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ORIGINAL RESEARCH

Energy Consumption and Bitcoin Market

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Abstract
This paper is the first empirical paper to study the relationship between Bitcoin energy consumption and its market. Using the variance decompositions in combination with realized semi-variances for daily data, we find a relationship between Bitcoin energy consumption and its returns as well as volumes. Additionally, the directional impact from Bitcoin trading volumes to its energy consumption is higher than returns in the long run. The second Bitcoin crash also induces a higher connectedness of energy usage. Finally, we found the predictive power of energy on Bitcoin returns and volume. It holds true for the opposite predictive direction. Our results draw a challenge to the cryptocurrency ecosystems to sustainably innovate to impede their carbon footprint.

Keywords Energy consumption; Bitcoin · Frequency domain

JEL Classification G10 · Q43

1 Introduction

In 2009, Satoshi Nakamoto (2009) introduced a new financial technology named Bitcoin. Until today, there are more than 2500 cryptocurrencies traded on the exchange market, which creates a new ecosystem of blockchain technology. There is a vast number of studies examining different aspects of this market, such as financial

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risk, market efficiency, and investor behaviour, among others (Yuneline, 2019). Although this market is considered as a solution for the financial world, their presence results in an extensive carbon footprint due to the energy use not only of mining but also for storage and transaction confirmation by their networks.

It is undoubted that the validation and mining process of Bitcoin, which is representative of the overall cryptocurrency market due to its significant market share, requires huge amount of energy Corbet et al. (2019). Krause and Tolaymat (2018) also raised the question of how the mining process of cryptocurrency is associated with environmental damages. The current literature indicates that human needs more energy to mine Bitcoin from time to time (for example, in January of 2016 1005 kWh of electricity is a value which needs for one Bitcoin; but by June 2018, this value increased to 60,461 kWh, Krause and Tolaymat (2018)). The extant literature also challenges the existence of cryptocurrency, which consumes a substantial amount of electricity for mining, trading, and confirming Howson (2019), Stoll et al. (2019), Truby (2018), De Vries (2018). Although the study of energy consumption and economic growth has been studied (Dey & Tareque, 2019), the in-depth understanding of the mechanism of cryptocurrency and the amount of energy is a very fascinating topic.

Our paper contributes to the extant literature of not only green finance but also cryptocurrency by being the first empirical study to analyse the impact of energy consumption on the Bitcoin market, and vice versa. Our finding indicates that there exists the connectedness between energy consumption and Bitcoin returns as well as volumes. However, the trading volumes matter the energy consumption rather than returns, which reflects towards the magnitude of connectedness. It suggests that liquidity, requiring the validity of confirmed transactions, leads to more demand in Bitcoin energy consumption. This causal relationship is also found with Bitcoin return. Meanwhile, Bitcoin energy consumption has weak effects on both returns and volumes. Therefore, we witnessed that trading Bitcoin causes environmental degradation, which refers to the terminology 'crypto-damage' from the previous literature Goodkind et al. (2020).

We summarized our main findings in three main folds. First, there is a dynamic relationship between Bitcoin energy consumption, its returns and volumes. Second, the Bitcoin crash also induces a higher connectedness of energy usage. Finally, after controlling the rigorous determinants, Bitcoin's returns and volumes can be used to predict its energy consumption. The inversed effects are found from energy to returns and volumes. These main findings offer important insights into the potential mechanism of trading behaviours and energy consumption.

The remainder of this paper is organized as follows. Section 2 briefly reviews previous research and discussions on this topic. Section 3 summarizes our data and methodology. Section 4 discusses the empirical results and Sect. 5 concludes.

