all ESG regional indexes except Asia Pacific Developed ESG and North America ESG, after the conflict announcement. Contrary to that, Future Payments increases its influence on the ESG regional indexes for all of them, but Mid-East and Africa Developed ESG, Asia Pacific Emerging ESG and North America ESG in post-conflict announcement times. Although the results are rather mixed regarding the increase or decrease in the dependence of ESG regional indexes on Democratized Banking and Distributed Ledger

Panel A: Pre-Conflict announcement



Panel B: Post-Conflict announcement

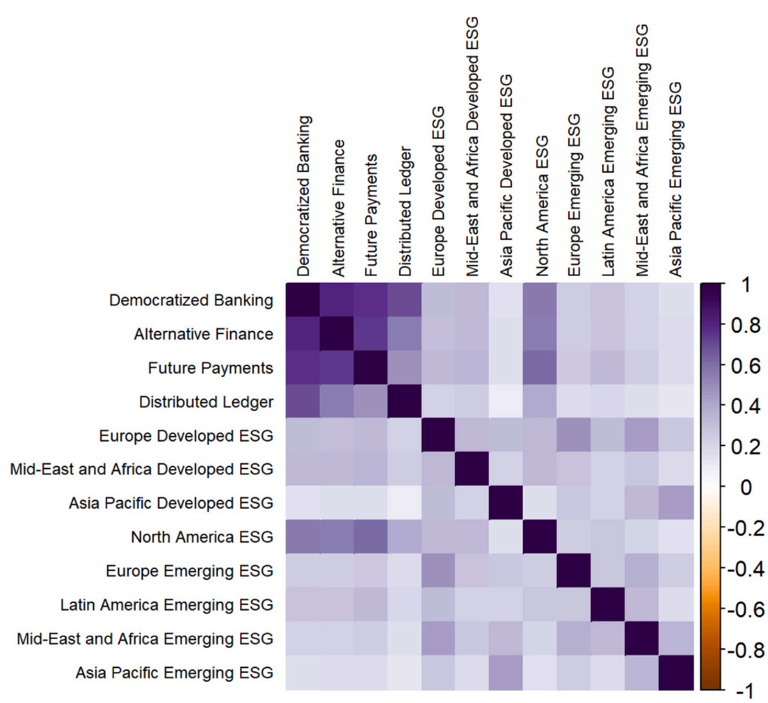


Fig. 3. Correlogram of returns series. Note: The heatmap illustrates pairwise correlation coefficients between FinTech and ESG indices across regions. Coefficients range from −1 (perfect negative correlation) to +1 (perfect positive correlation), with darker shades indicating stronger correlations. Panel A: Pre-Conflict announcement. Panel B: Post-Conflict announcement.

due to the military conflict, the majority indicate a decrease in this dependence. Even though our results in Table 5 are consistent with Naysary and Shrestha (2024), who find a positive correlation between three Fintech indexes, namely, Alternative Finance, Future Payments, and Democratized Banking, with global ESG index, our findings indicate the existence of heterogeneous response of different ESG markets to Alternative Finance, Future Payments, Democratized Banking and Distributed Ledger. Overall, our results demonstrate that Fintech industry has mainly temporal, but nonetheless positive, impact on ESG regional indexes.

Overall, our results indicate consistently positive impacts of Fintech on ESG before the conflict, suggesting that Fintech activity strongly complements ESG performance across most regions. The time-varying results reveal that North America and developed European markets

Table 2
Descriptive statistics.

	Democratized Banking	Alternative Finance	Future Payments	Distributed Ledger	Europe Developed ESG	Mid-East and Africa Developed ESG	Asia Pacific Developed ESG	North America ESG	Europe Emerging ESG	Latin America Emerging ESG	Mid-East and Africa Emerging ESG	Asia Pacific Emerging ESG
Panel A: Pre-Conflict announcement												
Mean	0.023	−0.031	0.042	0.029	0.025	0.059	0.021	0.057	0.013	0.007	0.010	0.020
Std. Dev.	1.823	1.998	1.820	2.746	1.197	1.307	0.993	1.342	1.637	1.960	1.704	1.056
Skewness	−1.032	−0.594	−1.090	−0.044	−1.880	−1.037	−0.125	−1.021	−1.234	−1.406	−0.754	−0.651
Kurtosis	12.773	8.892	13.546	7.368	27.432	15.573	8.316	21.570	11.058	16.274	7.544	7.394
ADF	−20.412***	−10.621***	−20.411***	−15.385***	−19.841***	−10.232***	−19.438***	−8.961***	−30.011***	−10.342***	−30.737***	−19.747***
Fourier ADF	−20.517***	−33.140***	−20.508***	−15.543***	−19.897***	−10.26***	−19.508***	−9.020***	−30.234***	−10.418***	−30.772***	−19.798***
№ obs.	974	974	974	974	974	974	974	974	974	974	974	974
Panel B: Post-Conflict announcement												
Mean	0.018	0.002	0.022	0.032	0.028	0.016	0.019	0.048	−0.092	0.026	−0.007	0.003
Std. Dev.	2.169	2.138	1.830	4.485	1.163	1.313	1.018	1.113	3.833	1.379	1.199	1.039
Skewness	0.094	0.101	−0.106	0.335	−0.022	−0.198	0.010	−0.165	−14.303	0.109	0.333	0.304
Kurtosis	3.151	3.512	3.686	3.438	6.108	6.048	3.774	5.031	275.825	4.288	4.057	6.239
ADF	−24.580***	−24.082***	−24.624***	−24.305***	−25.309***	−24.682***	−24.195***	−24.817***	−28.208***	−21.374***	−19.466***	−23.175***
Fourier ADF	−24.594***	−24.131***	−24.620***	−24.342***	−8.361***	−24.711***	−24.258***	−24.841***	−27.662***	−21.477***	−19.515***	−23.233***
№ obs.	636	636	636	636	636	636	636	636	636	636	636	636

Note: The table is divided into two panels, A and B, representing the pre- and post-conflict announcement periods, respectively. Both ADF and Fourier ADF tests have a null hypothesis of a unit root, against their corresponding alternatives. The Fourier ADF test is especially effective for addressing structural breaks, as it can accommodate an unknown number of level shifts. The lag length is selected by BIC. *** indicates significance at the 1 % level.

exhibit the highest intensities, while Asia Pacific Developed and Emerging regions display comparatively lower levels. Among the Fintech proxies, Future Payments and Democratized Banking consistently record stronger ESG linkages than Distributed Ledger, reflecting their broader integration within mainstream financial systems and consumer markets (Asl and Jabeur, 2024; Liu, 2024). After the conflict announcement, a general decline in intensity is observed across all regions and categories, implying a reduced capacity of Fintech innovation to reinforce ESG performance under heightened geopolitical and financial uncertainty. Regional variation likely stems from differences in financial market maturity, regulatory environments, and ESG disclosure standards.

5.2. Dynamic connectedness of total spillover

Fig. 4 presents the Total Connectedness Index (TCI) at different quantiles. The TCI signifies the variation in the connectedness between Fintech and ESG regional indexes over time at different quantiles of the distribution: 5th percentiles (lower quantile), 50th percentiles (median quantile), and 95th percentiles (upper quantile).[4] Our findings determine that extreme events heighten the connectedness between Fintech and ESG regional indexes. In fact, the connection between Fintech and ESG regional indexes is relatively stronger soon after the onset of the COVID-19 pandemic, and the outbreak of the military conflict between Russia and Ukraine in 2022 compared to the other periods. In fact, at the 5th and 95th percentiles, Panel A (B) reveals average TCI values of 81.64 % (80.69 %) and 81.37 % (80.49 %), respectively. Hence, this suggests a symmetric pattern of the interconnectedness between Fintech and ESG regional indexes in times of both adverse and flourishing market conditions.

Although the TCI values at the extreme quantiles are in close proximity to each other, the TCI value at the median quantile suggests much weaker connectedness between Fintech and ESG regional indexes. As such, the average TCI value at the median quantile in Panel A (B) is 65.60 % (61.00 %). On one side, the military conflict led to slightly weaker connectedness between Fintech and ESG regional indexes. On the other side, this result signifies the existence of asymmetric behaviour in the connectedness between Fintech and ESG regional indexes across different quantiles, and is consistent with the findings on asymmetry from the previous literature on the connectedness between Fintech and other markets (see, Demir et al., 2022; Abakah et al., 2023; Su and He, 2024).

5.3. The impact of Fintech-ESG connectedness on Cleantech

This section evaluates the impact of the strength of Fintech-ESG connectedness on Cleantech energy transition risk (CETR). Notably, the existing literature does not provide evidence on whether the relationship between the Fintech sector and ESG increases exposure to transition risk in clean technology. If such a relationship does exist, it remains an open question whether a stronger Fintech-ESG connectedness has a positive or negative effect on CETR, specifically, the sign direction of this relationship. Additionally, the magnitude of this impact on Cleantech energy transition risk also requires investigation. To address these questions, our study employs the TCI, calculated from Eq. (7), to examine the relationship across various market regimes, i.e., across different quantiles of the distribution. This approach allows us to assess how the strength of the Fintech-ESG connectedness varies and influences Cleantech energy transition risk under different market conditions.

To determine whether the Fintech-ESG connectedness has an impact on CETR, we conduct similar analysis to Section 5.1. As such, we start

[4] The results on directional spillover effects and connectedness, along with their corresponding discussion, are presented in Appendix B.

Table 3
Regression estimates of the impact of Fintech dimensions on ESG regional indexes.

	Democratized Banking		Alternative Finance		Future Payments		Distributed Ledger	
	β_2	(s.e.)	β_2	(s.e.)	β_2	(s.e.)	β_2	(s.e.)
Panel A: Pre-Conflict announcement								
Europe Developed ESG	0.387***	(0.041)	0.352***	(0.041)	0.373***	(0.042)	0.177***	(0.038)
Mid-East and Africa Developed ESG	0.490***	(0.041)	0.380***	(0.053)	0.485***	(0.040)	0.226***	(0.043)
Asia Pacific Developed ESG	0.178***	(0.024)	0.164***	(0.025)	0.168***	(0.025)	0.085***	(0.020)
North America ESG	0.636***	(0.047)	0.511***	(0.059)	0.638***	(0.044)	0.282***	(0.056)
Europe Emerging ESG	0.441***	(0.042)	0.401***	(0.044)	0.423***	(0.043)	0.205***	(0.041)
Latin America Emerging ESG	0.654***	(0.098)	0.604***	(0.094)	0.654***	(0.096)	0.277***	(0.071)
Mid-East and Africa Emerging ESG	0.441***	(0.044)	0.405***	(0.047)	0.427***	(0.045)	0.199***	(0.041)
Asia Pacific Emerging ESG	0.282***	(0.019)	0.258***	(0.024)	0.266***	(0.021)	0.133***	(0.022)
Panel B: Post-Conflict announcement								
Europe Developed ESG	0.252***	(0.024)	0.253***	(0.025)	0.317***	(0.029)	0.086***	(0.012)
Mid-East and Africa Developed ESG	0.305***	(0.026)	0.305***	(0.028)	0.389***	(0.029)	0.100***	(0.014)
Asia Pacific Developed ESG	0.110***	(0.019)	0.120***	(0.019)	0.136***	(0.024)	0.035***	(0.009)
North America ESG	0.401***	(0.021)	0.401***	(0.020)	0.504***	(0.018)	0.133***	(0.014)
Europe Emerging ESG	0.234***	(0.044)	0.256***	(0.043)	0.384***	(0.111)	0.064***	(0.016)
Latin America Emerging ESG	0.282***	(0.023)	0.285***	(0.024)	0.368***	(0.030)	0.091***	(0.012)
Mid-East and Africa Emerging ESG	0.190***	(0.020)	0.201***	(0.020)	0.232***	(0.024)	0.068***	(0.010)
Asia Pacific Emerging ESG	0.130***	(0.025)	0.142***	(0.025)	0.160***	(0.029)	0.046***	(0.011)

Note: This table reports the estimated coefficient β_2 from Eq. (16), showing how Fintech affects ESG. The standard errors are provided in brackets. *** indicates significance at the 1 % level.

