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Analyzing the nexus of green economy, clean and financial technology

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A B S T R A C T

The connection between the green economy, technology, and finance has recently become a popular topic for analyzing economic and policy matters. Financial technology can provide not only an opportunity to tap into new pools of private capital to finance green and sustainable projects through innovative financial instruments but also provide support to clean technologies through the adoption of voluntary sustainability codes of conduct. However, there is still a lack of clear scientific evidence in the literature about how the green economy interacts with these relevant indicators of sustainable finance. Thus, this paper examines the time-varying causal relationship between indexes of financial technology (FinTech), clean technology (CleanTech), and the green economy (GECON), by applying the novel method proposed by Shi et al. (2018, 2020) on daily data from June 15, 2012 to December 15, 2021. This study finds a higher volatility and causality running from GECON to CleanTech and FinTech for the entire period. Furthermore, the green economy Granger causes FinTech and CleanTech with very significant episodes, especially at the start of the COVID-19 pandemic. The robustness of the results was checked with a rolling window and recursive evolving techniques that overall confirm bidirectional causal relationships between green economy and technology variables. The findings imply that global initiatives to achieve low-carbon economies need to be complemented with the use of clean technologies in the production process and the continuous digitalization of financial sectors. The promotion of clean technology production by governments and the increased interest of investors in FinTech industries will stimulate green economic growth.

1. Introduction

The much-debated shift towards a more resilient and green economy necessitates massive public and private investment (Cheng et al., 2021). While approximately two hundred nations have publicly expressed their intentions in terms of greenhouse gas reductions according to recent climate summits, financing has become the main trigger behind a transition to a cleaner and greener economy. Given that the fundamental aim of the Paris Agreement is to control the

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level of emissions to lessen climate change (Li et al., 2022a), many developing countries are relying on affluent countries' support to provide them with billions of dollars per year in order to fulfill their plans for completing adaptation and mitigation measures (Knuth, 2018). It is ultimately agreed that environmental benefits and economic efficiency mostly contradict each other, and the only plausible solution to this discord is to ensure sustainable green economic growth (Pan et al., 2019). However, developing countries are most unlikely to meet their targets for emission reduction purely through mitigation and adaptation finance. Therefore, innovative and sustainable financial channels, such as green bonds and FinTech, should be investigated in order for developing countries to meet their carbon reduction targets (Pickering et al., 2015). The green economy can drive successful sustainable economic goals and accelerate the conversion to low-carbon and efficient resources. Moreover, climate change significantly impacts agriculture production efficiency through knowledge spillover (Aldieri et al., 2021).

Technology has become an engine of growth that stimulates the global economy through ecologically-friendly products. The green economy is said to have a correlative role with the achievement of sustainability goals. Therefore, any stimulation of the green economy will result in a substantial improvement in social equity and human wellbeing, as well as a decrease in environmental risks (Khoshnava et al., 2019). In addition, Li et al. (2022b) find that technological innovations help improve the quality of environmental initiatives. Moreover, Lee et al. (2020) tested the impact of financial innovations on bank growth and found that a higher level of financial innovation within banks in some countries was reflected in increased profits, assets, and loans. Furthermore, Lee et al. (2022) report that green economies can be promoted through technology. The adoption of potential clean technologies was originally motivated by the desire to decrease greenhouse gas emissions, reduce climate change, and reduce reliance on external energy sources. Major interest in CleanTech industry and businesses has triggered much academic research on this topic. Researchers have investigated the ability of CleanTech companies to construct their external partnerships and collaborations (Hansen, 2014), penetrate foreign and global markets (Steinz et al., 2016), build successful markets for their CleanTech products (Doganova and Karnœ, 2015; Cumming et al., 2016), entice venture capital funding and investments (Criscuolo and Menon, 2015), and obtain capital using specialized crowdfunding channels (Bonzanini et al., 2016; Giudici et al., 2019). The CleanTech Index is a stock market index reflecting the emerging global demand for clean technology in goods and services, tracking the performance of the world's most traded public CleanTech companies. It has become the industry-reliable standard index underlying an expanded, developed range of financial instruments, such as exchange-traded funds (ETFs), mutual funds, and other derivatives. This index currently includes 51 businesses that are global clean technology leaders in multiple industries, operating in the fields of substitutive energy, advanced materials, pollution prevention, power transmission, water desalination, and efficient transportation.

FinTech has gained wide prominence in international financial markets and business and recently become widely employed to enhance activities in the finance industry. Many studies have praised its rise, suggesting that these up-to-date technologies could dramatically revolutionize financial services by making financial transactions more secure, convenient, and affordable (Begenau et al., 2018; Chen et al., 2019; Zhu, 2019). Furthermore, Gao (2022) claims that FinTech is more inclusive and provides additional opportunities for dealing with financial constraints in contrast to traditional financial instruments. For example, cost reductions achieved through FinTech innovation investment have been significantly linked to the fiscal policy and graphic proximity of Chinese new energy companies (Wen et al., 2022, 2023; Wu et al., 2022).