2 Literature Reviews

Bitcoin can potentially replace the role of fiat currencies in the global economy when there is further step taken by the government to ensure the safety of bitcoin against foul plays (Singhal & Rafiuddin, 2014). The adoption and usage of Bitcoin have increased rapidly in Europe and other regions (Krause & Tolaymat, 2018; Kurihara & Fukushima, 2017) encourage the government to regulate cryptocurrency as soon as possible. In the scope of investment management, Bitcoin has a controversial position as a hedging instrument versus other asset classes. Bouri, Jalkh, et al. (2017) discussed that bitcoin has hedge and safe-haven properties against other asset classes before the crash in December 2013. This research also concluded that after the crash in 2013, Bitcoin could only act as a diversifier. Other discussions considered Bitcoin and other cryptocurrencies as an alternative investment for gold in hedging against stocks, bonds (Wang et al., 2019). Besides, Bitcoin can be a hedging instrument against indices in developing countries but can only be a diversifier in developed countries and commodities. (Dey & Tareque, 2019; Stensås et al., 2019). In the same vein, the studies about the return and volatility relationship between Bitcoin and other financial assets have been ongoing, for example, green bonds, stock indices and Bitcoin in Huynh, Hille & Nasir (2020), energy commodities in the studies of Huynh, Burggraf, et al. (2020), Huynh, Hille, et al. (2020), Huynh, Shahbaz, et al. (2020)), Maghyereh, Awartani and Bouri (Maghyereh et al., 2016), the equity funds and cryptocurrency from Kristjanpoller, Bouri and Takaishi (2020). To sum up, Yuneline (2019) summarizes that Bitcoin exhibits financial assets' characteristic for investment (Bouri, Molnár, et al., 2017), the commodity trait for speculation and hedging (Shahzad et al., 2019), as well as the exchanged values (Foley et al., 2019). Although the strand of literature regarding cryptocurrency and its features in the financial world is well-developed, the other perspective is still missing including the environmental degradation (Corbet, Lucey and Yarovaya, 2021) or trading behaviors (Bouri et al., 2019). The extant literature indicates that the searching term could predict the Bitcoin returns and volatility (Balcilar et al., 2017; Burggraf et al., 2020; Nasir et al., 2019). Furthermore, the trading volume acts as a pivotal role in forecasting the cryptocurrencies' returns and volatility in normal time as well as uncertainties (El Alaoui et al., 2019; Huynh, Wang and Vo, 2021; Naeem et al., 2020). After reviewing these factors, we decided to use these determinants as control variables in our predictive models for energy consumption. Thus, this paper fills the gap by addressing the linkage between energy consumption and Bitcoin markets with several econometrics' models.

Currently, many sources of opinions from various researchers about the legality of the new financial asset—Cryptocurrency. Ji al et. (2019) tested the dependency relationships between different assets through a time-varying entropy approach and the results showed that information spillovers change over time with electricity bills becoming more prominent in the monetary system. According to Gkillas al et. (2020), specifically looking at the high-moment relationship between gold, crude oil, and Bitcoin markets, there is clearly a spillover between markets through the causality Granger and general impulse response analysis. Since then, researchers have been trying to answer the question "Is Bitcoin an asset or a currency?", when the determinants of the actual value of a cryptocurrency are still a big question. Hayes (2017) has outlined three main types of costs that create the fundamental value of money, including the degree of competition in the mining network of producers, the rate of unit production and the complexity of the algorithm used for mining cryptocurrencies. The formalization of the production cost model to determine the fair value of Bitcoin is a difficult task in the context of high demand for mining hardware; the "*Bitcoin Mine*" is gradually becoming depleted, and especially with the escalating global energy costs (Das, 2020). Therefore, the actual profitability of miners needs to be more carefully considered.