Table 4
Pooled Wald test of slope equality in the regression of ESG on Fintech before and after the conflict announcement.

	Democratized Banking		Alternative Finance		Future Payments		Distributed Ledger	
	$Wald_{stat}$	p-value	$Wald_{stat}$	p-value	$Wald_{stat}$	p-value	$Wald_{stat}$	p-value
Europe Developed ESG	7.998	0.005	4.234	0.040	1.231	0.267	4.827	0.028
Mid-East and Africa Developed ESG	13.585	0.000	1.473	0.225	3.680	0.055	6.947	0.008
Asia Pacific Developed ESG	5.016	0.025	2.027	0.155	0.872	0.350	5.100	0.024
North America ESG	19.618	0.000	2.885	0.089	7.495	0.006	6.110	0.013
Europe Emerging ESG	11.416	0.001	5.358	0.021	0.100	0.751	9.574	0.002
Latin America Emerging ESG	12.714	0.000	10.041	0.002	7.563	0.006	6.238	0.013
Mid-East and Africa Emerging ESG	25.420	0.000	15.004	0.000	13.922	0.000	8.943	0.003
Asia Pacific Emerging ESG	23.140	0.000	10.456	0.001	8.965	0.003	11.648	0.001

Note: This table reports Wald χ^2 test statistics, $Wald_{stat}$, from Eq. (16), testing the equality of slopes in the regression of ESG on Fintech across the two sub-periods (pre- and post-conflict announcement). The null hypothesis is $H_0 : \beta_2^{pre} = \beta_2^{post}$. Corresponding p-values are also reported.

with a time-invariant (full sample) regression model specified as follows:

$$CETR_t = \delta_1 + \delta_2 TCI_{\lambda,t} + \varepsilon_t \quad (18)$$

where $CETR_t$ denotes the Cleantech energy transition risk at time t, $TCI_{t,\lambda}$ corresponds to the Fintech-ESG connectedness at time t and quantile λ, ε_t is the error term.

Table 6 presents the results from Eq. (18). To distinguish between different market regimes, the TCIs are derived across the following quantiles, λ: $\lambda = 0.05$ ($TCI_{\lambda=0.05}$), $\lambda = 0.5$ ($TCI_{\lambda=0.5}$), $\lambda = 0.95$ ($TCI_{\lambda=0.95}$). Our results show that the TCI has a negative impact on CETR at the lower quantile. In other words, the stronger the connection between the Fintech industry and ESG regional indexes, the slower the transition is towards clean technology in times of market turmoil. The results for the upper quantile are also suggesting a negative impact of TCI on CETR in pre-conflict times, however, the impact turns positive after the outbreak of the military conflict between Russia and Ukraine in 2022. The opposite is found for the impact of TCI on CETR in the median quantile, particularly, the impact is positive before the onset of the conflict, however, it becomes negative after its outbreak. Nonetheless, all coefficients are found to be statistically insignificant. Such a finding may be triggered due to the time-invariant nature of the models (see, Halevy, 2015). Using a pooled regression with an interaction term, we conduct a Wald test to compare slopes across the two sub-periods (last column, Table 6). The test fails to reject slope equality. Therefore, our next step is to extend Eq. (18) to a time-varying model.

To account for time-variability, we extend Eq. (18) to a dynamic rolling-window regression:

$$CETR_{t,t+\omega} = \beta_{1,t+\omega} + \beta_{2,t+\omega} TCI_{\lambda,t,t+\omega} + \varepsilon_{t,t+\omega} \quad (19)$$

where $CETR_{t,t+\omega} = CETR_t, CETR_{t+1}, \dots, CETR_{t+\omega}$, $TCI_{\lambda,t,t+\omega} = TCI_{\lambda,t}, TCI_{\lambda,t+1}, \dots, TCI_{\lambda,t+\omega}$, ω is the rolling window size. Consistent with Eq. (17), we set a 40-day rolling window.

Table 7 reports the net time-varying intensity, based on the results from Eq. (19), of the impact of Fintech-ESG connectedness (TCI) on Cleantech energy transition risk (CETR) across different quantiles, λ. It can be noticed that the TCI has predominantly positive impact on CETR in times of market turmoil in both sub-periods. Regarding the level of significance, there is no sign disagreement across the pre- and post-conflict announcement periods or across quantiles. Nonetheless, the majority of the cases suggest that the Fintech-ESG connectedness has

Table 5
Net time-varying intensity of the impact of Fintech on ESG regional indexes.

	Democratized Banking		Alternative Finance		Future Payments		Distributed Ledger	
	5 %	10 %	5 %	10 %	5 %	10 %	5 %	10 %
Panel A: Pre-Conflict announcement								
Europe Developed ESG	0.912	0.945	0.929	0.957	0.833	0.879	0.717	0.833
Mid-East and Africa Developed ESG	0.990	0.994	0.852	0.887	0.971	0.988	0.851	0.896
Asia Pacific Developed ESG	0.257	0.361	0.264	0.380	0.234	0.310	0.232	0.286
North America ESG	1.000	1.000	0.948	0.974	1.000	1.000	0.918	0.967
Europe Emerging ESG	0.763	0.839	0.817	0.873	0.664	0.730	0.566	0.662
Latin America Emerging ESG	0.844	0.913	0.821	0.902	0.868	0.913	0.736	0.791
Mid-East and Africa Emerging ESG	0.686	0.790	0.758	0.852	0.632	0.705	0.544	0.676
Asia Pacific Emerging ESG	0.910	0.954	0.788	0.875	0.769	0.837	0.646	0.734
Panel B: Post-Conflict announcement								
Europe Developed ESG	0.916	0.950	0.878	0.913	0.933	0.980	0.710	0.814
Mid-East and Africa Developed ESG	0.740	0.807	0.648	0.740	0.869	0.950	0.499	0.563
Asia Pacific Developed ESG	0.405	0.549	0.419	0.519	0.429	0.536	0.193	0.327
North America ESG	0.998	1.000	0.982	0.985	0.985	0.987	0.889	0.935
Europe Emerging ESG	0.725	0.787	0.742	0.806	0.687	0.771	0.556	0.667
Latin America Emerging ESG	0.829	0.893	0.784	0.884	0.894	0.935	0.630	0.709
Mid-East and Africa Emerging ESG	0.727	0.786	0.747	0.784	0.727	0.807	0.447	0.503
Asia Pacific Emerging ESG	0.318	0.492	0.407	0.538	0.471	0.549	0.219	0.296

Note: This table reports the net time-varying intensity of the impact of Fintech on ESG based on Eq. (17). The positive percentage frequency is calculated by dividing the total number of significant and positive β_2 coefficients by the total number of rolling window tests, while the negative percentage frequency is determined by dividing the number of significant and negative, or zero, β_2 coefficients by the total number of rolling window tests. The results are provided for significance levels of 5 % and 10 %.

positive impact on the CETR. In contrast, the TCI at the median quantile has positive impact on CETR before the conflict onset, however, the impact is set to become negative after the outburst of the 2022 Russia-Ukraine conflict. These findings suggest asymmetry in the response of the Cleantech energy transition risk to the strength of Fintech-ESG connectedness, which is highly determined by the market conditions. As such, policymakers should adopt diverse strategies to stimulate transition towards clean energy taking into account the market conditions.

5.4. Results of the Granger causality test

Table 8 presents the outcomes from time-invariant Granger-causality tests on the causal relationship between TCI and CETR. The results do not determine the existence of causality in either direction for neither the pre- nor the post-conflict announcement periods. Thus, the outcomes suggest that there is no causal relationship between Fintech-ESG connectivity (TCI) and the Cleantech energy transition risk (CETR). However, the relationship may be changing over time, which the standard Granger causality test cannot capture. Therefore, we proceed by employing the TVP-GC developed by Rossi and Wang (2019).

Table 9 shows the results from the TVP-GC test. To strengthen the reliability of our results, we use three different test statistics to validate the outcome of the null hypothesis: mean Wald (MeanW), Nyblom (Nyblom), and Quandt Likelihood Ratio (SupLR) (see, Rossi, 2005, for a discussion). Causality is only inferred if two or more of the test statistics are significant at the 10 % level. Otherwise, no causal relationship is concluded (see, Zhou et al., 2024). Therefore, the findings in Table 9 indicate robust evidence for bi-directional causality between Fintech-ESG connectedness and Cleantech energy transition risk. The only exception to this is the lower quantile regarding the causal impact of CETR on TCI in the conflict period. Therefore, we can conclude that the TCI has a causal impact on CETR across all quantiles at both sub-periods. However, the evidence in the case of the reverse causality, i.e., from CETR to TCI, is rather weaker, especially for the conflict period. As such, our findings determine a weakening of the impact of the Cleantech energy transition risk on Fintech-ESG connectedness after the onset of the conflict between Russia and Ukraine in 2022. This evidence has implications for policymakers and adds to the safe haven literature in terms of ESG and energy sector (see, Ahad et al., 2024; Yang et al., 2024). Nonetheless, our findings confirm that there is a causal link between the TCI and CETR, which is likely to be time-varying. This research is among the first to examine how the strength of Fintech-ESG connection impacts the transition towards clean technology.

5.5. Dynamic causal inferences over time

This section displays the particular time periods where a causal relationship is observed between Fintech-ESG connectedness (TCI) and Cleantech energy transition risk (CETR). This analysis is critical for both policymakers and investors, as it helps determine how consistently Fintech-ESG connectedness is linked to the transition towards clean technology. Additionally, it provides insight into whether this interconnectedness appears immediately after events like the onset of the 2022 Russia-Ukraine conflict or emerges after a time lag. To identify the precise periods of (non-)causality, we base our graphical analysis on the results from the TVP-GC tests.