Therefore, FinTech is gaining traction around the world. While there is no standard definition, the incorporation of both smart technology and financial activity is at the heart of FinTech, which is being propelled forward by technological advancements. As described by the Financial Stability Board (FSB), Financial Technology is the technology-driven version of financial innovation and services. However, it can also be used to describe companies based on business type, such as FinTech payment companies and lending companies (Navaretti et al., 2018). This study contends that the three indices of FinTech, the green economy, and Clean Technology have a rising correlative relationship. FinTech has an impact on investment in the green economy and climate technology in two ways. On the one hand, it offers a way to dig into new areas of private cash to finance green projects via novel financial products. On the other hand, as Weber (2018) points out, FinTech is linked to sustainability. The adoption of discretionary sustainability rules of behavior would establish a sustainable financial regimen where environmental hazards are adequately acknowledged and addressed. Investors could decrease their exposure to climate change risks in this way, limiting the amount of money they could lose owing to the impact of climate change on assets (Caldecott et al., 2013). From another perspective, FinTech innovation is fundamental in the promotion of the green economy through enhancing green finance, which indeed has a greater significance for many countries (Zhou et al., 2022).

This research contributes to the literature in the field in three ways. First, our study is the first to analyze the threefold relationship between clean technology, the green economy, and financial technology in the light of the debates mentioned above. Second, this paper is among the few studies that applies a time-varying causality technique. In particular, this research builds on the novel econometric approach used by Shi et al. (2018, 2020). Third, this study uses daily data from June 15, 2012 to December 15 2021. The timeframe of this study is particularly interesting because it encompasses the COVID-19 pandemic. In practice, the nexus of indices investigated in this work will aid policymakers and investors in developing their knowledge of the relationship between implemented variables and the performance of their businesses.

The remainder of this paper is organized as follows: Section 2 discusses the literature and critically engages with recent studies in the field. The study hypotheses are also discussed. Section 3 describes the used data. The methodology used and discussion are explained in Section 4. Finally, Section 5 concludes the paper.

2. Literature review and theoretical background

2.1. The nexus of FinTech and CleanTech

FinTech provides digital payment solutions and cryptocurrency technologies to help companies, banks, and financial institutions disintermediate. Financial innovation is critical for CleanTech companies, and data-driven business models may help them contribute to a more sustainable economy. Several CleanTech clusters are partnering with investment managers and integrating with FinTech hubs as time goes on, seeking a way to scale financing across supply chains. Financial innovation has been a strategic priority in the CleanTech sector since the founding of the Global CleanTech Cluster Association. The group wants to create a new, scalable financial mechanism that would allow pension funds to participate in CleanTech companies with reasonable risk and return expectations. This is in the context of specific climate and greenhouse gas emission alleviation policies deeply shaking up financial markets. In contrast, Breitenstein et al. (2022) highlight the nature of standard assets by addressing the nexus between financial and physical assets, which are both negatively affected by heavily carbon-intensive industries.

The CleanTech sector is growing in tandem with global energy needs, though CleanTech firms in their early stages face challenges in obtaining funding. A large portion of this funding goes on research and development expenditures to deal with technological and market risks (Brahmana and Kontesa, 2021). Many factors present major obstacles in promoting CleanTech, such as the risk aversion of firms, energy price volatilities, and resource sustainability (Laux, 2015; Song and Wang, 2018). Specifically, prospective risk and shocks of innovation tend to prevent investment in new technologies and schemes. Hence, FinTech generates unique finance methods that enable early-stage funding to be made available. FinTech opens up new possibilities for CleanTech entrepreneurs by providing a variety of investment opportunities aimed at supporting CleanTech in the long term. By satisfying the urgent need for capital and assistance, FinTech provides a viable future for renewable energy.

There have been few studies of CleanTech companies using financial technology, arguably owing to the scant availability of data, except in the case of financing sources, such as venture capital and crowdfunding studies of energy finance (Hegeman and Sørheim, 2021; Cumming et al., 2017; Gaddy et al., 2017). Therefore, the objective of this analysis is to comprehend the relationship between FinTech and CleanTech. Moreover, our paper is the first study to use the rolling window and recursive evolving model algorithms to test the link between financial technology and CleanTech indices.

Hypothesis I. Clean Technology is linked to Financial Technology.

2.2. The nexus of the green economy and CleanTech

The evolution of CleanTech is widely considered as crucial to the formation of a green economy (Chapple et al., 2011). Notwithstanding the green economy's changing boundaries, the CleanTech sector is acknowledged as the center of economic activity contributing to environmental industrial services, processes, and business (Horwitch and Mulloth, 2010). In fact, activities packaged together under the nascent CleanTech banner are promoted as examples of the green economy (Davies, 2013). In other words, the CleanTech industry is critical to the green economy's evolution (Hamdouch and Depret, 2010; Pernick and Wilder, 2008). Clean technology has been linked to consumption and economic growth mediated by strict environmental measures (Wang and Lee, 2022). It is also tied to growing public concern about energy security, climate change, and the Peak Oil scenario, leading CleanTech's growth to be hailed as an emerging industrial revolution (Pernick and Wilder, 2008). CleanTech, like the green economy, lacks a definite noncontroversial definition. However, CleanTech is commonly understood to refer to the vast variety of innovative solutions, goods, and services, that maximize the usage of limited and renewable resources for long-term commercial and environmental sustainability (Ernst and Young, 2011).