The cryptocurrency market is growing day by day and attracting more and more investors hence becomes a billion dollars of capitalization market. Since then, there is also a large number of bitcoin miners who want to gain high profits. The reason is that the energy expense in mining is much lower than the profit that Bitcoin brings back (O'Dwyer & Malone, 2014; Salimitari et al., 2017), which has attracted more and more investors to participate in mining. Then, there have been many serious concerns about the direct and negative impact on the environment when energy consumption is spiking. according to De Vries (2020), the greater the profits from mining are, the higher power efficiency below the optimal level of the Bitcoin network that investors make. Conventional estimation applications cannot control the market behavior and certain circumstances, with the majority of participants based on optimistic estimates of seasonal and geographic variations in electricity prices. However, the increase of mining equipment, possibly older ones with better availability and lower purchasing costs, is accompanied by increasing energy consumption (De Vries, 2018; Vranken, 2017) and generating large electronic waste, low depreciation, and consecutive frequency of Bitcoin mining network as a major flaw to the development of the cryptocurrency market. Greenberg and Bugden (2019), who have studied the explosion in energy consumption from crypto mining in the US local communities, include: (1) the covariate effect between energy supplies and prices, (2) unclear socioeconomic benefits, (3) the illegality of cryptocurrencies, (4) environmental consequences of increasing the amount of electricity waste, (5) disconnection from local heritage and community economic identity. On the other hand, the study by Delgado-Mohatar et al. (2019) has shown that Bitcoin mining is unprofitable even with the most efficient equipment and the lowest energy prices, which is the reason many Western miners have left with many difficulties in estimating consequences of the future of cryptocurrencies. Parallelly, crypto mining and security require complex and continuous computations, leading to higher levels of energy consumption. However, the mining hardware is gradually evolving from CPUs, GPUs, and FPGAs to ASICs with an exponential increase in performance and energy efficiency (Taylor, 2013). Furthermore, arguments for energy consumption in Bitcoin mining are negated by Vranken (2017). Because, as Bitcoin becomes more popular and with increasing bitcoin mining efforts, the rival for a finite amount of Bitcoin has forced miners to adopt new technologies such as more modern methods or mining hardware and has the lowest cost to increase profits. Therefore, the sustainability of this activity becomes less and less risky due to energy consumption.

Table 1 Summary of statistics

Variable	Mean	Std. dev	Skewness	Kurtosis	JB	Stationary
Energy	3.653	0.682	−0.797	2.079	134.1***	−4.325***
Return	0.002	0.044	−0.025	6.214	409***	−30.927***
Volume	22.18	1.232	−0.875	3.549	133.1***	−3.603***

*This table presents descriptive statistics for Bitcoin return & volume, and energy consumption for the period from February 2017 to September 2019. Std. Dev. is standard deviation and JB is the Jarque–Bera test of normality. There is a total of 995 observations for each variable. There is only one significant correlation value between energy & volume (0.8106 at 1% significance level). *** $p<0.01$; ** $p<0.05$; * $p<0.10$*

Accordingly, many studies provide evidence indicating that Bitcoin mining factors, indirectly, a significant increase in the world's carbon emissions through electricity consumption. More specifically, according to research by Stoll et al. (2019), the energy consumption Bitcoin mining is lower compared to other. However, other factors such as environment, community, and level of control are negatively affected. Nevertheless, despite Bitcoin's concerns regarding carbon emissions, technologies developed from Blockchain to control climate change are currently potential. This allows businesses and the state to manage emissions at low costs and is beneficial to both society and the environment (Calvo-Pardo, 2020; Howson, 2019; Truby, 2018).

3 Data and Methodology

3.1 Data

We obtained two types of data to investigate the previous research objective. First, Bitcoin data are extracted from coinmarketcap.com. Second, the Bitcoin energy consumption index is obtained from the method from digiconomist.net. To be more precise, De Vries (2018) supported an economic model to estimate daily Terawatt-hours per year. There are four steps that this study also determines (i) calculating total (USD) mining revenues (ii) estimating which part is spent on electricity (iii) pointing how much miners pay per kWh and (iv) converting costs to consumption. There are many previous studies that used this index as a proxy to measure the energy consumption for Bitcoin investment such as Li et al. (2019); Howson (2019); Mora et al. (2018). Afterwards, Cambridge Centre for Alternative Finance also introduced the index named '*Cambridge Centre for Alternative Finance*'. However, we also employ the 'Bitcoin energy consumption index', which is widely used by the extant literature. Also, there is a confirmation that the Bitcoin Energy Consumption Index and the Cambridge Bitcoin Electricity Consumption mostly share the perfect agreement. After gathering raw data, we calculate the daily returns for Bitcoin by log-differencing the closing prices each day. To normalize the value of the trading volume of Bitcoin and Estimated Bitcoin energy consumption, we perform the natural logarithm algorithm. Since the data was launched in 2017, our data