Fig. 5 shows the TVP-GC results from Fintech-ESG connectedness (TCI) to Cleantech energy transition risk (CETR). Our findings determine that a causal impact of TCI on CETR exists, but it is time-varying and rather abrupt over time. This finding contributes to the literature on ESG investing (Halbritter and Dorfleitner, 2015; Giese et al., 2019; Avramov et al., 2022) and its intersection with the Fintech industry (Chen et al., 2019; Goldstein et al., 2019; Allen et al., 2021; Guo et al., 2023), by highlighting the importance of collaboration between Fintech industry and ESG factors in facilitating successful transitions towards clean technology and reducing potential risks affecting such transition, particularly in times of economic downturn. Reflecting on the results from Panels A and B in Fig. 5, we notice that the military conflict between Russia and Ukraine in 2022 has a significant impact on the causal

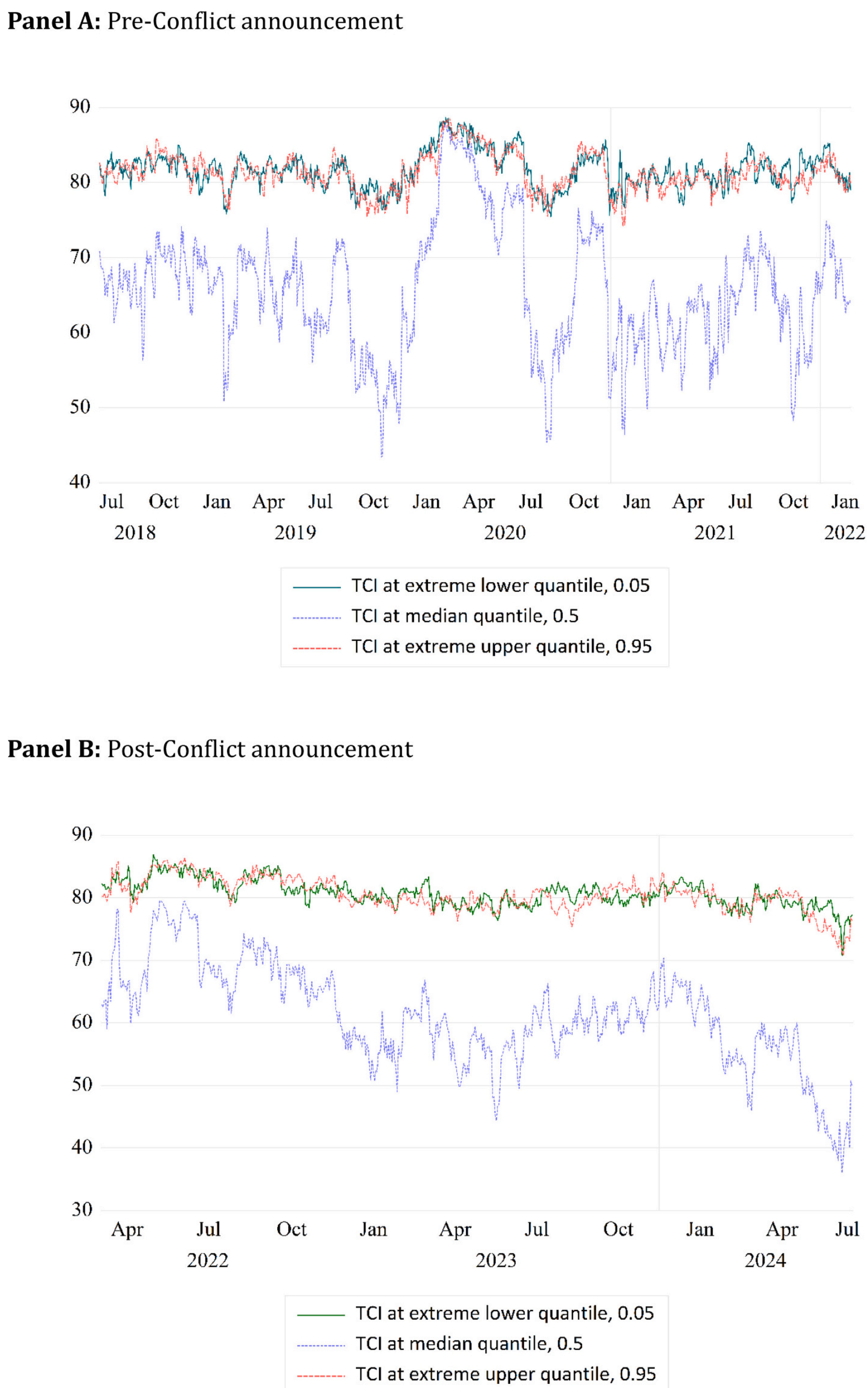


Fig. 4. TCI at different quantiles of the distribution.

effect of TCI on CETR.

The outcomes from Panel A in Fig. 5 suggest non-existence of causal relationship in the extreme quantiles until the outbreak of the COVID-19 pandemic. In fact, Fintech-ESG connectedness exhibits causal influence on CETR, for both extreme quantiles, only after mid-2020, when the COVID-19 pandemic is at its peak. The results from the median quantile show similarities to those from the extreme quantiles, with the main difference being the presence of short-term causality detected in early

Table 6
Regression estimates and slope equality test for TCI effects on Cleantech energy transition risk (CETR).

	Pre-Conflict announcement		Post-Conflict announcement		$Wald_{stat}$
	δ_2	(s.e.)	δ_2	(s.e.)	
$TCI_{\lambda=0.05}$	−0.015	0.043	−0.002	0.036	0.056
$TCI_{\lambda=0.5}$	0.005	0.012	−0.003	0.010	0.255
$TCI_{\lambda=0.95}$	−0.007	0.038	0.013	0.031	0.159

Note: This table reports coefficient δ_2 from Eq. (18) to reveal the impacts of Fintech-ESG connectedness (TCI) on Cleantech energy transition risk (CETR). The standard errors are provided in brackets. $Wald_{stat}$ refers to the Wald χ^2 test statistics on testing the existence of slope differences across the two sub-periods (pre- and post-conflict announcement). The null hypothesis of the pooled Wald test of slope equality is $H_0 : \delta_2^{pre} = \delta_2^{post}$. *, **, *** indicate significance at the 10 %, 5 % and 1 % level, respectively.

Table 7
Net time-varying intensity of the impact of TCI on Cleantech energy transition risk (CETR).

	Pre-Conflict announcement		Post-Conflict announcement	
	5 %	10 %	5 %	10 %
$TCI_{\lambda=0.05}$	0.008	0.021	0.032	0.052
$TCI_{\lambda=0.5}$	0.070	0.087	−0.038	−0.061
$TCI_{\lambda=0.95}$	0.021	0.013	0.025	0.055

Note: This table reports the net time-varying intensity of the impact of Fintech-ESG connectedness (TCI) on Cleantech energy transition risk (CETR). The results are provided for significance levels of 5 % and 10 % across different quantiles.

Table 8
Results from standard time-invariant Granger causality test.

	Pre-Conflict announcement		Post-Conflict announcement	
	H_0: TCI ⇏ CETR	H_0: CETR ⇏ TCI	H_0: TCI ⇏ CETR	H_0: CETR ⇏ TCI
$TCI_{\lambda=0.05}$	0.169	0.482	0.734	0.837
$TCI_{\lambda=0.5}$	1.304	0.402	0.869	0.088
$TCI_{\lambda=0.95}$	0.096	0.599	0.374	1.184

Note: The table reports the test statistics from time-invariant Granger causality tests between Fintech-ESG connectedness (TCI) and Cleantech energy transition risk (CETR). BIC determines the lag length. H_0 : TCI⇏CETR (⇏ means "does not Granger-cause"). *, **, *** indicate significance at the 10 %, 5 % and 1 % level, respectively.

2019 at the median quantile. It can be inferred that prior to the COVID-19 pandemic, the connection between Fintech and ESG initiatives had little influence on the transition towards clean technology. However, the pandemic acted as a major turning point, accelerating shifts in both sectors. The global disruption highlighted the importance of sustainable investments and the role of financial technology in supporting ESG goals (see, Ding et al., 2024). As a result, our outcomes indicate that the pandemic brought significant changes by emphasizing the urgency for clean technology and sustainable financing models consistent with the findings by Fu and Mishra (2022). In fact, Fintech solutions, such as digital platforms for green investments, began playing a crucial role in fostering the adoption of ESG principles, accelerating the transition towards clean energy and environmentally friendly technologies. This shift illustrates the growing alignment between technological innovation and sustainability in the post-pandemic economy.

The results from Panel B in Fig. 5 show that the causal relationship from Fintech-ESG connectedness (TCI) to the Cleantech energy transition risk (CETR) significantly weakens and fades shortly after the outbreak of the Russia-Ukraine conflict, and this pattern holds consistently across all quantiles. This suggests that the geopolitical and economic disruptions caused by the conflict overshadowed the influence of Fintech-ESG interactions on the transition to clean technology. The rapid diminishment of this causal link indicates that the market dynamics, which had previously supported the Cleantech energy transition, were temporarily destabilized due to the broader uncertainties and shocks introduced by the conflict (see, Ahad et al., 2024, for a discussion). Despite the diminishing impact of Fintech-ESG connectedness on Cleantech energy transition risk following the Russia-Ukraine conflict, some signs of recovery are observed by the last quarter of 2023. Additional evidence becomes clearer in early 2024, suggesting a modest resurgence of this connection. This indicates that the influence of Fintech-ESG interactions on the Cleantech energy transition, as denoted by TCI and CETR respectively, is gradually recovering. The long-lasting conflict market environment may have stabilized enough to reignite the role of Fintech in promoting ESG initiatives, which in turn supports the ongoing transition to clean technology. This recovery likely reflects increasing market resilience and the renewed focus on sustainability as geopolitical pressures ease or adapt to new realities.

Fig. 6 displays the TVP-GC results illustrating the causal relationship from Cleantech energy transition risk (CETR) to Fintech-ESG connectedness (TCI). The analysis confirms a time-varying causal link between the two variables, similar to our findings from Fig. 5. In Panel A of Fig. 6, which covers the pre-conflict period, frequent causality is observed, particularly after the onset of COVID-19 pandemic. Among the quantiles, the lower quantile shows less evidence of causality than the median and upper quantiles, implying that in times of market downturn, Cleantech energy transition risk is less likely to transfer to Fintech-ESG connectedness. After the outbreak of the Russia-Ukraine conflict, evidence of causality fades and remains absent until late 2023, when a brief period of causality reappears before fading again by early 2024. This pattern is more prominent in the median quantile, with the lower quantile showing causality for a few months after the conflict, but not

Table 9
Results from TVP-GC tests.

	H_0: TCI ⇏ CETR			H_0: CETR ⇏ TCI		
	MeanW	Nyblom	SupLR	MeanW	Nyblom	SupLR
Panel A: Pre-Conflict announcement						
$TCI_{\lambda=0.05}$	13.362***	63.110***	77.599***	20.373***	1.565	69.230***
$TCI_{\lambda=0.5}$	14.355***	629.274***	86.400***	10.544**	0.996	263.565***
$TCI_{\lambda=0.95}$	13.245***	235.932***	66.649***	21.310***	1.514	64.216***
Panel B: Post-Conflict announcement						
$TCI_{\lambda=0.05}$	4.723	76.028***	32.564***	4.587	0.666	31.595***
$TCI_{\lambda=0.5}$	5.289	4804.482***	33.051***	8.239*	1.220	47.704***
$TCI_{\lambda=0.95}$	3.514	2094.284***	26.007***	33.939***	0.544	182.167***

Note: The table shows the three test statistics obtained from the TVP-VAR Granger causality test: mean Wald (MeanW), Nyblom (Nyblom), and Quandt Likelihood Ratio (SupLR). BIC determines the lag length. H_0 : TCI⇏CETR (⇏ means "does not Granger-cause"). *, **, *** indicate significance at the 10 %, 5 % and 1 % level, respectively.