Emergent CleanTech activities are being praised as real-world instances of green economy activity. Both at the transnational and national levels, these initiatives are attempting to influence development paths (Davies, 2013). CleanTech activities have attracted significant funding from both private and public investors, with the sector's growth accelerating immensely throughout the last decade. Estimates differ, yet Ernst and Young (2012) confirm that it has risen by more than 220% since 2008, increased by 30% from 2009, with $243 billion invested in 2010. The objective of testing this connection is to explore the link between CleanTech and the green economy. In fact, our paper is the first to apply the rolling window and recursive evolving model methods to investigate the relationship between the green economy and CleanTech indexes by addressing CleanTech initiatives' connection with the green economy.

Hypothesis II. Clean Technology is linked to the green economy.

2.3. The nexus of FinTech and green economy

Financial technology is well positioned to act as a main trigger for the green economy, integrating both artificial intelligence and big data analytics to help consumers, as well as small and medium-sized businesses (SMEs), to shift to a green economy (Duchêne, 2020). The key to quality economic development and balancing green economic transformation

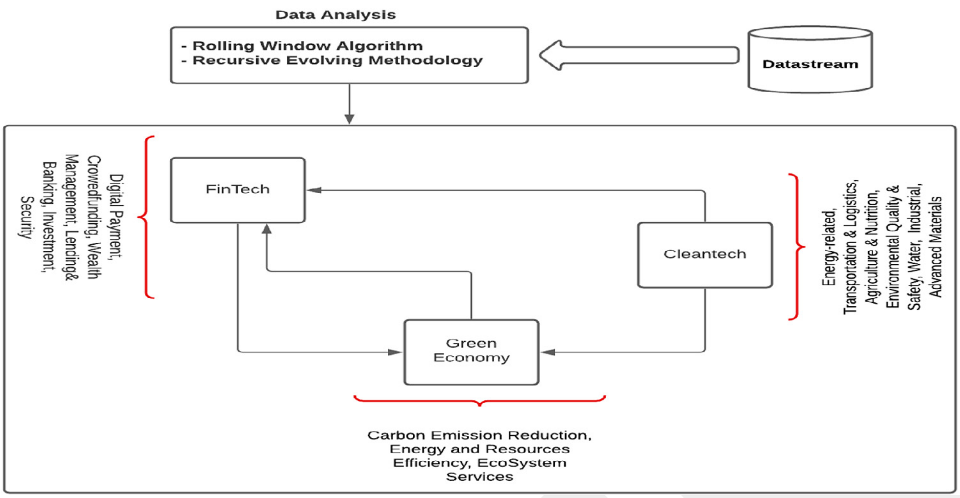

Fig. 1. Research framework.

is financial support for green economy development (Yao et al., 2021). The relationship between financial technology and green development has gradually emerged recently. However, when it comes to FinTech's function in environmental preservation, there is a research gap. The reason is because many FinTech businesses are not highly engaged in these endeavors. Other FinTech companies are embracing green financial system initiatives that aim to improve resource efficiency and decrease carbon emissions through the usage of financial technology. FinTech has been recognized for supporting the adoption of green development technologies through ensuring the availability of finance, increasing customer trust, as well as reducing information asymmetry (Yu et al., 2020). China's internet expansion, according to empirical evidence, has had a major adverse impact on energy consumption through boosting industrial upgrading and financial development (Ren et al., 2020). FinTech platforms may aid in the financial success of FinTech enterprises, while simultaneously acting as a channel for long-term green investment, a good example being green bonds assisting FinTech companies to improve their financial performance (Deng et al., 2019; Flammer, 2019). Wen et al. (2023) used the difference-in-difference method to address the link between the productivity of the low-carbon city pilot (LCCP) policy and the method of financing and investment. The evidence was that the LCCP policy has significantly enhanced the total productivity of energy condensed companies.

FinTech can help accelerate the move to a more renovative green finance system that encourages clean production, through smart and green management methods. Green bonds are debt instruments whose proceeds are invested in projects that benefit the environment, such as renewable energy, water, energy efficiency, bioenergy, and low-carbon transportation (Campiglio, 2016). Green bonds may not yet have a common definition, but there is growing agreement on what they are supposed to do. According to the index, a green bond is a fixed-income financial instrument used to raise cash to finance or refinance qualifying green projects. As a result, both investors and regulators regard green bonds as particularly valuable. Governments, on the one hand, require acceptable and dependable financial resources to meet their duties. On the other hand, investors are increasingly being urged to alter their company strategy in order to generate more than simply financial but also social and environmental values (Schoenmaker, 2017). Generally, we believe that FinTech is playing a key role in promoting the development of the green economy, through reducing the financing costs of companies and supporting investment in environmentally-driven innovations, to fill the financing gap for the development of green sustainable technology. Hence, our objective is to identify this link and study the two-sided relationship between them.

Hypothesis III. Green Economy is linked to Financial Technology.

2.4. Research framework

The framework of our research is shown in Fig. 1. It describes the working steps to test the hypotheses outlined above. Starting with taking data from DataStream, then analyzing it using both the rolling window and the recursive evolving model algorithms, the study will investigate the nexus between FinTech, CleanTech and the green economy.

3. Data

This research study uses daily data for the green economy, financial technology and clean technology from June 15, 2012 to December 15, 2021. In detail, the *Green Economy Index* (GECON) is a market-capitalization weighted index

Table 1
Descriptive statistics and unit root tests.