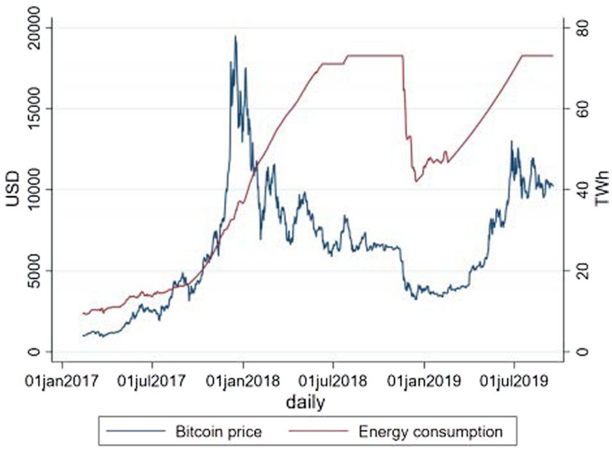

Fig. 1 Bitcoin prices and Bitcoin Energy consumption index

range from 11th February 2017 to 18th September 2019. Table 1 demonstrates the summary statistics of our variables.

Overall, this period covers two crash-time of Bitcoin (one in 2018 and afterward in early 2019). However, the daily Bitcoin return exhibits a positive value. Our variables do reject the null hypothesis of Jarque–Bera, which means that they are non-normal distribution. Additionally, three over three series are stationary, accordingly ADF unit-root test. Figure 1 also demonstrates the time-varying patterns of the Bitcoin prices and Bitcoin energy consumption index.

As seen from Fig. 1, Bitcoin has two crashes (the beginning of 2018 and the early period of 2019). It is quite interesting to witness three things from these patterns. Intuitively and firstly, Bitcoin prices and Bitcoin energy consumption had the co-movement pattern. Secondly, although Bitcoin was crashed in 2018, people were likely to maintain their mining behaviors, which continuously and gradually induced energy consumption until the second crash. Thirdly, it is likely to see that people postponed their mining patterns in the beginning of 2019 when the second crash happened. Afterwards, Bitcoin prices had a reversed direction, which demonstrates an increase in the middle of 2019. Concomitantly, the energy consumption also drew a parallel line with Bitcoin price movements.

3.2 Methodology

In this paper, we use the method from the work of Barunik and Krehlik (2018) and Barunik and Kocenda (2019) regarding the measurement of total spillovers index based on H-step-ahead generalized forecast error variance decomposition matrix from Vector Auto-Regressions (VARs). It is important to note that we refer to the studies of Barunik and Krehlik (2018) and Barunik and Kocenda (2019) with the focus on realized volatility, calculated by the log-return. However, our main study will emphasize the role of return spillover effects generating from the energy consumption and Bitcoin markets. Thus, we will explain the relevant econometric steps to capture the return spillover with the energy consumption level. In the beginning, we have an N-dimensional vector of return (denoted as R), extracted by the continuous-time stochastic process of log prices. Let us have R_t n-dimensional vector to weakly stationary VAR(p) process as follows:

$$R_t = \sum_{t=1}^{p} \Phi_l R_{(t-1)} + \in_t \tag{1}$$

In which, $\in_t = N\left(0; \sum_{\in}\right)$, saying differently, residual has i.i.d vector while Φ_l stands for p coefficient matrices. Next, we proceed with the invertible VAR process with the moving average representation.

$$R_t = \sum_{l=0}^{\infty} \Psi_l \in_{t-l} \tag{2}$$

Coefficients Ψ_h conveyed in n×n matrices are acquired from the recursion $\Psi_l = \sum_{j=1}^{p} \Phi_j \Psi_{l-j}$ where $\Psi_1 = I_N$ and $\Psi_1 = 0$ for 1<0. The whole process helps us isolate the forecast errors for further computation. Diebold and Yilmaz (2012) introduce their method of constructing H-step-ahead generalized forecast error variance decomposition matrix as follows (It is noted that the studies of Barunik and Krehlik (2018) and Barunik and Kocenda (2019) mainly rely on Diebold and Yilmaz (2012) approach):

$$\Phi_{ij}^{H} = \frac{\left(\sigma_{kk}^{-1} \sum_{h=0}^{H-1} \left(e_i^{'} \Psi_h \sum_{\in} e_k\right)^2\right)}{\sum_{h=0}^{H-1} \left(e_i^{'} \psi_h \sum_{\in} \Psi_k^{\prime} e_k\right)} \tag{3}$$