Panel A: Pre-Conflict announcement **Panel B:** Post-Conflict announcement

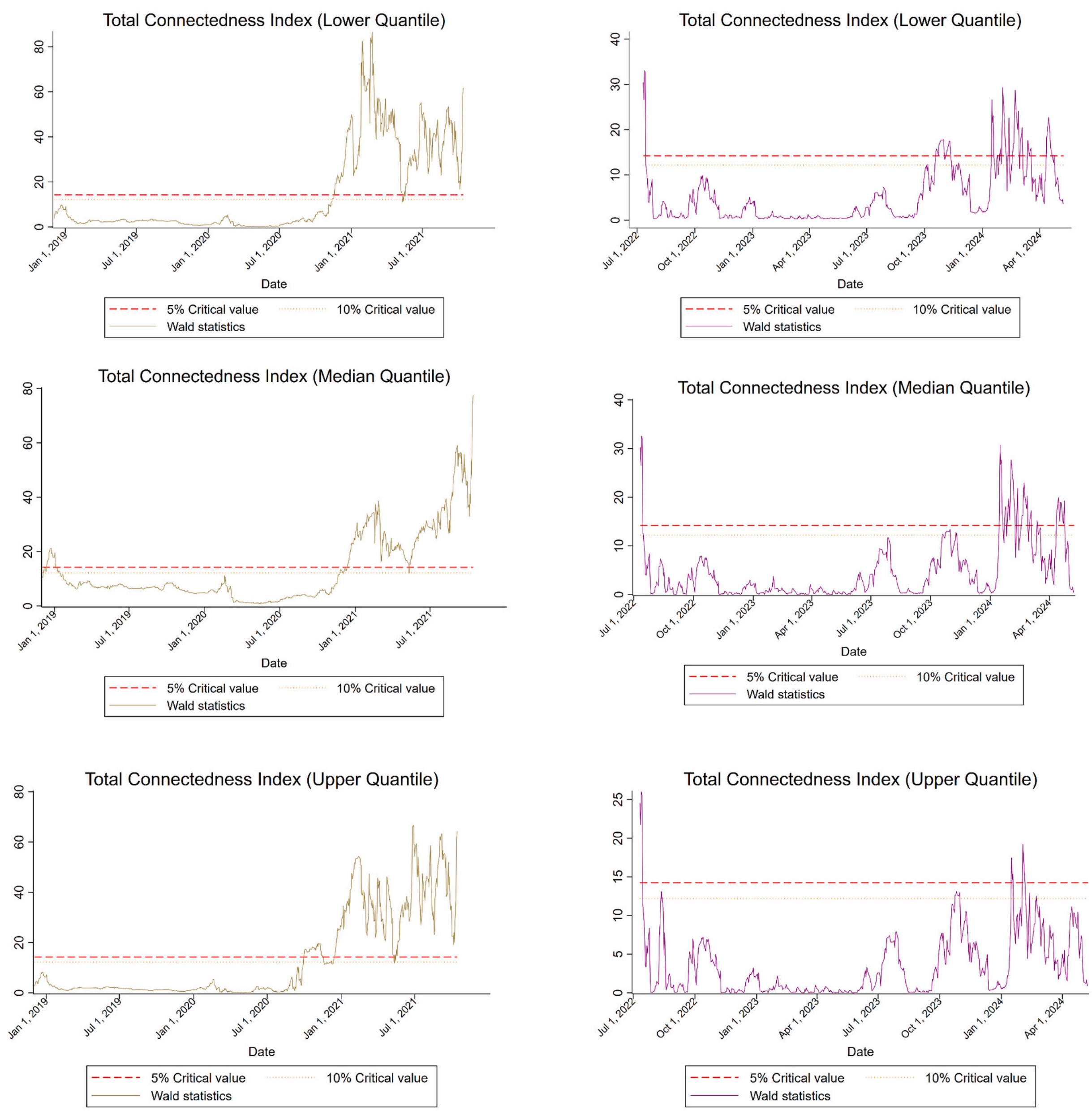


Fig. 5. Time-varying Wald test statistics: H_0 : $TCI \nRightarrow CETR$.

the median. The upper quantile exhibits a more persistent causal relationship, suggesting that CETR impacts TCI more during market upswings. Overall, the results demonstrate an asymmetric causal dependence of TCI on CETR across different quantiles. The Cleantech energy transition risk has the most pronounced causal impact on Fintech-ESG connectedness during periods of market growth or stability, especially in upper market conditions.

5.6. Results from TVP-SVAR-SV method

Although the above results confirm the existence of a relationship between ESG–Fintech connectedness and CETR, and establish the direction of causal predictability, they do not reveal the actual impact of this connectedness on CETR over time in terms of both the sign and magnitude of the effect. To address this, we extend the TVP-VAR framework to the TVP-SVAR-SV model of Nakajima (2011) to gain a deeper understanding of these dynamic relationships (see, Feng et al., 2023; Zhong et al., 2023; Jia and Dong, 2024; Ozkan et al., 2025). This framework further allows us to assess whether different levels of connectedness exert heterogeneous or asymmetric influences on CETR, capturing, for example, whether stronger ESG–Fintech integration amplifies or dampens clean energy transition risk over time.

Fig. 7 shows the results from the TVP-SVAR-SV model on the impact of Fintech-ESG connectedness (TCI) on Cleantech energy transition risk (CETR). To distinguish between the strength of the Fintech-ESG connectedness across different market regimes, the results for TCIs are derived across the following quantiles, λ: Lower quantile ($TCI_{\lambda=0.05}$), Median quantile ($TCI_{\lambda=0.5}$), Upper quantile ($TCI_{\lambda=0.95}$). The results for the pre- and post-conflict announcement periods are provided in Panels A and B, respectively. In order to examine the persistence of shocks, we evaluate 1-day (1-period-ahead), 1-week (5-period-ahead), and 1-month (22-period-ahead) forecasting horizons. The results indicate an asymmetric impact of the TCI on CETR across different market regimes, i.e., across TCI quantiles. Moreover, the predominant effect of TCI on CETR

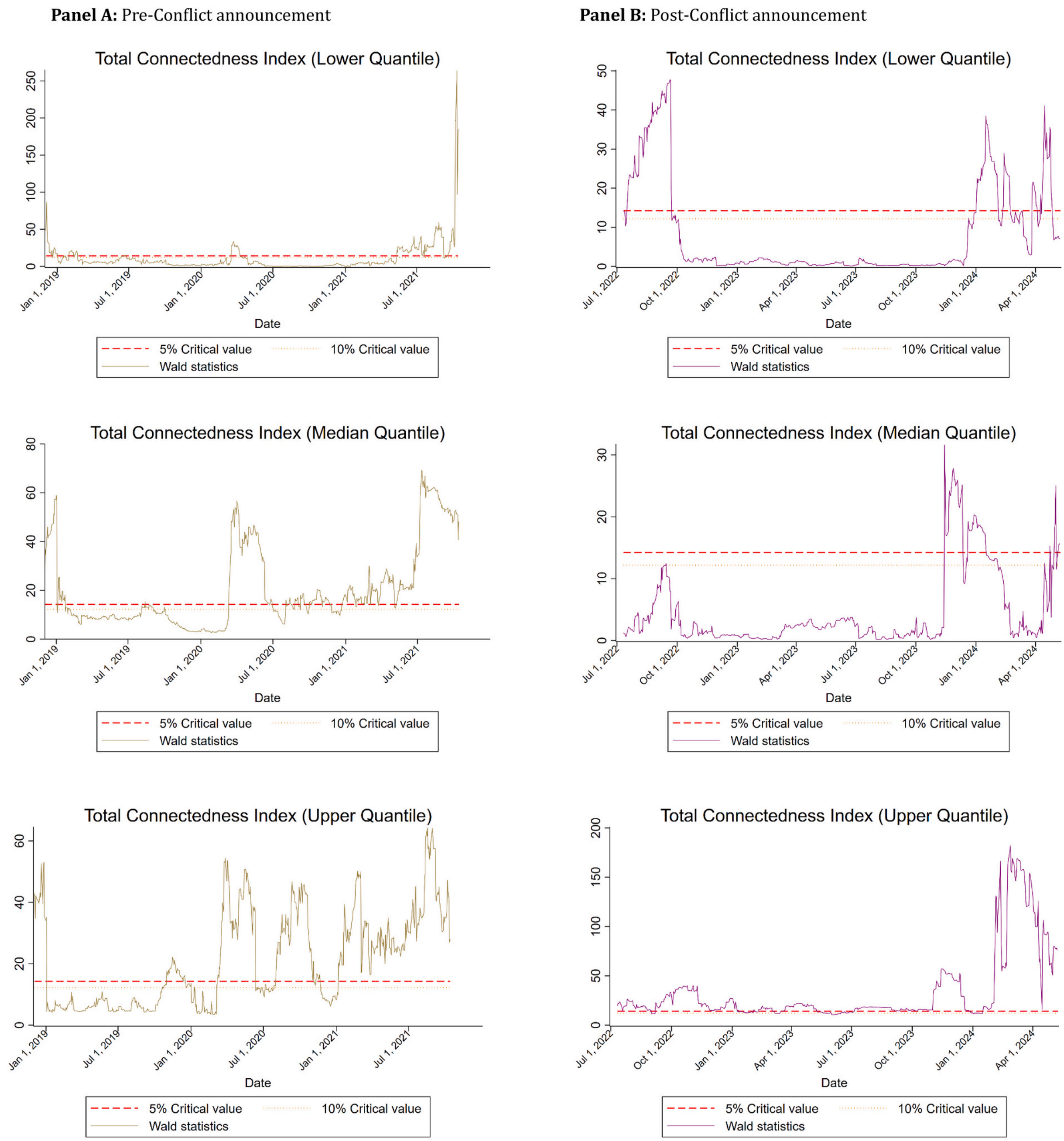


Fig. 6. Time-varying Wald test statistics: H_0 : $CETR \nRightarrow TCI$.

is positive after the outbreak of the Russia–Ukraine conflict, which is consistent with our earlier findings. In addition, the sign of the impulse response functions remains broadly consistent with the time-varying estimates reported in Table 7, which details the dynamic effects of TCI on CETR. Overall, the largest impact in magnitude occurs for $TCI_{\lambda=0.5}$ during the pre-conflict period and $TCI_{\lambda=0.95}$ during the conflict period. This finding adds to the existing literature, which documents that geopolitical risks emanating from Russia and the United States exert a positive effect on the volatility of green investment assets (Adekoya et al., 2025).

