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Connectedness network and dependence structure mechanism in green investments

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ABSTRACT

We present an empirical study of renewable energy stock returns and their relation to four major investment asset classes—stocks, currency, US Treasury bonds, and oil—and several sources of uncertainty. Applying nonlinear causality and connectedness network analysis on data covering the period 2004–2016, we investigate the directionality and connectedness among different asset classes, as well as between uncertainties. First, from the results of the estimation of directionality and network spillovers, it can be concluded that the European stock market has a strong market dependence on renewable energy stock prices. Second, uncertainties have an economically significant impact on both return and volatility spillover in energy investments. Third, most of the uncertainties are net transmitters of volatility connectedness during the global financial crisis (GFC) and European sovereign debt crisis (ESDC).

1. Introduction

The increased interest in renewable energy is motivated by climate change and supporting policies are necessary to accelerate the transition into a low-carbon society. The 21st Conference of the Parties (COP21) agreement highlights the importance of renewable energy, as it will support the achievement of climate policy goals. The fundamental importance of a solid framework on green investments is essential for long-term supportive policies that may result in low-risk investments (Loock, 2010; Liu and Zeng, 2017), as previous studies documented the complexity and uncertainties to investment in clean energy stocks (Ortas and Moneva, 2012; Schröder, 2007; Rezec and Scholtens, 2017). Therefore, technological development via innovation and supporting policies for clean energy may result in a reduction of the investment risk in renewable sectors (Liu and Zeng, 2017).

Since the Paris climate change agreement in 2015, the characteristics of renewable energy investment have received greater attention from energy policy makers and academics. In 2015, the share of renewables in total electricity generation was 23%, while a record amount of 285.9 billion US dollars was invested in renewables. According to the International Energy Agency (IEA, 2016), solar and wind energy sources are the dominant contributors in the renewable market. By 2021, the share of renewables in electricity generation is expected to increase to 28%. Europe is a global leader in renewable energy. The supportive policies of the European Union (EU) and its ambitious goals for renewable energy have inspired the rest of the world to follow its path. On the other hand, the United States is also one of the world's major renewable energy players in terms of production capacity, however their proportion of renewable energy used in total power generation is negligible. The absence of supporting policies is considered a major hurdle to US efforts to increase their share of renewables used to produce energy (Verzijlbergh et al., 2017).

Renewable energy is reaching a broader spectrum of the industrial and market participants. For example, Rezec and Scholtens (2017) argue that the transition towards a low-carbon society depends on the emergence of an energy financial market, as well as the participation of energy investors. Prior research compared the market dynamics of renewable and non-renewable energy sources and documented the impact of oil price changes on renewable energy (Henriques and Sadorsky, 2008; Reboredo et al., 2016). Their findings suggest that renewable and non-renewable energy stocks exhibit both differences and similarities, in terms of investment opportunities. By comparing returns from stocks

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of alternative energy sources with those from other financial asset classes, investors may find opportunities to diversify their existing portfolios of conventional assets, by including clean energy stocks.

The primary aim of this study is to investigate the directionality and connectedness of network-based spillovers between renewable energy stock returns and four major investment asset classes—stocks, currency, Treasury bonds, and oil—and several sources of uncertainty during the period 2004–2016. In this context, we quantify the directionality via linear and nonlinear causality (Diks and Panchenko, 2006), and spillover connectedness network among different asset classes using the Diebold and Yilmaz (2012, 2014) framework. Both approaches allow us to detect the direction of nonlinear dependence and explore the complex connectedness among green investments, conventional investments and various uncertainties. The results of our study show that the link between non-renewables and the financial market is coherent. Our results suggest that the European stock market index used in the study has a strong dependence on renewable energy prices. Furthermore, economic and financial uncertainties play an important role in energy sources.

Our contributions to the literature are four-fold. First, as indicated above, this is the first study that investigates the directionality and connectedness network between renewable energy stock returns and four major investment asset classes. We consider the three major clean stock price indices, including the S&P 500 Global Clean Index (S&P GCE), the European Renewable Energy Index (ERIX), and the Wilder Hill Clean Energy Index (WHCE). The motivation to include stocks, currency, bond, and a set of uncertainties in the index is based on their impact on clean energy, technological advancement, and relevance to policy decisions. Second, this study shows how renewable and non-renewable energy are connected, after controlling for non-stationarity in time series by determining a cointegrating vector and second order moments via a GARCH process. Previous research has mainly focused on comparing renewable energy with non-renewable energy, whereas we find it is interesting to compare their return behavior relative to the stock market and other asset classes. By comparing clean and non-clean energy sources, we achieve a greater understanding of their impact on investment opportunities. Third, the study contributes to the field of economics by including financial and economic uncertainty in the analysis, thereby giving interpretation to the impact of the effect of uncertainties on investments in renewable energy. Finally, this study also explores the connectedness network to determine the net-transmitter or net-recipient of information among non-renewable and renewable energy investments, conventional investments and various uncertainties.