In which, Ψh is the vector having the moving average coefficient calculated from the forecast at time t. $\sum_{\in}$ stands for the variance matrix for the error vector. t σkk k is the k th diagonal element of $\sum_{\in}$ In addition, e_j and e_k are selection vectors, with one as the j^{th} or k^{th} element and zero otherwise. The normalization process of each row is calculated as $\tilde{\theta}_{jk}^{H} = \frac{\theta_{jk}^{H}}{\sum_{k=1}^{N} \theta_{jk}^{H}}$. Hence, the total connectedness from return shocks in the estimation to total forecast error variance:

$$S^H = 100 \times \frac{1}{N} \sum_{j,k=1; j \neq k}^{N} \tilde{\theta}_{jk}^{H} \tag{4}$$

It is worth noting that PN jk = 1 and PN j,k = 1 jk = N. In our work, we replicated the 200-day rolling wind as the working day in one year from t—199 to point t. In addition, we choose the VAR lag length based on AIC criteria. After calculating the total spillover effect, based on the study of Diebold and Yilmaz (2012), we estimate the directional spillover that all the assets send to asset j and vice versa. The main reason that we use this method to capture the spillover effects between Bitcoin returns and its energy consumption is to obtain better results for time-varying coefficients in the Vector Auto-regression model as the literature suggestions (Pham &

Table 2 Connectedness between energy consumption on Bitcoin market

	1 day to 4 days			4 days to +∞ days		
From	Energy	Return	Volume	Energy	Return	Volume
Energy	0.03	0.05	0.18	68.28	7.63	25.84
Return	1.44	72.94	0.16	0.75	24.59	0.11
Volume	0.04	0.04	3.35	0.92	10.77	84.89

The values reported are the variance decomposition, which is based on the study of Baruník & Kocenda (2019). Our optimal lag selection for the VAR model was based on the Akaike Information Criterion (AIC) with the level of – 10.4528

Huynh, 2020; Huynh, Hille, and Nasir, 2020). Therefore, instead of using the conventional approach of VAR (p), we rely on the time-varying and the high time–frequency domain to obtain better results to see whether the Bitcoin returns and its energy consumption exhibit dependency.

4 Empirical Results

4.1 The Connectedness Between Energy Consumption and the Bitcoin Market

The numbers which lie on a diagonal represent the extent to which the deviation of a specific variable impacts its own subsequent deviation. Meanwhile, other values in the matrix demonstrate the return spillover impact from one variable to another variable. Because Akaike Information Criterion (AIC) suggested that the optimal lag is four, we choose two-period as the optimal lag and estimate the connectedness in Table 2.

We do observe a bidirectional spillover effect from energy to Bitcoin returns as well as volumes and vice versa. There is a number of fascinating findings from Table 2. First, Bitcoin energy consumption has stronger self-spillover-effect in long term period than short term period while Bitcoin return has the opposite direction. The self-spillover effects of volumes are quite weak. Second, Bitcoin energy consumption is likely to receive the highest contagion return from volume after a four-day period. Energy consumption sensitively received more shocks in the long run. These effects coming from volumes are larger than the return. Third, the short-term shocks in Bitcoin energy consumption cause more in Bitcoin return than volume in less than four trading days. However, in comparison with the return, Bitcoin volumes are more sensitive compared to energy shocks in the long run. To capture the time-varying connectedness between the energy consumption and the Bitcoin market, we estimate the time-varying connectedness among our variables by using a 200-day rolling window (about 1 trading year). Figure 2 demonstrates the total connectedness of energy consumption on both Bitcoin returns and volumes. It can be seen that:

The spillover effect in the second crash is significantly higher compared to the first crash. In addition, it is observable that the total connectedness between Bitcoin