6. Robustness checks

To assess the persistence of connectedness between the Fintech industry and ESG regional indexes, represented by the Total Connectedness Index (TCI), and to validate the results across different quantiles and rolling windows, we implement the following steps. First, we investigate whether altering the forecast horizon impacts the connect-

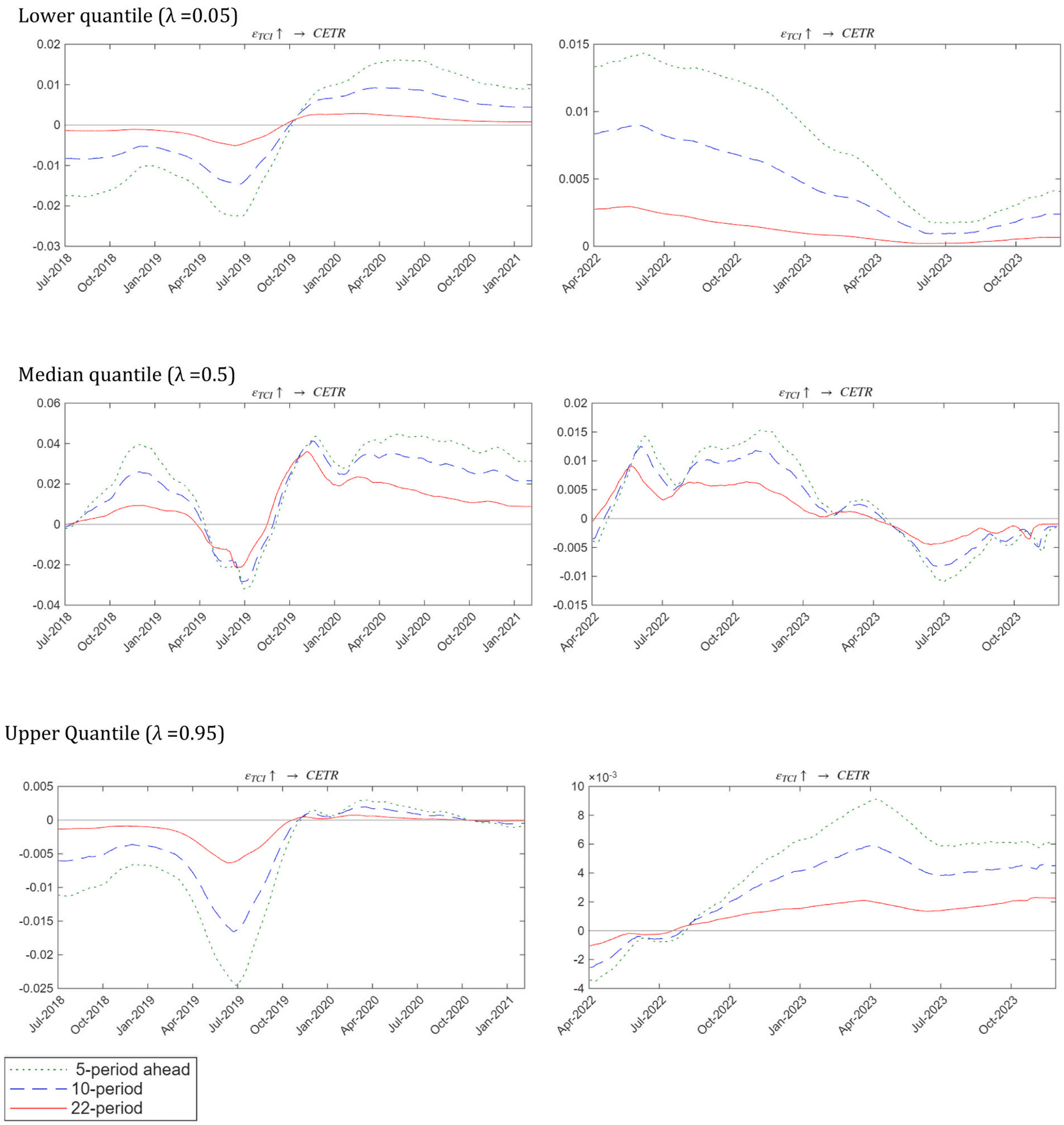


Fig. 7. TVP-SVAR-SV model on the impact of Fintech-ESG connectedness (TCI) on Cleantech energy transition risk (CETR).

Table 10
Quantile connectedness (TCI) at different forecast horizons.

	Pre-Conflict announcement			Post-Conflict announcement		
Horizon(h)	$\lambda = 0.05$	$\lambda = 0.5$	$\lambda = 0.95$	$\lambda = 0.05$	$\lambda = 0.5$	$\lambda = 0.95$
1	81.64	65.60	81.37	80.69	61.00	80.49
2	84.82	73.37	84.47	84.78	72.63	84.27
3	87.46	77.49	86.86	87.67	78.22	87.12
4	89.14	80.21	88.60	89.49	81.76	89.15
5	90.04	82.11	89.55	90.27	84.05	90.14
10	91.23	86.17	91.14	91.39	88.30	91.39
22	91.51	88.18	91.55	91.62	89.92	91.58
66	91.62	88.90	91.60	91.64	90.41	91.55

Note: h denotes the forecast horizons and λ is the quantile level.

edness between the Fintech and ESG sectors. This step helps to determine how varying time frames affect the dynamic relationships within the network, ensuring that the connection holds over both shorter and longer horizons. Second, we analyse the effect of different rolling window sizes on the TCI across various quantiles. This entails applying multiple rolling window sizes, *rw*, to see if the connectedness varies under different time structures, testing sizes like $rw \in \{40, 60, 80\ldots, 300\}$, to check the consistency of the results.

Table 10 presents the estimated Total Connectedness Index (TCI) values across different forecasting horizons, specifically considering horizons ranging from 1 to 5 days $h \in \{1, 2, 3, 4, 5\}$, 1 week $h \in \{10\}$, 1 month $h \in \{22\}$, and 1 quarter $h \in \{66\}$, as discussed in Uddin et al. (2019). The findings demonstrate a slight but consistent increase in connectedness across these time frames for all three quantiles, reflecting both the pre- and post-conflict periods. Notably, the results suggest that as the forecast horizon lengthens, the connection between the Fintech industry and ESG regional indexes becomes stronger. This growing

Table 11
Quantile connectedness (TCI) at different rolling window sizes.

Rolling-window (rw)	Pre-Conflict announcement			Post-Conflict announcement		
	λ = 0.05	λ = 0.5	λ = 0.95	λ = 0.05	λ = 0.5	λ = 0.95
40	81.64	65.60	81.37	80.69	61.00	80.49
60	84.66	68.28	84.50	83.82	63.46	84.11
80	85.99	69.65	85.80	85.27	64.75	85.53
100	86.82	70.51	86.56	85.99	65.32	86.29
120	87.34	71.20	87.06	86.47	65.72	86.77
140	87.68	71.82	87.35	86.79	66.06	87.11
160	87.95	72.36	87.58	87.06	66.31	87.31
180	88.16	72.86	87.76	87.26	66.48	87.49
200	88.35	73.36	87.92	87.41	66.56	87.65
220	88.50	73.83	88.05	87.52	66.61	87.75
240	88.62	74.31	88.16	87.60	66.64	87.81
260	88.72	74.82	88.26	87.69	66.70	87.84
280	88.80	75.37	88.35	87.75	66.77	87.89
300	88.85	75.94	88.44	87.80	66.79	87.92

Note: *rw* denotes the rolling window size and λ is the quantile level.

connectedness is particularly evident at longer horizons, where the median quantile results begin to converge with those of the extreme quantiles. This convergence implies that the impact of extreme market events, while significant in the short term, tends to dissipate over time, aligning with the longer-term trend (see, Kerkemeier and Kruse-Becher, 2022). Overall, these findings confirm that the relationship between Fintech and ESG regional indexes is robust and persists across varying horizons. Even under longer timeframes, the extreme connectedness remains consistent with the values found in the primary analysis, especially for the extreme quantiles.

Table 11 displays the estimated TCI values across various rolling-window sizes, *rw*, specifically examining $rw \in \{40, 60, 80, \ldots, 300\}$. The analysis shows variation across different quantiles, λ. A key observation is that TCI values increase with larger rolling-window sizes across all quantiles, reflecting a steady rise in connectedness as the window expands. Interestingly, this trend holds consistently for both subperiods, with the exception of the median quantile. In the pre-conflict period, the median quantile reveals greater divergence from the conflict period as the rolling window size increases, suggesting a more pronounced impact of the conflict on connectedness in this specific quantile. Additionally, the TCI values between the lower and upper quantiles remain quite similar, especially as the rolling window size increases. This consistency aligns with the core findings from the main analysis, underscoring the robustness of the results. In sum, the robustness check confirms that while the choice of rolling-window size can influence TCI estimations, the overall findings remain qualitatively aligned with the main results, indicating that window size has only limited effect on the estimation of connectedness between Fintech industry and ESG regional indexes.

7. Conclusions

This paper seeks to address an emerging gap in the existing literature by exploring whether the deepening of Fintech-ESG relationship, specifically the strong co-moving pattern under extreme conditions, impacts the risk associated with the clean technology (Cleantech) energy transition. Cleantech energy transition is initially costly, like any other new technology, as companies have to bear huge transition costs from traditional mechanism. However, if there is a clear signal from market expansion, such as the way financial technology can re-shape the business dynamics in the coming decades, given its inclusivity and sustainability traits, investors and companies will be more inclined to steadfastly adopt clean technology. In this context, our research is an important first attempt in the literature to explore how the strength of Fintech-ESG connection dictates the objectives of a fast-paced energy transition towards clean technology.

By employing a TVP-GC method coupled with quantile technique, our empirical investigation offers predictive insights into the role of the strength of Fintech-ESG relationship and Cleantech energy transition risk. We elicit substantial evidence for time-varying causal relationship between Fintech-ESG connectedness and Cleantech energy transition risk across the distribution (capturing heterogeneity of impacts). The 2022 Russia-Ukraine conflict seems to have weakened the impact of Fintech-ESG strength on Cleantech energy transition, but as companies adapt to uncertainty persistence following this crisis, a positive effect of Fintech-ESG connection on Cleantech energy transition appears to emerge. Furthermore, our results show that the impact of extreme events tends to wither away in the long-run, reflecting that Cleantech companies revert to their long-term expectations that, as the strenght of the Fintech-ESG linkage deepens, the transition to clean technology becomes more profitable for both businesses and society.

The implications of our findings suggest that strengthening the integration of financial technology within sustainability objectives should play a more prominent role at the sectoral and market levels. As the analysis is based on regional ESG and Fintech indexes, the results capture broad market behaviour rather than firm-level dynamics, highlighting how financial ecosystems can channel capital flows towards sustainable sectors such as renewable energy and clean technology. Investors and practitioners aiming to operationalize these insights could utilize exchange-traded funds (ETFs) or derivatives that replicate ESG–Fintech indexes, depending on market liquidity and availability. From a policy perspective, regulators and policymakers can play a critical role by creating supportive frameworks that encourage sustainable digital finance, such as tax incentives for green fintech innovation, enhanced ESG disclosure standards, and regulatory sandboxes to foster clean technology integration. By aligning financial innovation with sustainability policy, governments can amplify the positive role of Fintech in promoting environmental stewardship, accelerating the transition towards a more resilient and low-carbon economy.

Future research may explore how the strength of Fintech–ESG connectedness influences different dimensions of financial and non-financial risk, or undertake more detailed, industry-specific analyses to uncover sectoral heterogeneity. Additionally, extending the sample period, subject to data availability, would allow for a more comprehensive assessment of the long-term dynamics between Fintech development and ESG performance.