	Obs#	Mean	Median	Std. Dev.
GECON	2,394	1,680.25	1,468.36	591.03
CTECH	2,394	1,744,01	1,503.75	692.81
FINTECH	2,394	319.15	245.99	168.73

	Levels		First-differences		Outcome
	ZA	PP	ZA	PP	
GECON	−4.54	−0.48	−17.34*	−48.66*	I(1)
CTECH	−5.01	−1.37	−17.63*	−46.82*	I(I)
FINTECH	−5.29	−2.35	−17.73*	−47.08*	I(I)

*Denotes the statistical significance at 1 % level.

designed to track the performance of companies across the spectrum of industries most closely associated with a sustainable development economic model in every sector. GECON includes companies involved with industries such as energy efficiency, renewable energy generation, advanced materials, green building, and healthy living. The *FinTech Index* (FINTECH) tracks the performance of companies that utilize/provide transformational and innovative software solutions within the financial services industry, including business payment solutions, insurance, deposits and lending, capital raising, investment management, market provisioning, banking administration & accounting services; The *CleanTech Index* (CTECH) is the first, and only, stock market index intended to reflect the surging demand for clean technology products and services. The index is comprised of companies that are global leaders in CleanTech across a broad range of industry sectors, from alternative energy and energy efficiency, to advanced materials, air and water purification, eco-friendly agriculture/nutrition, and power transmission. The data were drawn from Datastream (www.refinitiv.com) and can be made available upon request for replication purposes.

Table 1 shows the descriptive statistics of indices and the output of unit root tests. The variables under consideration show large standard deviations (variations) and similar patterns over the time period. First, we applied Zivot and Andrews (2002)'s unit root test with a structural break (ZA) and Phillips and Perron (1982)'s unit root test (PP), to determine the order of integration of the variables under investigation. Table 1 indicates that green economy, CleanTech and FinTech are stationary series at their first differences.

4. Methods and empirical results

We applied the novel time-varying methods recently proposed by Shi et al. (2018, 2020) to detect changes in the Granger causal relationship between the green economy, financial technology and clean technology. If the Wald statistic sequence exceeds its corresponding critical value during a period, then a significant causality is detected.

Following Shi et al. (2018, 2020) we tested rolling causality and recursive evolving causality. Suppose y_t is a k-vector time series, which is inferred from the following model:

$$y_t = \alpha_0 + \alpha_1 t + u_t \tag{1}$$

where u_t follows a *VAR(p)* process

$$u_t = \beta_1 u_{t-1} + \cdots + \beta_p u_{t-p} + \varepsilon_t \tag{2}$$

where ε_t is the error term. Substituting u_t using Eq. (2) $u_t = y_t - (\alpha_0 + \alpha_1 t)$ into Eq. (1) we obtain

$$y_t = \gamma_0 + \alpha\gamma_1 t + \beta_1 y_{t-1} + \cdots + \beta_p y_{t-p} + \varepsilon_t \tag{3}$$

where γ_i embodies the function of α_i and β_j in which $i = 0,1$ and $j = 1,\ldots,p$.

Dolado and Lutkepohl (1996) and Toda and Yamamoto's (1995) lag augmented VAR enabled us to carry out a causality test for a possibly integrated variable, where y_t can be denoted as

$$Y = \tau\Gamma' + X\Theta' + B\Phi' + \varepsilon \tag{4}$$

where $Y = (y_{1,\ldots}, y_T)_{T\times n'}$, $\tau = (\tau_{1,\ldots,}\tau_T)_{T\times 2'}$, $\tau_t = (1, t)_{2x1'}$, $X = (x_1, \ldots, x_T)_{T\times np'}$, $x_t = (y_{t-1'}, \ldots, y_{t-p'})_{np\times 1'}$, $\Theta = (\beta_1, \ldots, \beta_p)_{n\times np}$, $B = (b_1, \ldots, b_T)_{T\times nd'}$, $b_t = (y_{t-1'}, \ldots, y_{t-p-d'})_{nd\times 1'}$, $\Phi = (\beta_{p+1}, \ldots, \beta_{p+d})_{n\times nd}$ and $\varepsilon = (\varepsilon_1, \ldots, \varepsilon_T)_{T\times n'}$ with d represents the maximum order of integration for y_t.

The Wald statistics to test the null hypothesis, H_0:R$\theta = 0$, are depicted as follows:

$$w = \left[R\hat{\theta}\right]' \left[R(\hat{\Omega} \otimes \left(X'QX\right)^{-1})R'\right]^{-1} \left[R\hat{\theta}\right] \tag{5}$$

in which $\hat{\theta} = vec\left(\hat{\Theta}\right)$ stands for the row vector, $\hat{\Omega} = \frac{1}{T}\hat{\varepsilon}'\hat{\varepsilon}$ and $\otimes$ is the Kronecker product. $\hat{\Theta}$ signifies the OLS estimator being $\hat{\Theta} = \left(X'QX\right)^{-1}$ and R is a $m \times n^2 p$ matrix with m being the number of restrictions. Toda and Yamamoto (1995) and Dolado and Lutkepohl (1996) explain that the Wald statistics in the model have the usual χ^2_m asymptotic null distribution.

Following Shi et al.'s (2018, 2020) approach, a real time-varying causality test was generated from supremum (sup) Wald statistic sequences by using a rolling window (Swanson, 1998) and a recursive evolving methodology (Phillips et al., 2015b,a).