The remainder of this paper is organized as follows. Section 2 presents a review of the literature. Section 3 describes the data and conducts a preliminary analysis. Section 4 discusses the methodology used in this study. Section 5 reports and discusses the empirical results. Section 6 provides concluding remarks.

2. Related literature review

A large body of literature has examined the dynamic interdependence between oil prices, clean energy, and technology stocks, finding evidence of causality, dependence, and spillovers. The main argument is that a rise in oil prices leads to an increase in the prices of clean energy stocks, which in turn causes prices of technology stocks to rise. Several empirical studies showed a positive Granger causal relationship between clean energy stocks and technology stocks. Henriques and Sadorsky (2008) examined the Granger causality test between oil prices and stock prices of renewable energy companies during 2001–2007. They found evidence of linear Granger causality from technology stock prices and the oil price to the stock prices of renewable energy companies. As in the study by Henriques and Sadorsky (2008), studies by Kumar et al. (2010), Huang et al. (2011), and Bondia et al. (2016) tested for Granger causality between clean energy stocks, technology stocks and the oil price, finding that both technology stock prices and oil prices affect the prices of clean energy stocks. This result further confirms the similarity in observed behavior between high technology stocks and those of renewable energy companies. This can be explained by the high level of technology used by companies in the clean energy sector. Considering the presence of structural breaks in the clean energy markets, Managi and Okomoto (2013) employed a Markov-switching VAR approach and discovered the existence of a similar market response in technology stock price indices and those for clean energy stocks. The study also found a positive relationship between clean energy prices and oil prices after including a structural break. Bondia et al. (2016) showed a result similar to that of Managi and Okomoto (2013), using a regime-shifting model for cointegration and a Granger causality test; their finding confirms the fact that ignorance of structural breaks in long-term time series data can lead to misleading results.

Another strand of literature has focused on the impact of financial stress on market spillovers. For instance, Sadorsky (2012) analyzed the volatility spillover between oil prices, technology stock prices, and clean energy stock prices using multivariate GARCH (MGARCH) models (BEKK, diagonal, CCC, and DCC). According to the result of the study, correlation peaked during the financial crisis of 2008. The correlation between clean energy and technology stock prices was higher than that between clean energy stocks and the oil price. In addition, this result indicates that the price of alternative energy stocks is related to technology stock prices rather than the oil price. Likewise, Wen et al. (2013) used a bivariate asymmetric BEKK model, to investigate the return and volatility spillover effect between stock prices of Chinese new energy (nuclear and renewable energy) and fossil fuel firms. They documented that the new energy investments are riskier and more speculative in nature than those in fossil fuels. Further, the positive news regarding new energy has an impact on the overall appeal of fossil fuels. Ahmad (2017) also identified the direction of volatility spillover between crude oil prices and stock prices of technology and clean energy companies using the MGARCH model and spillover index method. Their study suggests that clean energy stocks provide an efficient hedging opportunity in a portfolio with crude oil, rather than technology stocks. More recently, Reboredo et al. (2017) use a wavelet approach to investigate the dynamic correlation between time-scales and whether the short-run and long-run results are different. The dynamic interaction between oil and renewable energy stock prices is weak in the short-run but strengthens in the long run, mainly for the period 2008–2012. These findings suggest that investors should hedge for different investment horizons, depending on the oil price.

As renewable energy investments are associated with a large amount of capital and technological innovation, it is important to examine the risks connected to renewable energy investments. Schröder (2007) uses the ordinary least squares method to determine how socially responsible investments perform relative to their benchmarks. The result demonstrated a similar risk-adjusted return between socially responsible investments and the benchmark, but a higher risk was found for socially responsible investments. Similarly, Rezec and Scholtens (2017) concluded that the adjusted risk-return from renewable energy is modest; therefore, they find that renewable investments are unattractive financial investments. Furthermore, Angelopoulos et al. (2017) assessed the risk elements in relation to the policies and quantified the cost of capital for renewable energy investments in Greece. Liu and Zeng (2017) also analyzed the risks associated with investments in renewable energy projects in China. Using a system dynamics approach and numeric examples, three main types of risks—policy, technical, and market—are identified. Their analysis implies that policy risk was the main factor affecting the investments in the early stage, whereas market risk was the major source of uncertainty in the mature stage of the projects.

Focusing on the three country groups (the EU, the G20, and the OECD), Paramati et al. (2017) investigate whether stock markets and foreign capital inflows affect clean energy consumption. They find that both factors play a significant role in promoting clean energy consumption during the period of 1993–2012. Malen and Marcus (2017) examine how political, social, and economic factors influence clean energy