CRediT authorship contribution statement

Martin Enilov: Writing – review & editing, Writing – original draft, Software, Methodology, Investigation, Data curation, Conceptualization. **Edna Delantar:** Writing – review & editing, Writing – original draft, Visualization, Validation, Investigation, Formal analysis. **Mamata Parhi:** Writing – review & editing, Writing – original draft, Validation, Supervision, Investigation, Formal analysis, Conceptualization.

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Appendix A. Appendix

Table A.1
Definition of Fintech and ESG series.

Name	Index	Bloomberg code
Europe Developed ESG	S&P Europe Developed LargeMidCap ESG Index (USD)	SPEDLMUT INDEX
Mid-East and Africa Developed ESG	S&P Mid-East and Africa Developed LargeMidCap ESG Index (USD)	SPMADLUT INDEX
Asia Pacific Developed ESG	S&P Asia Pacific Developed Large Mid ESG Index (USD)	SPAPDLUT INDEX
North America ESG	S&P North America LargeMidCap ESG Index (USD)	SPNALMUT INDEX
Europe Emerging ESG	S&P Europe Emerging LargeMidCap ESG Index (USD)	SPEELMUT INDEX
Latin America Emerging ESG	S&P Latin America Emerging LargeMidCap ESG Index (USD)	SPLAELUT INDEX
Mid-East and Africa Emerging ESG	S&P Mid-East and Africa Emerging LargeMidCap ESG Index (USD)	SPMAELUT INDEX
Asia Pacific Emerging ESG	S&P Asia Pacific Emerging LargeMidCap ESG Index (USD)	SPAPELUT INDEX
Democratized Banking	S&P Kensho Democratized Banking	KFIN Index
Alternative Finance	S&P Kensho Alternative Finance	KALTFIN Index
Future Payments	S&P Kensho Future Payments	KPAY INDEX
Distributed Ledger	S&P Kensho Distributed Ledger	KLEDGER INDEX

Appendix B. Directional spillover effects and connectedness

Tables B.1 and B.2 provide the outcomes from the quantile directional spillover models. “From” indicates spillovers originating from other markets, while “To” represents the impact of spillovers to other markets. The “NET” value indicates the net effect of the spillover. A negative “NET” value suggests the market is a net recipient of spillovers, whereas a positive “NET” value implies the market is a net contributor. The tables are split into three panels referring to the returns spillovers across different quantiles: Panel A for the lower quantile ($\lambda = 0.05$), Panel B for the median quantile ($\lambda = 0.5$), and Panel C for the upper quantile ($\lambda = 0.95$).

Table B.1 provides the results from the pre-conflict times. The TCI value is 65.6 % at the median quantile, indicating that approximately 66 % of the information is transmitted among the sample variables. Based on Ren et al. (2024), this suggests that the system’s overall level of information transfer is moderately high, making it suitable for hedging and portfolio diversification analysis. In contrast, the TCI values at the lower (upper) tail of the distribution are almost a quarter larger than the TCI value at the median, specifically, are 81.64 % (81.37 %). This result confirms that, in comparison to normal market conditions, extreme conditions have a greater impact on spillovers. This could be due to the fact that in extreme scenarios, particularly during negative shocks, financial markets become more vulnerable to systemic risk, leading to a significant increase in interconnectedness (Su and He, 2024). Further to that, our findings reveal that the returns evolution driven by within-market behaviour is considerably smaller at the extreme quantiles than at their median counterpart. This indicates asymmetric behaviour in shock spillovers during extreme market events, such as times of market turmoil (see, Zhou et al., 2024). Therefore, this evidence confirms the suitability of adopting quantile method within our framework.

Additionally, we observe that the most affected market in the network is Democratized Banking, where 84.81 % (84.66 %) of its shock evolution attributed to interactions within the market network at the lower (upper) quantile, as shown in Table B.1. Among ESG regional indexes, North America ESG emerges as the most interconnected, with 83.75 % (83.03 %) of its shocks evolution attributable to network connections at the lower (upper) quantile. In contrast, Distributed Ledger is identified as the least connected Fintech sector within the network, while Asia Pacific Developed ESG is the least connected stock market among all ESG regional markets. This signifies that developed Asia Pacific markets are less integrated in the system than their emerging counterparts. In the case of Europe and Mid-East and Africa, the ESG regional indexes from the emerging markets are found to be more affected by shocks evolution in the network than their developed counterparts. This finding signifies heterogeneous responsiveness of stock markets to returns spillover, as well as interconnectedness due to economic development stage (see, Griffin et al., 2010; Prasad et al., 2018, for a discussion).

Similarly, the largest contributor to the network from the Fintech industry is the Democratized Banking, with a value of 99.33 (99.73), whereas the least one is Distributed Ledger, with a value of 80.30 (80.35) at the 5th (95th) percentile of the distribution. With respect to the ESG regional indexes, the Mid-East and Africa Emerging ESG and Asia Pacific Emerging ESG are found to have larger impact to the system than their developed peers. In the case of Europe, the developed markets are stronger determinant of shocks spillover to the network than their emerging counterparts. Nonetheless, the largest contribution of spillover to the network is North America ESG. Overall, our results signify a stronger connectedness of the Fintech industry with the network than ESG regional indexes, and also heterogeneity in the ESG regional indexes responsiveness to shocks spillover reflecting their stage of economic development.

To distinguish between the extreme tails and the median of the distribution, our study presents the results of quantile directional spillover at the median, as shown in Panel B of Table B.1, for the pre-conflict period. The results are qualitatively similar among the quantiles, but it is evident that the market spillover effects are more pronounced during periods of extreme market conditions. This may be due to the fact that, in extreme cases, especially during negative shocks, financial technology markets are exposed to systemic risk (Fu and Mishra, 2022), which causes a significant increase in connectedness (Su and He, 2024).

Table B.2 provides the results from the quantile directional spillover for the post-conflict announcement period. The findings suggest that Democratized Banking is the most interconnected with the network across all variables and quantiles, whereas the least connected variable at the lower (median) quantile is Asia Pacific Developed ESG with a value of 77.57 % (46.83 %). In case of the upper quantile, the least connected variable is Asia Pacific Emerging ESG with a value of 77.65 %. This finding is quite interesting as it highlights that ESG Asia Pacific index is the least connected with other ESG indexes and Fintech industry. As such, our finding contributes to the literature on hedging and safe haven assets (see, Baur and Lucey, 2010) by revealing such properties in the ESG indexes (see, Yang et al., 2024, for a discussion) from the Asia Pacific market towards their peers from the other regions, as well as, the Fintech stocks. Moreover, prior literature indicates that ESG index demonstrates safe-haven properties during the COVID-19 pandemic (see, Rubbaniy et al., 2022; Döttling and Kim, 2024). In addition to this, our findings suggest that the financial products derived from the ESG indexes, such as exchange-traded funds (ETFs), can serve as effective hedge or safe haven instruments during periods of military conflict, such as the 2022 Russia-Ukraine conflict (see, El Khoury et al., 2023), particularly those comprising stocks from Asia Pacific region. To achieve the diversification benefits represented by an index, investors typically use index-tracking instruments such as ETFs or index mutual funds, which replicate index composition and provide practical access to diversified market exposure.

Last but not least, the net spillover results for both sub-periods suggest a persistency in the direction of the spillover transmission across both extreme quantiles. In fact, the biggest transmitter of shocks is Democratized Banking irrespective of the quantile or the sub-period. Interestingly, Distributed Ledger is the only net receiver of shocks in the network among all Fintech sectors. This result holds for all quantiles and both sub-periods. Reflecting on the results from ESG regional indexes, only two out of the eight markets act as net transmitters of shocks, namely Europe Developed ESG and North America ESG. The result holds across all quantiles and both periods, with the exception of the conflict period, during which North America ESG, with a net value of −0.88, is a net receiver of shocks at the median quantile. Nonetheless, we can clearly notice variations in the magnitude of net values across different quantiles, which are clearly affected by the outbreak of the military conflict between Russia and Ukraine in 2022, as shown in Tables B.1 and B.2.

In summary, we can conclude that the Fintech sectors primarily function as transmitters of shocks within the network, while the majority of ESG regional indexes predominantly act as receivers. Reflecting on the quantile estimates, our study identifies the presence of asymmetric behaviour between the extreme tails and the median. Beyond that, our study contributes to the literature on geopolitical risk (see, Baur and Smales, 2020; Mensi et al., 2021, for a discussion) by revealing that the 2022 Russia-Ukraine conflict reduces the overall connectedness between Fintech sectors and ESG regional indexes but has a minimal effect on the net direction of the spillover effects.

Fig. B.1 illustrates the net directional connectedness. It is notable that ESG regional index from Asia Pacific developing markets are the largest receivers of shocks within the network prior to the conflict, particularly at the extreme lower and upper quantiles. However, their role as a leading recipient diminishes after the outbreak of the conflict, being surpassed by ESG regional index from Middle East and Africa developed markets at the upper quantile, and nearly surpassed at the lower and median quantiles. In contrast, Democratized Banking continues to be the largest transmitter of shocks in the network across all quantiles, for both the pre- and post-conflict announcement periods.

Nonetheless, our graphs show a slight reduction in reception after the outbreak of the conflict, suggesting that ESG regional indexes and Fintech sectors may serve as safe haven in times of military conflict. In this way, our findings contribute to the financial economics conflict literature (see, Abakah et al., 2023) by providing deeper insights into the direction of connectedness between regional ESG indexes and Fintech sectors during military conflict, and how these relationships are influenced by the stage of economic development in different countries. Importantly, we notice a large disconnectedness between the variables in the network in the post-conflict announcement times, especially at the median quantile. These findings indicate that the 2022 Russia-Ukraine conflict has prompted an asymmetric response in ESG regional indexes, consistent with the study by Jiang et al. (2023).

Table B.1
Quantile directional spillovers, pre-conflict announcement.