The Wald statistic over $[f_1, f_2]$ has a sample size fraction of $f_w = f_2 - f_1 \geq$ and is represented by $W_{f_2}(f_1)$ in the recursive evolving algorithm. The supremum Wald statistic is obtained as

$$SW_f\ (f_0) = \frac{sup}{(f_1, f_2) \in \wedge_0, f_2 = f} \{Wf_2(f_1)\} \tag{6}$$

where $\wedge_0 = \{(f_1, f_2) : 0 < f_1 \leq f_2 \leq 1\}$ and $0 < f_1 \leq 1 - f_0$ and $f_0 \in (0, 1)$ denote the minimum number of observations required to estimate the VAR system.

The rolling procedure of (Swanson, 1998) necessitates the statistic sequences to be as follows:

$$\hat{f}_e = \frac{inf}{f \in [f_0, 1]}\{f : W_f(f - f_0) > cv \text{ and } \hat{f}_f = \frac{inf}{f \in [\hat{f}_e, 1]}\{f : W_f(f - f_0) < cv \tag{7}$$

The recursive evolving procedure of Phillips et al. (2015b,a) entails the statistic sequences to be as follows:

$$\hat{f}_e = \frac{inf}{f \in [f_0, 1]}\{f : SW_f(f_0) > scv \text{ and } \hat{f}_f = \frac{inf}{f \in [\hat{f}_e, 1]}\{f : SW_f(f_0) < scv \tag{8}$$

where $\hat{f}_e$ and $\hat{f}_f$ represent the first estimated observations that exceed or fall below, respectively, the critical values in the causality; cv is the critical value of W_f and scv is the critical value of SW_f statistics.

Considering the unit root test results, time-varying causality based on the rolling and recursive evolving methodologies was obtained from a lag augmented model with d=1. Figs. 1–3 displays the time-varying test statistics and their bootstrapped critical values. When the Wald statistics sequence exceeds the corresponding critical value, a significant causality is detected during that respective period. The results show that both the rolling window and the recursive evolving model provide significant results at 5% and 10% significance levels, suggesting bidirectional causal relationships between the GECON, FinTech and CleanTech indices. The figures show that many of the significant episodes detected were dispersed during the 2012–2021 period, where the Wald test statistics exceed the critical values. Noticeably, when we compare the outcomes of the two algorithms, the recursive algorithm provides higher significance results, but the significant episodes in both approaches overlap, suggesting that both methodologies provide consistent results.

Fig. 2 suggests that the GECON index is Granger caused by the CleanTech index using the rolling window algorithm, with very significant episodes. This is most noticeable around the first half of 2014, the second half of 2015, the first half of 2017, the final months of 2017 until the end of 2018, March 2020 (the start of the COVID-19 pandemic), the end of 2020, and the beginning of 2021. The recursive evolving methodology provides the same results with higher Wald statistics and captures more significant days around the observed period. CleanTech is Granger caused by GECON, but this relationship is less significant than the other way around. Yet again, the recursive evolving algorithm captures higher significance than the rolling window in this causality relationship. What is to be noted here is that the statistical validity of this Granger causality relationship escalates after 2015. If we investigate this relationship, we can assume that CleanTech likely explains the changes in the green economy. As the United Nations Environment Program defines, green economy refers to a transition that is driven by a reconfiguration of the production technologies and consumption patterns using investments (Eaton, 2013). Following this definition, it is easier to posit that investments in CleanTech can explain investment in the green economy. Technological change and innovation are characterized as the trigger behind the growth in productivity, income and welfare (Baumol, 2002). Nevertheless, technological change is possible with the income and resources generated by growth. Green and McCann (2011) suggest that the green economy provides room for more innovation and technology. So, consistent with the literature, we suggest a feedback relationship between GECON and CTECH, which is stronger than from CTECH to GECON.

Fig. 3 displays the causal relationship between the GECON and FINTECH indices. The first two graphs suggest that FINTECH Granger causes GECON with Wald statistics exceeding the 5 and 10% statistical significance levels. The significance levels of this relationship are slightly higher with the recursive evolving methodology than the rolling window approach. FinTech has an important role in promoting the green economy by providing resources for energy efficiency and clean energy investments (Liao and Ren, 2020; Wang, 2021; Wang et al., 2021; Zhou et al., 2022). Recent evidence also notes the emergence of new sources of financing green economic growth in the form of cryptocurrencies using financial technologies, such as blockchain-based renewable energy certificates (Croutzet and Dabbous, 2021). Fig. 3 also indicates that GECON Granger causes FINTECH with increasing statistically significant episodes over the observed period. Clearly, moreover, the recursive-evolving methodology captures higher significant episodes than the former. What is striking about Fig. 3 is that in the second half of 2012, we witness a very high significant feedback relationship between the two indices, which is followed by lower significant episodes until 2016. Following 2016, this relationship is dominated by GECON, but still with a bidirectional relationship between the two indices. Considering that FINTECH is an extension of the financial

