Nexus Between COVID-19 Infections, Exchange Rates, Stock Market Return, and Temperature in G7 Countries: Novel Insights From Partial and Multiple Wavelet Coherence

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This study attempts to analyze the time-varying pattern between the exchange rates, stock market return, temperature, and number of confirmed COVID-19 cases in G7 countries caused by the COVID-19 pandemic. We have implemented our analysis using wavelet coherence and partial wavelet coherence (PWC) on independent variables from January 4, 2021 to July 31, 2021. This paper contributes to the earlier work on the same subject by employing wavelet coherence to analyze the effect of the sudden upsurge of the COVID-19 pandemic on exchange rates, stock market returns, and temperature to sustain and improve previous results regarding correlation analysis between the above-mentioned variables. We arrived at the following results: 1) temperature levels and confirmed COVID-19 cases are cyclical indicating daily temperatures have a material bearing on propagating the novel coronavirus in G7 nations; 2) noteworthy correlations at truncated frequencies show that a material long-term impact has been observed on exchange rates and stock market returns of G7 and confirmed COVID-19 cases; 3) accounting for impact of temperature and equity market returns, a more robust co-movement is observed between the exchange rate returns of the respective nations and the surge in COVID-19 cases; and 4) accounting for the influence of temperature and exchange rate returns and the increase in the confirmed number of coronavirus-infected cases and equity returns, co-movements are more pronounced. Besides academic contributions, this paper offers insight for policymakers and investment managers alike in their attempt to navigate the impediments created by the coronavirus in their already arduous task of shaping the economy and predicting stock market patterns.

Keywords: COVID-19, temprature, stock market return, exchange rate, G7, wavelet coherence

INTRODUCTION

COVID-19 has been one of the most unexpected global events that has challenged the sustainability and resilience of almost every social and economic system. The continuity of almost every man-made system has been challenged, and the uncertainty of the control and spread of the COVID-19 virus has put to the test every system of estimation and valuation. This event has triggered various studies analyzing correlations between the number of confirmed COVID-19 cases and various other social and economic parameters (Martínez and Cervantes, 2021) (Shahzad et al., 2021). Within a couple of months of confirmation of the novel existence of SARS-CoV-2 by WHO (World Health Organization), the number of cases had crossed 4.5 million, and the death toll had exceeded 0.3 million (G. Sharma et al., 2021). The number of new cases has shown a sinusoidal behavior since 2020 with two peaks; 1.7 million new cases on January 21, 2021 followed by a fall to 0.26 million on February 26, 2021 and back to 0.89 million cases on april 23, 2021 with a drop back to 0.29 million cases on July 13, 2021. In August 2021, as we are writing this paper, the cases have crossed 0.7 million new cases per day. In comparison, the number of fatalities peaked at 17,700 on February 3, 2021, which reduced to 7,600 on March 8, 2021. This surged back to 14,900 on april 29, 2021 and fell to 6,300 casualties on May 6, 2021. Recently, there was a spike of 19,800 cases on July 21, 2021, creating fears of a third wave (Wikipedia, 2021). The virus is very communicable (R^0 = 2–5), implying each infected vector can infect two to five subjects, exacerbating the spread. The myriad of symptoms such as fever, pneumonia, dry cough, myalgia, and fatigue sharing commonalities with many other seasonal ailments makes it even more difficult to keep a tab on the infected vectors (Qi et al., 2020; Rosario et al., 2020; Wang et al., 2020). Numerous studies have been conducted using daily average temperature (Huang et al., 2020; Park et al., 2020; Wang et al., 2020) to understand the impact of temperature and weather conditions on the spread and intensity of the COVID-19 virus.

Earlier studies on SARS (Severe Acute Respiratory Syndrome) have shown a negative correlation between the spread of the virus and temperature conditions (Wallis and Nerlich, 2005; Bedford et al., 2015). Similar results have been found for the influenza virus and dengue virus (Chan et al., 2010) (Chumpu et al., 2019). Studies also revealed a dysentery epidemic and temperature had a positive correlation (Li et al., 2019). Experts reason that as COVID-19 falls into a similar category of coronavirus, it is expected to show similar behavior (Ksiazek et al., 2003; Lipsitch, 2003; Wilder-Smith et al., 2020). Contrary to this, studies argue the minimal impact of temperature on the spread of COVID-19 (J. Liu et al., 2020; Shi et al., 2020; Xie and Zhu, 2020). Some authors argue that in colder regions, the dry cold will keep citizens indoors in heated environments and hence curb the spread of the COVID-19 virus (Molteni, 2020). Contradicting this, a research in India concluded that lower temperatures enhance the spread of viruses in the population, weakening the immune response, and making the proliferation of the virus easy (Roy, 2020; Sharma et al., 2020; Hossain et al., 2021; McClymont and Hu, 2021). These contradictory views on the

correlation between the temperature and the spread of the COVID-19 virus make a case for further investigation on the same subject.