	Democratized Banking	Alternative Finance	Future Payments	Distributed Ledger	Europe Developed ESG	Mid-East and Africa Developed ESG	Asia Pacific Developed ESG	North America ESG	Europe Emerging ESG	Latin America Emerging ESG	Mid-East and Africa Emerging ESG	Asia Pacific Emerging ESG	FROM
Panel A. Spillover at extreme lower quantile (λ = 0.05)													
Democratized Banking	15.19	11.04	12.66	9.98	6.40	7.24	4.43	10.62	5.37	6.21	5.05	5.83	84.81
Alternative Finance	12.15	16.90	9.87	8.36	6.86	6.60	4.80	9.81	6.07	6.91	5.54	6.12	83.10
Future Payments	13.36	9.47	16.12	8.65	6.38	7.48	4.67	10.77	5.58	6.27	5.29	5.96	83.88
Distributed Ledger	11.76	8.93	9.62	18.43	6.70	7.03	5.02	9.10	5.77	6.34	5.37	5.92	81.57
Europe Developed ESG	7.41	7.25	6.99	6.61	17.94	7.14	6.32	8.18	9.03	7.35	8.79	6.99	82.06
Mid-East and Africa Developed ESG	8.94	7.52	8.80	7.46	7.60	19.20	5.66	9.21	6.37	6.40	6.52	6.33	80.80
Asia Pacific Developed ESG	6.35	6.29	6.36	6.09	7.65	6.47	22.57	6.60	7.44	6.58	7.87	9.74	77.43
North America ESG	11.26	9.45	10.86	8.30	7.54	7.93	4.95	16.25	5.76	6.47	5.56	5.67	83.75
Europe Emerging ESG	6.70	6.85	6.60	6.11	9.67	6.37	6.51	6.73	19.42	8.18	9.59	7.27	80.58

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Table B.1 (*continued*)

	Democratized Banking	Alternative Finance	Future Payments	Distributed Ledger	Europe Developed ESG	Mid-East and Africa Developed ESG	Asia Pacific Developed ESG	North America ESG	Europe Emerging ESG	Latin America Emerging ESG	Mid-East and Africa Emerging ESG	Asia Pacific Emerging ESG	FROM
Latin America Emerging ESG	7.73	7.83	7.41	6.72	7.83	6.41	5.80	7.60	8.26	19.49	8.22	6.70	80.51
Mid-East and Africa Emerging ESG	6.29	6.28	6.25	5.67	9.35	6.54	6.84	6.49	9.59	8.15	19.27	9.27	80.73
Asia Pacific Emerging ESG	7.37	7.01	7.14	6.35	7.49	6.44	8.56	6.71	7.34	6.76	9.32	19.51	80.49
TO	99.33	87.93	92.55	80.30	83.49	75.65	63.56	91.82	76.57	75.61	77.1	75.82	979.72
NET	14.52	4.83	8.67	−1.28	1.43	−5.15	−13.87	8.07	−4.01	−4.91	−3.62	−4.68	TCI = 81.64
Panel B. Spillover at median quantile ($\lambda = 0.5$)													
Democratized Banking	22.79	12.99	16.48	11.49	4.50	6.00	1.69	11.39	2.73	3.98	2.53	3.41	77.21
Alternative Finance	15.53	28.62	10.68	7.47	5.57	4.64	1.91	10.09	3.55	4.91	3.01	4.02	71.38
Future Payments	18.14	9.93	25.32	8.38	4.47	6.52	1.82	12.40	2.74	4.33	2.62	3.33	74.68
Distributed Ledger	15.65	8.65	10.22	33.41	4.09	5.60	1.62	8.79	2.95	3.25	2.54	3.23	66.59
Europe Developed ESG	5.98	6.26	5.37	4.17	31.65	5.47	4.57	8.02	9.20	5.84	8.34	5.14	68.35
Mid-East and Africa Developed ESG	9.06	6.12	9.02	6.47	6.12	37.74	2.54	8.97	3.72	3.68	3.21	3.34	62.26
Asia Pacific Developed ESG	3.03	2.94	3.04	2.31	6.23	3.02	50.29	3.61	4.84	4.23	5.55	10.93	49.71
North America ESG	12.93	9.47	13.01	7.61	6.99	6.96	2.39	26.92	3.42	4.45	2.82	3.02	73.08
Europe Emerging ESG	4.19	4.49	3.84	3.55	10.77	3.79	3.94	4.53	38.40	7.37	9.92	5.22	61.60
Latin America Emerging ESG	5.98	6.29	5.90	3.81	6.65	3.63	3.56	5.93	7.50	40.35	6.71	3.69	59.65
Mid-East and Africa Emerging ESG	3.95	4.04	3.76	3.02	9.52	3.26	4.48	3.86	10.04	6.75	38.24	9.08	61.76
Asia Pacific Emerging ESG	5.59	5.39	4.96	4.01	5.94	3.58	8.71	4.26	5.28	3.89	9.29	39.10	60.90
TO	100.03	76.55	86.29	62.29	70.85	52.48	37.23	81.84	55.98	52.68	56.54	54.41	787.17
NET	22.83	5.17	11.61	−4.30	2.49	−9.77	−12.49	8.76	−5.63	−6.97	−5.21	−6.49	TCI = 65.60
Panel C. Spillover at extreme upper quantile ($\lambda = 0.95$)													
Democratized Banking	15.34	10.77	12.56	9.97	6.54	7.29	4.60	9.74	5.34	6.14	5.38	6.34	84.66
Alternative Finance	11.89	17.13	9.69	7.91	7.12	6.43	5.01	9.21	6.12	6.77	5.85	6.86	82.87
Future Payments	13.25	9.25	16.25	8.35	6.67	7.80	4.70	10.26	5.44	6.39	5.44	6.21	83.75
Distributed Ledger	11.77	8.51	9.35	18.51	6.62	7.47	5.18	8.56	5.71	6.22	5.62	6.49	81.49
Europe Developed ESG	7.55	7.41	7.32	6.48	18.02	7.07	6.50	8.20	8.63	7.48	8.32	7.03	81.98
Mid-East and Africa Developed ESG	9.00	7.27	9.14	7.87	7.56	19.52	5.53	8.96	6.33	6.25	6.21	6.37	80.48

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Table B.1 (*continued*)

	Democratized Banking	Alternative Finance	Future Payments	Distributed Ledger	Europe Developed ESG	Mid-East and Africa Developed ESG	Asia Pacific Developed ESG	North America ESG	Europe Emerging ESG	Latin America Emerging ESG	Mid-East and Africa Emerging ESG	Asia Pacific Emerging ESG	FROM
Asia Pacific Developed ESG	6.49	6.41	6.30	6.21	7.94	6.23	22.63	6.59	7.09	6.47	7.70	9.94	77.37
North America ESG	10.61	9.06	10.64	7.96	7.81	7.91	5.14	16.97	5.91	6.26	5.61	6.12	83.03
Europe Emerging ESG	6.79	6.97	6.58	6.19	9.56	6.46	6.35	6.86	20.07	8.08	9.02	7.05	79.93
Latin America Emerging ESG	7.76	7.72	7.64	6.64	8.17	6.34	5.79	7.21	8.05	20.08	8.06	6.56	79.92
Mid-East and Africa Emerging ESG	6.75	6.65	6.49	5.98	9.01	6.26	6.77	6.43	8.95	8.04	19.81	8.86	80.19
Asia Pacific Emerging ESG	7.86	7.62	7.30	6.80	7.46	6.37	8.49	6.95	6.80	6.40	8.72	19.24	80.76
TO	99.73	87.63	93.01	80.35	84.46	75.63	64.05	88.96	74.39	74.49	75.92	77.81	976.43
NET	15.06	4.77	9.25	−1.14	2.48	−4.85	−13.31	5.93	−5.54	−5.44	−4.27	−2.95	TCI = 81.37

Note: TCI refers to the Total Connectedness Index.

Table B.2
Quantile directional spillovers, post-conflict announcement.

	Democratized Banking	Alternative Finance	Future Payments	Distributed Ledger	Europe Developed ESG	Mid-East and Africa Developed ESG	Asia Pacific Developed ESG	North America ESG	Europe Emerging ESG	Latin America Emerging ESG	Mid-East and Africa Emerging ESG	Asia Pacific Emerging ESG	FROM
Panel A. Spillover at extreme lower quantile (λ = 0.05)													
Democratized Banking	15.96	12.96	12.57	11.53	6.31	5.75	4.68	8.79	5.34	6.03	5.25	4.81	84.04
Alternative Finance	13.28	16.36	12.53	9.14	6.48	5.92	4.99	9.17	5.57	6.11	5.41	5.04	83.64
Future Payments	12.70	12.37	16.10	8.15	6.76	6.35	4.85	9.84	5.69	6.55	5.52	5.12	83.90
Distributed Ledger	13.78	10.50	9.48	19.36	6.16	5.87	5.18	7.79	5.36	5.69	5.53	5.30	80.64
Europe Developed ESG	7.11	7.14	7.52	5.91	18.06	6.72	6.89	7.69	9.46	7.73	9.26	6.51	81.94
Mid-East and Africa Developed ESG	7.55	7.59	8.30	6.57	7.81	21.86	6.34	8.52	6.74	5.97	6.74	6.01	78.14
Asia Pacific Developed ESG	6.42	6.69	6.58	6.06	8.32	6.58	22.43	6.58	6.84	6.77	7.67	9.07	77.57
North America ESG	9.75	9.97	10.86	7.36	7.59	7.23	5.34	17.93	5.81	6.41	5.76	5.99	82.07
Europe Emerging ESG	6.71	6.83	7.06	5.80	10.47	6.42	6.41	6.60	20.82	7.58	8.77	6.53	79.18
Latin America Emerging ESG	7.60	7.54	8.18	6.16	8.54	5.67	6.31	7.23	7.55	20.71	8.48	6.03	79.29
Mid-East and Africa Emerging ESG	6.45	6.48	6.70	5.81	10.07	6.28	6.92	6.40	8.56	8.23	20.06	8.03	79.94
Asia Pacific Emerging ESG	6.51	6.64	6.81	6.14	7.70	6.10	8.94	7.16	6.89	6.35	8.73	22.05	77.95
TO	97.86	94.7	96.6	78.63	86.21	68.9	66.85	85.76	73.81	73.42	77.12	68.44	968.29
NET	13.83	11.06	12.7	-2.01	4.27	-9.24	-10.73	3.68	-5.36	-5.88	-2.82	-9.52	TCI=80.69
Panel B. Spillover at median quantile (λ =0.5)													
Democxratized Banking	24.55	17.17	16.17	14.89	3.51	3.58	1.37	9.28	2.50	3.18	2.18	1.63	75.45

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Table B.2 (*continued*)