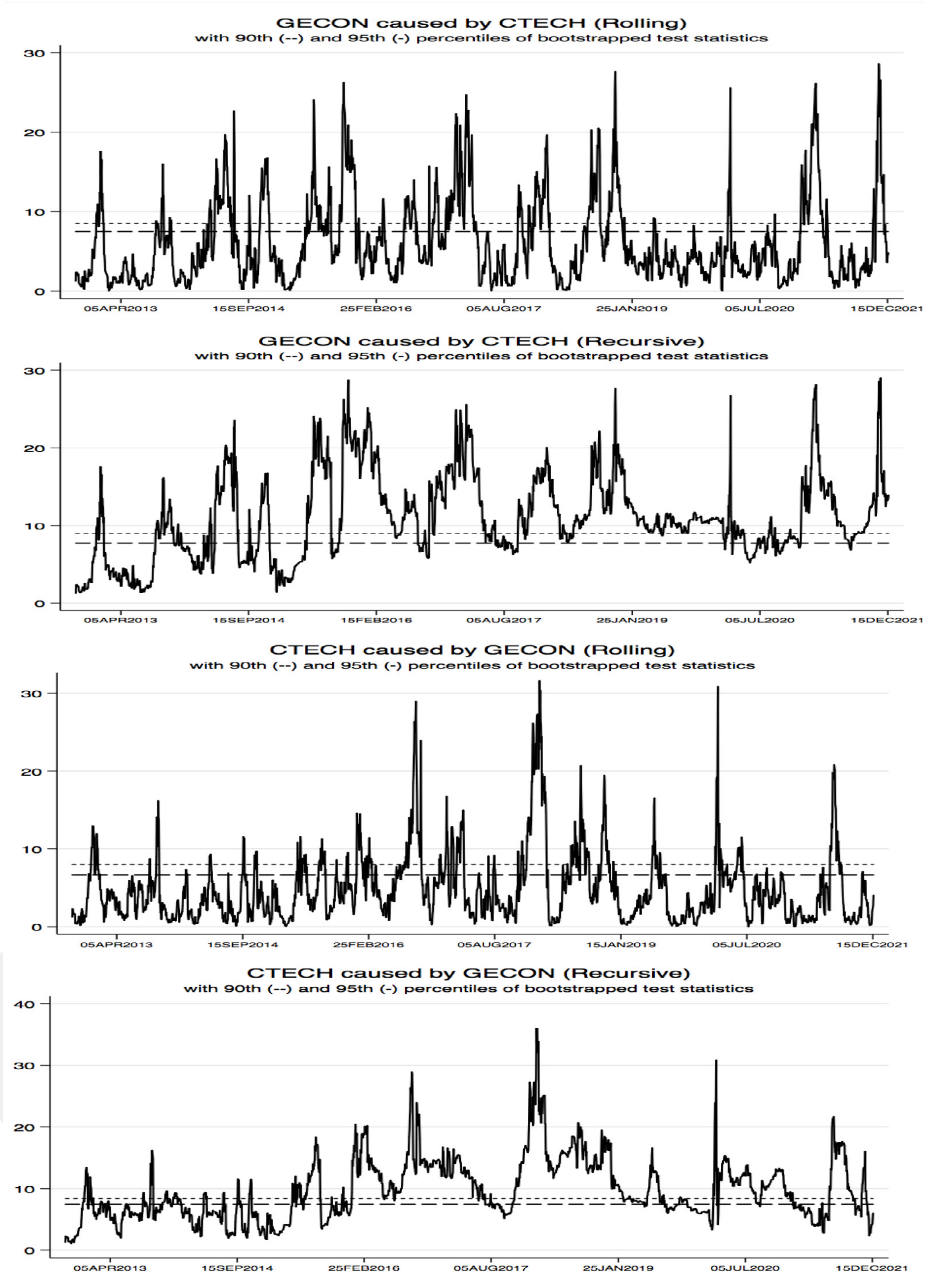

Fig. 2. Time-varying causality between green economy and clean technology.

system, which experienced revolutions in payment systems, credit markets, innovative insurance systems, and the use of block chain-based smart contracts in the period (Thakor, 2020), it is possible to suggest that GECON might have had a significant impact on the development of these financial solutions.

Fig. 4 presents the causality relationship between the FINTECH and CTECH indices. The first two graphs show indications of Granger causality from CTECH to FINTECH. Once more, we notice that the recursive evolving algorithm detects higher significant episodes than the rolling window approach. Nevertheless, the significance fades and is very