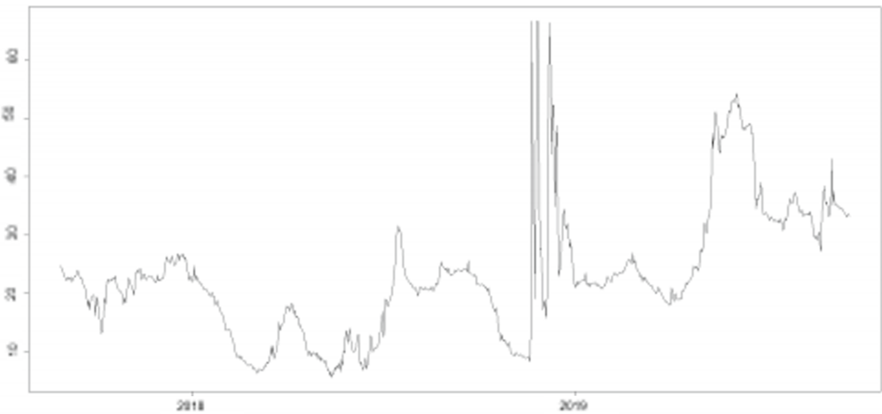

Fig. 2 The total connectedness of energy consumption on the Bitcoin market

energy and its market gradually increases in 2019. Thus, the second crash could be the reason to cause higher return transmission due to the storage of shocks. Our results present evidence that the movement in the Bitcoin market is found to be positively correlated, and increasingly connected to the energy consumption we consumed to mine, store and trade this coin. Our study also confirms the unsustainable role in the Bitcoin market (Corbet, Lucey, and Yarovaya, 2021). Concomitantly, the mining process of Bitcoin might increase the amount of carbon dioxide (Mora et al., 2018); however, these "mining behaviors" might change the supply–demand side. Therefore, the effects on prices and volatility can be observed in the market. However, in this section, we only focus on how Bitcoin and energy consumption exhibit the interrelationship without justifying the predictive power. The extant literature emphasizes a number of Bitcoin returns' determinants, volatility, and volumes. However, we would like to test whether this environmental factor can be served as the predictive factor.

4.2 The Predictive Power of the Bitcoin Market on the Bitcoin Energy Consumption

Since the current literature indicates the predictive factors of Bitcoin such as the ratio of Gold and Platinum (Burggraf; Huynh; Wang et al., 2019) or the Economic Policy Uncertainty index (Huynh, Wang, Vo, 2019). The results are summarized in Table 3.

Our findings are also in line with the previous connectedness results. Furthermore, by using the other control factors to mitigate the endogeneity problem, we also found that energy consumption exhibits positive (negative) power on Bitcoin returns

Table 3 The predictive power of energy consumption as well as Bitcoin markets

Variables	BTC return	BTC volume	Energy	Energy
Energy consumption	−0.011**[−2.433]	0.785***[11.597]		
BTC Return			−0.631**[−2.439]	
BTC Volume				0.194***[16.142]
Gold/Platinum	0.003[0.117]	−0.521[−1.342]	−1.124***[−5.919]	−0.860***[−4.851]
US EPU	0.0001[1.515]	−0.000[−0.610]	−0.000[−1.166]	−0.000[−0.936]
US Equity EPU	−0.0001[−0.115]	−0.000[−0.123]	−0.001***[−4.888]	−0.001***[−4.727]
UK EPU	−0.0001[−0.947]	0.001***[2.626]	−0.000[−0.127]	−0.000
[−1.367]				
Constant	−0.011**[−2.433]	−30.327***[−6.645]	−50.430***[−24.381]	−37.129***[−17.370]
Time-effect	Yes	Yes	Yes	Yes
R-squared (%)	1.58	71.48	73.81	77.64

* < 0.1, ** < 0.05, *** < 0.01. Robust standard errors in the brackets. The regressions are mainly based on the Ordinary Least Squares (OLS) approach