	Democratized Banking	Alternative Finance	Future Payments	Distributed Ledger	Europe Developed ESG	Mid-East and Africa Developed ESG	Asia Pacific Developed ESG	North America ESG	Europe Emerging ESG	Latin America Emerging ESG	Mid-East and Africa Emerging ESG	Asia Pacific Emerging ESG	FROM
Alternative Finance	18.16	26.08	16.19	9.71	3.84	3.76	1.51	9.63	2.92	3.75	2.48	1.96	73.92
Future Payments	17.12	16.21	26.14	7.54	4.32	4.22	1.47	11.19	2.86	4.43	2.76	1.74	73.86
Distributed Ledger	20.83	12.38	9.42	35.27	2.94	3.00	1.47	6.72	1.98	2.24	1.94	1.82	64.73
Europe Developed ESG	4.79	4.99	5.53	3.17	35.29	4.77	4.94	5.45	10.6	6.61	10.05	3.78	64.71
Mid-East and Africa Developed ESG	5.70	5.71	6.50	3.72	5.61	49.70	2.96	6.80	4.34	2.38	4.05	2.53	50.30
Asia Pacific Developed ESG	2.70	2.85	2.64	2.37	6.91	3.60	53.17	2.21	4.47	4.26	7.04	7.78	46.83
North America ESG	11.77	11.62	13.61	6.46	5.03	5.28	1.52	32.48	2.37	4.14	2.79	2.93	67.52
Europe Emerging ESG	3.89	4.19	4.15	2.43	12.4	4.28	3.95	3.02	44.68	5.02	8.35	3.63	55.32
Latin America Emerging ESG	5.04	5.68	6.69	2.75	7.43	2.28	3.58	5.03	5.19	46.21	7.65	2.48	53.79
Mid-East and Africa Emerging ESG	3.28	3.48	3.88	2.44	11.19	3.65	5.56	3.30	8.05	7.22	41.41	6.53	58.59
Asia Pacific Emerging ESG	3.00	3.35	3.00	2.77	5.16	2.77	7.84	4.00	4.31	2.79	7.99	53.01	46.99
TO	96.28	87.64	87.8	58.26	68.34	41.17	36.18	66.64	49.59	46.02	57.27	36.81	732.01
NET	20.83	13.72	13.94	−6.47	3.63	−9.13	−10.65	−0.88	−5.73	−7.77	−1.32	−10.18	TCI = 61.00
Panel C. Spillover at extreme upper quantile ($\lambda = 0.95$)													
Democratized Banking	15.99	13.03	12.32	11.99	6.02	5.62	4.78	9.09	5.20	5.77	5.23	4.97	84.01
Alternative Finance	13.38	16.43	12.61	9.36	6.16	5.73	4.93	9.11	5.52	6.12	5.51	5.15	83.57
Future Payments	12.60	12.55	16.33	8.27	6.48	6.29	4.99	9.80	5.65	6.36	5.52	5.17	83.67
Distributed Ledger	14.23	10.71	9.47	19.18	6.40	5.63	4.91	8.00	5.21	5.63	5.36	5.28	80.82
Europe Developed ESG	7.00	7.01	7.39	6.38	18.84	6.66	6.84	7.23	9.43	7.83	9.05	6.32	81.16
Mid-East and Africa Developed ESG	7.49	7.48	8.24	6.45	7.67	22.23	6.54	8.32	6.92	5.84	7.01	5.81	77.77
Asia Pacific Developed ESG	6.46	6.52	6.60	5.74	7.94	6.67	22.21	6.24	7.23	7.15	8.48	8.76	77.79
North America ESG	10.25	10.02	10.85	7.70	7.03	7.07	5.19	18.22	5.66	6.38	5.94	5.69	81.78
Europe Emerging ESG	6.61	6.81	7.02	5.68	10.27	6.70	6.98	6.44	21.26	6.97	8.70	6.58	78.74
Latin America Emerging ESG	7.40	7.65	7.98	6.22	8.50	5.55	6.82	7.21	7.00	21.05	8.59	6.05	78.95
Mid-East and Africa Emerging ESG	6.44	6.63	6.65	5.71	9.56	6.45	7.67	6.48	8.36	8.30	20.07	7.67	79.93
Asia Pacific Emerging ESG	6.79	6.85	6.92	6.18	7.38	5.92	8.85	6.82	7.00	6.39	8.54	22.35	77.65
TO	98.67	95.25	96.06	79.68	83.39	68.3	68.49	84.74	73.18	72.75	77.92	67.44	965.86
NET	14.66	11.67	12.39	−1.14	2.23	−9.48	−9.30	2.96	−5.56	−6.20	−2.01	−10.21	TCI = 80.49

Note: TCI refers to the Total Connectedness Index.

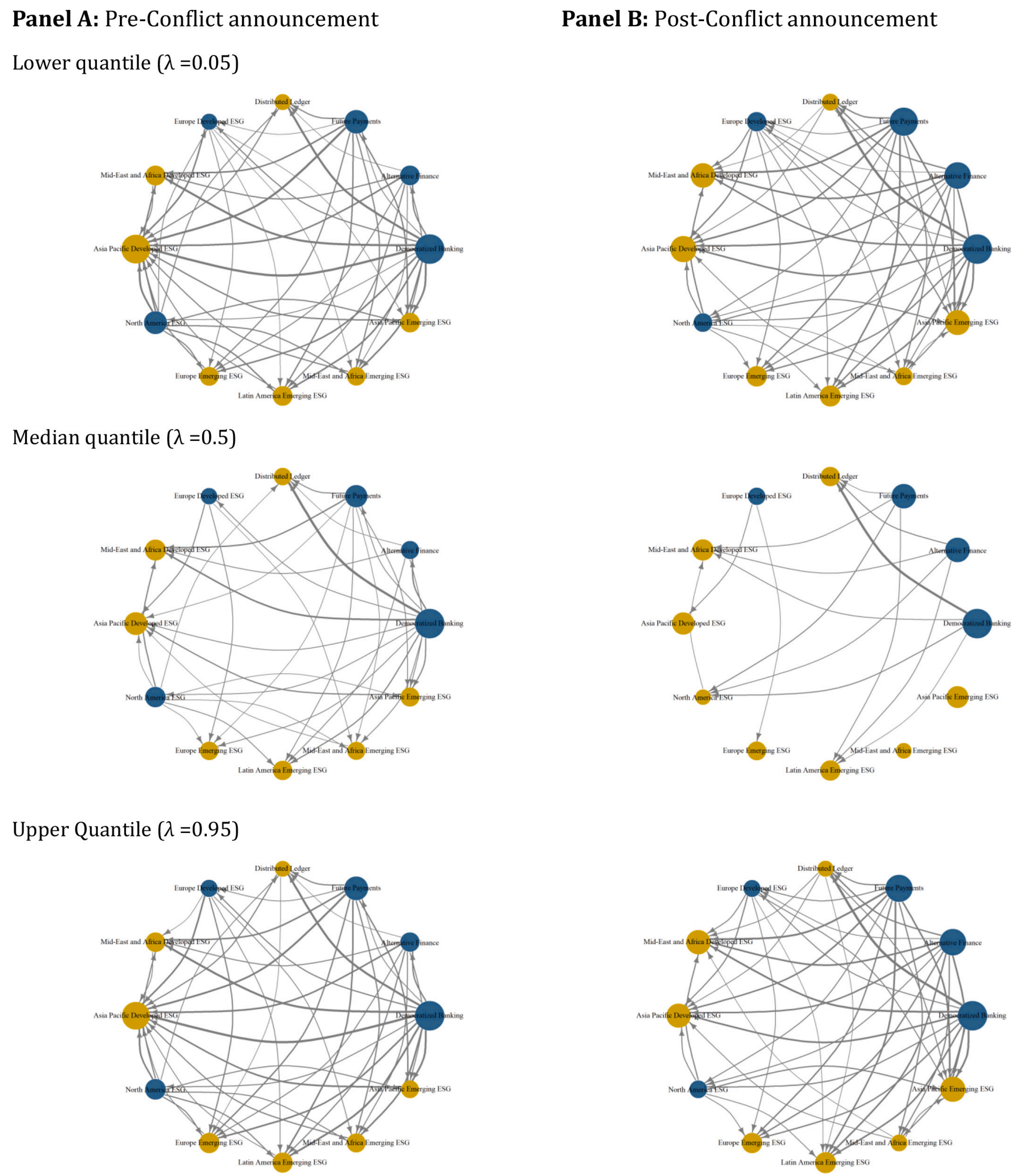

Fig. B.1. Spillover Network. Note**:** Yellow nodes denote the net shock receivers, while blue nodes are the net transmitters. The node size reflects the absolute values of the net connectedness index. The arrows indicate the direction of spillovers, and their thickness denotes their intensity.

Appendix C

Table C.1
Correlation coefficients between Fintech and ESG.

	Alternative Finance	Asia Pacific Developed ESG	Asia Pacific Emerging ESG	Democratized Banking	Distributed Ledger	Europe Developed ESG	Europe Emerging ESG	Future Payments	Latin America Emerging ESG	Mid-East and Africa Developed ESG	Mid-East and Africa Emerging ESG	North America ESG
Panel A: Pre-conflict announcement												
Alternative Finance	1.000	0.171	0.284	0.663	0.456	0.338	0.289	0.534	0.320	0.317	0.258	0.500
Asia Pacific Developed ESG	0.171	1.000	0.426	0.158	0.125	0.294	0.255	0.139	0.187	0.184	0.265	0.159
Asia Pacific Emerging ESG	0.284	0.426	1.000	0.289	0.229	0.327	0.298	0.260	0.224	0.244	0.404	0.238
Democratized Banking	0.663	0.158	0.289	1.000	0.629	0.341	0.274	0.782	0.317	0.404	0.249	0.616
Distributed Ledger	0.456	0.125	0.229	0.629	1.000	0.265	0.229	0.506	0.250	0.335	0.195	0.448
Europe Developed ESG	0.338	0.294	0.327	0.341	0.265	1.000	0.455	0.314	0.340	0.333	0.429	0.367
Europe Emerging ESG	0.289	0.255	0.298	0.274	0.229	0.455	1.000	0.241	0.356	0.247	0.413	0.267
Future Payments	0.534	0.139	0.260	0.782	0.506	0.314	0.241	1.000	0.318	0.400	0.228	0.614
Latin America Emerging ESG	0.320	0.187	0.224	0.317	0.250	0.340	0.356	0.318	1.000	0.211	0.341	0.301
Mid-East and Africa Developed ESG	0.317	0.184	0.244	0.404	0.335	0.333	0.247	0.400	0.211	1.000	0.216	0.400
Mid-East and Africa Emerging ESG	0.258	0.265	0.404	0.249	0.195	0.429	0.413	0.228	0.341	0.216	1.000	0.223
North America ESG	0.500	0.159	0.238	0.616	0.448	0.367	0.267	0.614	0.301	0.400	0.223	1.000
Panel B: Post-conflict announcement												
	Alternative Finance	Asia Pacific Developed ESG	Asia Pacific Emerging ESG	Democratized Banking	Distributed Ledger	Europe Developed ESG	Europe Emerging ESG	Future Payments	Latin America Emerging ESG	Mid-East and Africa Developed ESG	Mid-East and Africa Emerging ESG	North America ESG
Alternative Finance	1.000	0.156	0.162	0.804	0.558	0.304	0.236	0.747	0.290	0.323	0.221	0.560
Asia Pacific Developed ESG	0.156	1.000	0.431	0.146	0.093	0.318	0.266	0.159	0.219	0.229	0.335	0.151
Asia Pacific Emerging ESG	0.162	0.431	1.000	0.153	0.121	0.264	0.249	0.161	0.168	0.174	0.343	0.148
Democratized Banking	0.804	0.146	0.153	1.000	0.693	0.310	0.241	0.769	0.289	0.330	0.215	0.567
Distributed Ledger	0.558	0.093	0.121	0.693	1.000	0.227	0.176	0.484	0.196	0.246	0.156	0.392
Europe Developed ESG	0.304	0.318	0.264	0.310	0.227	1.000	0.483	0.328	0.316	0.335	0.436	0.338
Europe Emerging ESG	0.236	0.266	0.249	0.241	0.176	0.483	1.000	0.250	0.270	0.284	0.374	0.237
Future Payments	0.747	0.159	0.161	0.769	0.484	0.328	0.250	1.000	0.329	0.347	0.232	0.611
Latin America Emerging ESG	0.290	0.219	0.168	0.289	0.196	0.316	0.270	0.329	1.000	0.210	0.331	0.276
Mid-East and Africa Developed ESG	0.323	0.229	0.174	0.330	0.246	0.335	0.284	0.347	0.210	1.000	0.264	0.338
Mid-East and Africa Emerging ESG	0.221	0.335	0.343	0.215	0.156	0.436	0.374	0.232	0.331	0.264	1.000	0.210
North America ESG	0.560	0.151	0.148	0.567	0.392	0.338	0.237	0.611	0.276	0.338	0.210	1.000

Note: This table presents the correlation coefficients between the Fintech and ESG return series. The table has two panels, A and B, corresponding to pre- and post-conflict announcement periods, respectively.

Appendix D. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.eneco.2025.109090.

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