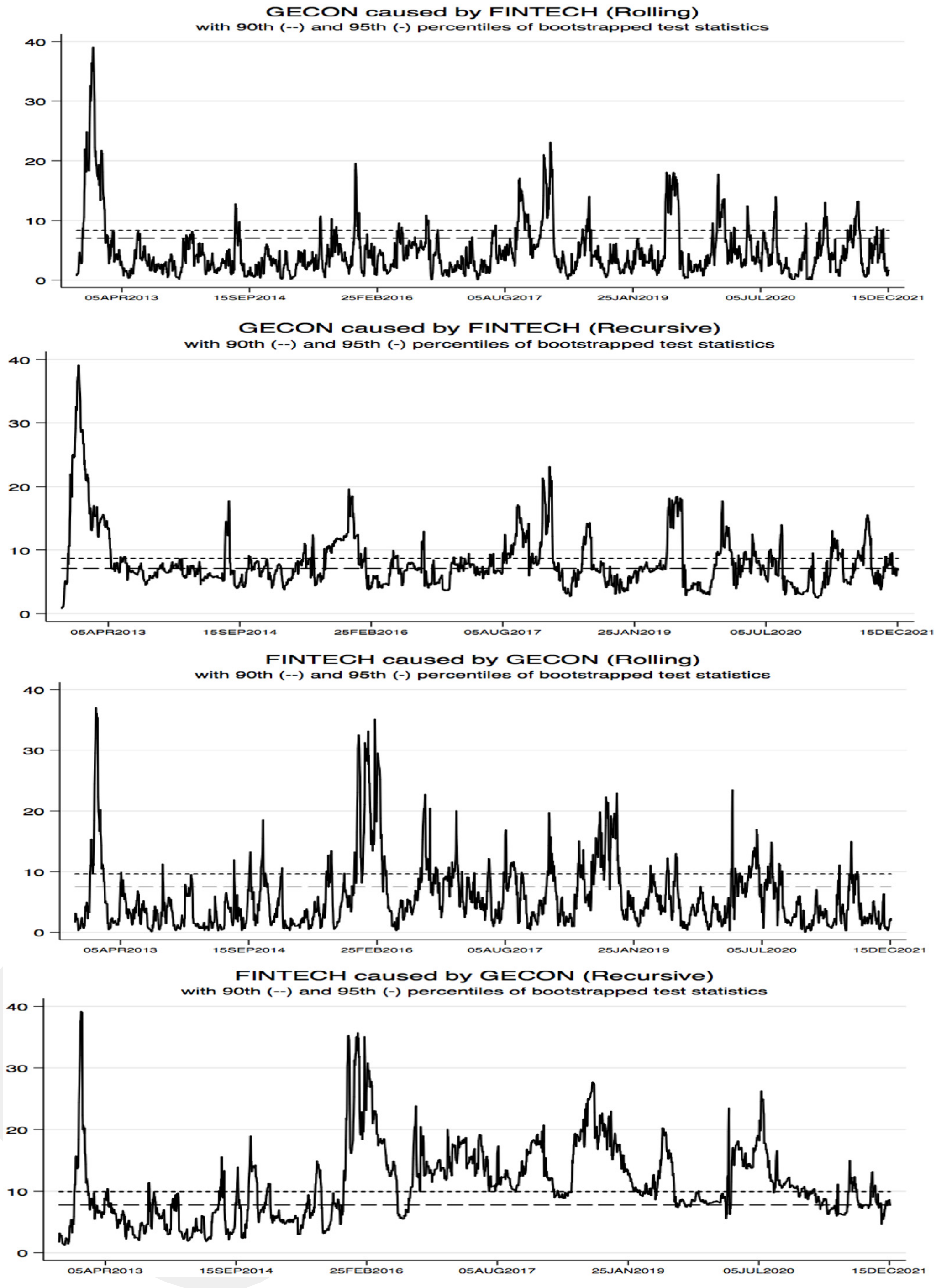

Fig. 3. Time-varying causality between green economy and financial technology.

rare following 2019. It appears that clean technology companies are utilizing financial technologies in their businesses. Moreover, the triggering mechanism from CTECH to FINTECH can be because of the necessity of attaining financial resources for inherently high-risk alternative energy and energy efficiency projects (Karltorp, 2016; Temmes et al., 2021). Hafner et al. (2020) also note the transition to clean technology and clean energy systems affects financing and stresses the necessity of new financing vehicles. As noted in the literature, FinTech provides wider opportunities and instruments to overcome funding constraints, especially with regard to clean technology, compared with traditional financial instruments (Gao, 2022). The last panel of Fig. 4 indicates lower levels of significance for Granger causality