(volumes). The opposite directions were found that Bitcoin returns (volumes) positively (negatively) correlate with the level of energy consumption. To offer further insights into the causal relationship, this study employs the Granger causality.[1] It turns out that only energy consumption causes the return at 10% significance level while the opposite direction was not found. More interestingly, there is no empirical evidence about causal relationship between Bitcoin volume and its energy consumption. Therefore, we only draw one main conclusion. The Bitcoin returns are mainly driven by the level of consuming energy, especially for mining with the computer system. While the current literature investigates the mounting factors, which could predict the Bitcoin returns and volatility such as Google search engine (Balcilar et al., 2017; Burggraf et al., 2020; Nasir et al., 2019), the sentiments and uncertainties from investors (El Alaoui et al., 2019; Huynh, Wang and Vo, 2021; Naeem et al., 2020; Burggraf et al., 2020). This paper contributes a new energy factor–Bitcoin energy consumption, which can be used to predict the variant of Bitcoin returns and volumes. Concomitantly, this paper is also consistent with the current literature regarding the environmental impacts of Bitcoin (Easley et al., 2019; Li et al., 2019). More noticeably, Corbet, Lucey and Yarovaya (2021) emphasized the heterogeneous effects of country energy consumption and Bitcoin markets while our study offers the global perspective, where the Bitcoin phenomenon is ubiquitous. Differing with Baur and Oll (2019), our study does not indicate the level of carbon footprint in mining Bitcoin, but we contribute the level of energy consumption, which induces the shortage of energy as well as uses "contaminated energy sources" by any cost from the miners.

[1] After taking the Vector Auto-regression (VAR) based on the optimal lag selection (from the criteria of AIC, HQIC, SBIC of 4 periods), we estimate the Granger causality.

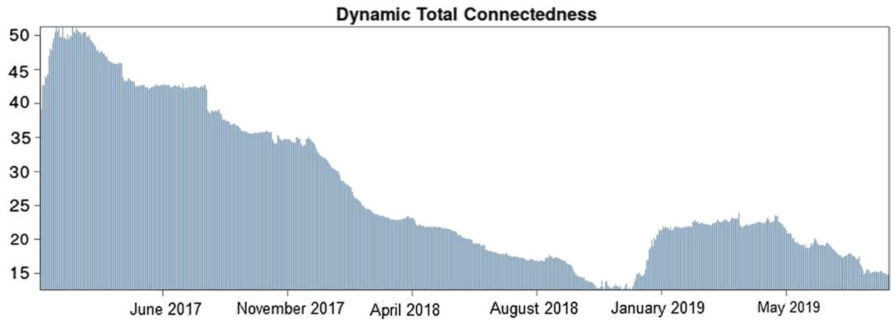

Fig. 3 The total dynamic connectedness by using TVP-VAR

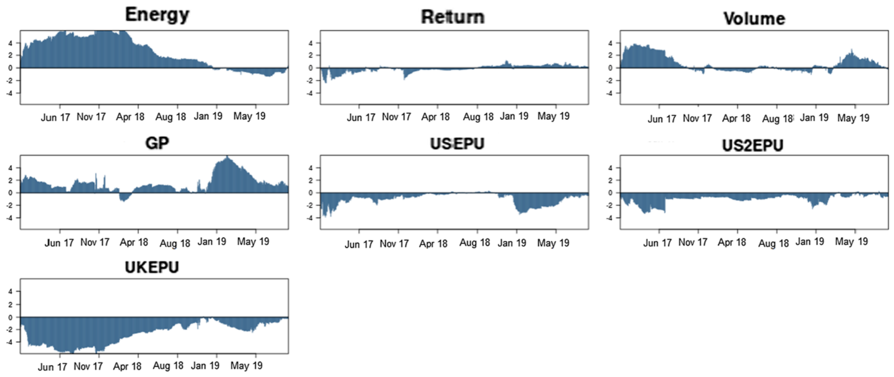

Fig. 4 Net spillover effects across the variables

4.3 Robustness Check

To increase the robust results, we perform the Time-varying Vector Auto-Regression (TVP-VAR) proposed by Antonakakis et al. (2020) to estimate the connectedness among all variables in Table 3, which indicates the predictive power of energy consumption and Bitcoin markets. There are several strengths raising from employing this method. First, this estimation does not rely on the size of the rolling window, which quickly accommodates the low frequencies as well as the data constraints. Second, there is no missing observations during the calculating process. Therefore, we can obtain a more accurate interference for considering the spillover effects among the variables.

Figure 3 summarizes the changes in the total connectedness among our variables, including energy consumption, Bitcoin returns, Bitcoin volumes, and other predictive factors. Accordingly, during the Bitcoin crash (after 2017), the dynamic connectedness is likely to decrease, which is in line with the substantial decline in Bitcoin prices. Afterwards, the spillover effect slightly increases since January 2019. When taking a closer look at the net spillover effect, Fig. 4

summarizes how these determinants are receiver or sender in terms of return shocks.

Figure 4 indicates how these determinants respond to the other shocks. Accordingly, before 2018, energy consumption plays a transmitting role. However, there exists the reversal position in the following periods. Interestingly, Bitcoin returns are likely to be immune to the other shocks with the contributing and receiving levels, which are around 2% during the period from 2017 to 2019. In contrast, Bitcoin volume tends to be sensitive to their kind of connectedness. More interestingly, the ratio of Gold and Platinum is dominant as the shocks sending while all Economic Policy Uncertainty indices (EPU indices) exhibit the receiving return shocks from these markets. Our further analysis supports the previous findings although we choose the alternative approach TVP-VAR to improve the quality of estimations.

5 Conclusion

Although the growth of cryptocurrency is hugely considered to be one the giant financial innovations in this decade, this paper is the first work to examine the impact of Bitcoin energy consumption on both returns and volumes, and vice versa. Our findings also contribute to existing literature, investors and users' behavior regarding electricity and utility consumption. We analyze Bitcoin energy consumption on its market towards two criteria (returns and volumes) using daily data over the period 2017 – 2019. We show that there is a bidirectional influence between energy consumption and Bitcoin returns (and volumes). We also find that liquidity, represented by Bitcoin trading volumes, matters to energy consumption. It means that the negative effect of block-chain in the validation process and decentralized data protocol causes more Bitcoin's carbon footprint Stoll et al. (2019). Especially, the Bitcoin crash is likely to be connected with the higher energy consumption afterwards. It challenges our current financial innovation, particularly the development of cryptocurrency, on having more carbon footprint on the Earth. Our work is also in line with the previous literature of Truby (2018) and Delgado-Mohatar et al. (2019) that Bitcoin mining and transactions seem to be an inefficient use of scarce energy resources although Bitcoin has many advantages in terms of financial aspects. Indeed, Mora et al. (2018) and Howson (2019) alerted that Bitcoin could be considered a power-hungry cryptocurrency.

Our results also indicate that the crash in Bitcoin market does not only impede energy consumption but also induces the connectedness of energy consumption after that. Hence, our frequency connectedness findings can also confirm the role of the uncertain market on energy consumption the most. This paper, once again, confirms the drawback of financial innovation on low-carbon investment as well as sustainable investment. Policymakers should take the environmental impact of cryptocurrencies miner into account while regulating this class of asset. More importantly, this paper challenges the development of blockchain industries, which requires a high amount of energy consumption. Although Bitcoin and other alternative cryptocurrencies have brought a new technology platform to investors with potential expected returns, the system also needs substantial energy stemming from the mining process as well as confirmed transactions. It will be better if the sources of energy coming from renewable and sustainable energy without a huge amount of carbon footprint or technological wastes. Therefore, we suggested that the Fintech industries (or the projects) should consider issuing a cryptocurrencies-backed-to green energy by issuing the 'green token' to finance sustainable development (Kovilage, 2020). Moreover, the reasonable selection of 'green source' might support the expected returns with the relevant premium that investors might be willing to pay more to obtain the sustainable and green coins. It concludes that the fintech industry is not the problem, but it is the wise choice which lies in investors' and firm's managerial decisions. Future research could facilitate the growth of the Bitcoin market by reducing energy consumption, for example, how to build a sustainable blockchain with the least amount of the human footprint.

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