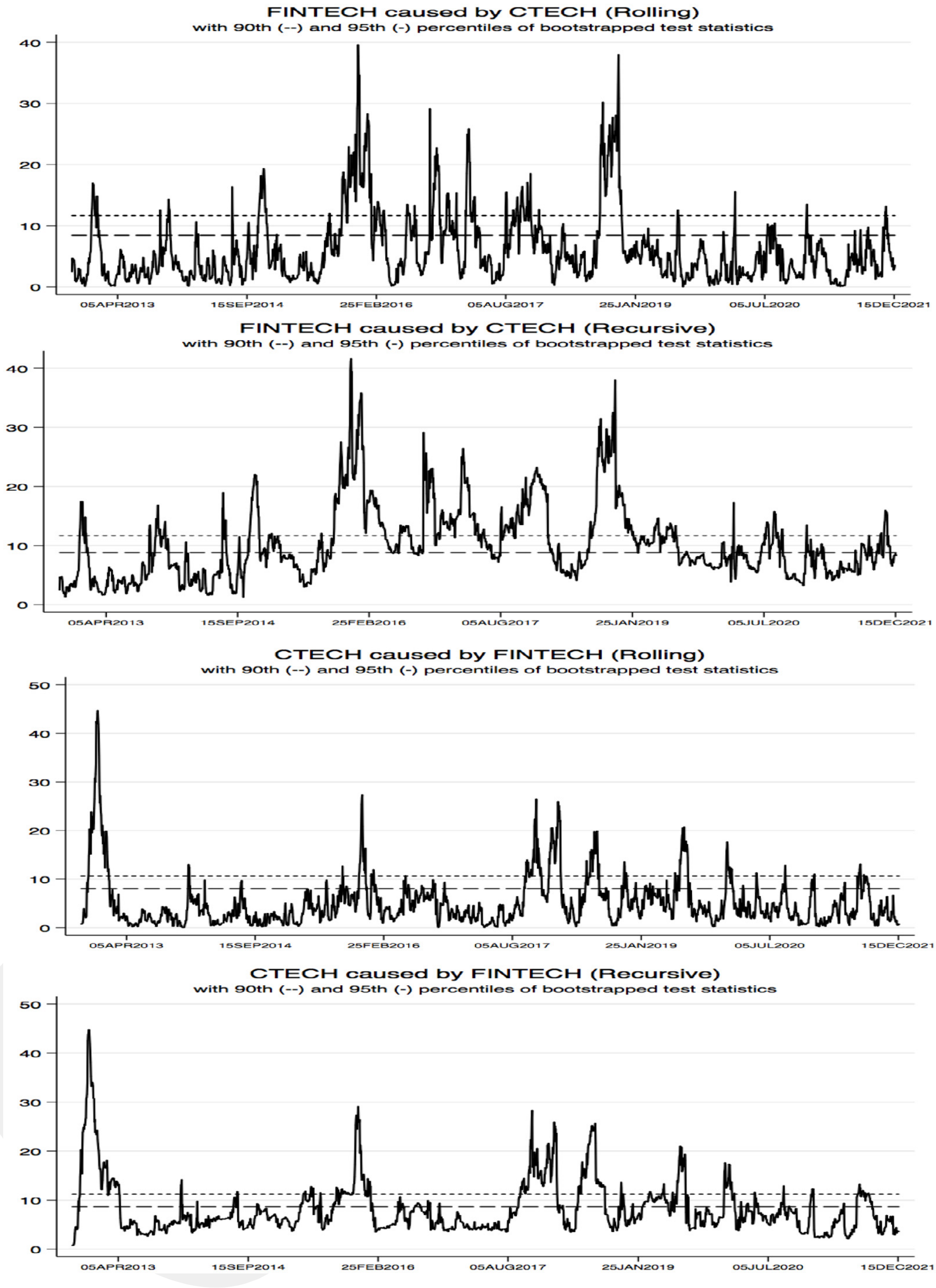

Fig. 4. Time-varying causality between financial technology and clean technology.

from FINTECH to CTECH. Obviously, these two indices have less predictive power to forecast each other compared to our previous analysis. Clean technology investments are impeded by many obstacles, owing to the uncertainties of renewable energy investments (Andersson et al., 2021) and financing these investments entails the development of specific competencies in the finance industry (Polzin and Sanders, 2020). The lower predictability from an investors' perspective suggests higher profit potential when these two indices or the constituents of these indices are combined in a portfolio (Ahmad, 2017).

5. Conclusion and policy implications

This study highlights the importance of FinTech as a factor influencing CleanTech and the green economy. As green economy development is motivated mainly by attempts to reduce carbon dioxide emissions, growing energy concerns, and oil price volatility, the findings of this paper are highly significant. Further investigation of these three classes is highly important for policy makers and investors to be able to understand their interdependence in portfolios and to expedite sustainability through the development of clean technology. FinTech is impacting consumption, savings, and investment decisions in the renewable energy sector. For instance, there are examples representing the wide application of blockchains of energy and clean technology certificates, as well as the crowdfunding of green energy projects. Our results show a significant bidirectional causal relationship between the green economy, FinTech, and CleanTech indices. We also find a causality relationship between CleanTech and the green economy. Considering that FINTECH is an extension of the financial system, and encompasses revolutions in payment systems, credit markets, innovative insurance systems, and the use of block chain-based smart contracts, it is possible to suggest that GECON might have even more impact on the development of these financial solutions. In addition, CTECH is Granger caused by GECON, but this relationship is less significant than vice versa. The strong association between CleanTech and GECON firms suggests that policy makers should take note that greener and sustainable growth is dependent on innovation and the adoption of novel technologies in this field. This finding is also highlighted by Nasreen et al. (2020). However, the FINTECH and CTECH indices have less predictive power in forecasting each other compared to CTECH and GECON. Finally, in consideration of the highly significant positive effect of green economy efficiency on FinTech activities, policy makers should concentrate much more on the major role of finance technology in strengthening green and sustainable development. For instance, they should focus more on the financial impact on the real economy, which will drive the development of financial backing for green-oriented businesses more effectively. Moreover, the financial success of the CTECH index is of the utmost importance for the advancement of the clean energy industry, since financial performance will be the principal factor in attracting investment (Elsayed et al., 2020).

Innovation and technological change clearly stand as triggering factors in promoting growth. Consequently, governments should promote green economic growth by encouraging clean technology production, and provide effective regulatory environments for the financial technologies that will provide core capital to these industries. Moreover, the clean technology industry may well suffer from insufficient incentives for innovation. Thus, governments should initiate programs to finance these technologies, or offer monetary rewards to those organizations that produce significant innovations. These incentives and rewards will provide direct financing for clean energy and technology projects, which will also boost the FinTech sector. Additionally, governments could take coercive measures to diminish environmental hazards, such as carbon emissions, which will increase the necessity for corporations to switch to clean energy and clean technology innovations. Such measures will also promote the financing of clean energy projects, through the increased expected returns of these industries. Future studies may develop additional strategies for investors by investigating the interrelationships of this group with other financial assets. Moreover, future studies can consider the relationship of these variables with those of other energy assets to come up with policy implications regarding the adaptation of policies for clean technologies.

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