Every spike in daily cases is usually followed by a slew of remedial and restrictive measures by local and federal governing bodies globally (Li and Mutchler, 2020; Sandeep Kumar et al., 2020). These include vaccination drives, compulsory mask-wearing in public places, lockdowns, restriction of gatherings, and restriction of manufacturing activities and economic output. This has dire consequences on the earnings of people living pay-check to pay-check (Lal, 2020). It was argued that in Japan the urban labor market was severely impacted directly due to the restrictions, while the rural labor market was impacted due to the shrinkage in the size of the economic opportunity and landscape (Lee and Cho, 2017). Overall, trade velocity has been adversely impacted with a greater impact on foreign trade (Au Yong and Laing, 2021; Biswas et al., 2021). The follow on from the impact on the stock markets cannot be downplayed (Amar et al., 2021; Louhichi et al., 2021; Yousfi et al., 2021). These restrictions have adversely impacted the balance sheets of most of the firms exposed to international trade along with the ones in domestic trade (Chang et al., 2020; Gunay, 2020; Jomo and Chowdhury, 2020). This, in turn, resulted in the major stock indices of the G7 nations along with that of the rest of the world nose-diving before quantitative easing by the central banks provided some respite (Liu et al., 2020; Rebucci et al., 2020; Rubbaniy et al., 2021; Wei and Han, 2021). Trade, financial markets, and central bank rates have impacted the international currency market as well (Andreou et al., 2013; Tsagkanos and Siriopoulos, 2013; Sui and Sun, 2016).

The commodity markets were not spared by the spread of COVID-19 either. For the first time, crude oil futures crashed into negative territory (Albulescu, 2020; Izzeldin et al., 2021; Salisu et al., 2020). At -ve $40, sellers were paying buyers to take oil. This was caused due to the low demand, excess supply, and lack of storage space (Joanna Wilson, 2020). The negative impact of COVID-19 on crude oil prices was short-lived. However, the spillover on the equity markets was more pronounced (Mzoughi et al., 2020). At the same time, the depreciation of the Japanese Yen against the USD caused an appreciation in the Japanese equity markets. "*A one standard deviation depreciation of the Yen during the COVID-19 period (equivalent to 0.588%) improved stock market returns by 71% of average returns*" (Narayan et al., 2020). During the first wave, the pronounced negative news flow about the infallible and uncontrollable spread of the novel coronavirus in the countries of western Europe plummeted the stock markets globally (Conlon and McGee, 2020; Sharif et al., 2020; Zhang et al., 2020). With the COVID impact not yet over and concerns of repetitive waves still looming, further analysis is warranted to analyze the impact and correlation between COVID-19 and the returns of the equity markets in the G7 nations.

This study derives its motivation from two major studies used to evaluate the impact on the environment (i.e., temperature) and the impact on the equity markets by the COVID-19 virus (G. D. Sharma et al., 2021; Shahzad et al., 2021). The data used in the first study are time-series data and deploy a multitude of models

such as the Susceptible Exposed Infectious Recovered model (SEIR) (Shi et al., 2020), Generalized Additive Model (GAM) (Ero lu, 2019; Xie and Zhu, 2020), etc. in the analysis of the magnitude of influence of temperature on the spread and surge in COVID-19 cases. Nonetheless, these studies refrain from ascertaining a firm correlation between the two. The various results obtained by the numerous studies subcategorized under this section are below:

i) temperature and the proliferation of the confirmed number of cases of COVID-19 are positively correlated (Auler et al., 2020; Douro et al., 2020; Kumar, 2020)
ii) temperature and confirmed COVID-19 cases are negatively correlated (Pequeno et al., 2020; Prata et al., 2020; Sarkodie and Owusu, 2020)

This inconclusive result in the available literature on temperature impacting the surge in COVID-19 cases creates a case for further evaluation of the same topic. The second type of evaluation assesses the economic impact of COVID-19 on the equity markets and other securitized tradable instruments (Goodell, 2020; Topcu and Gulal, 2020; Yarovaya et al., 2020a). Studies conducted on the foreign exchange (Holtmann et al., 2020; Iqbal et al., 2020; Sarmadi et al., 2020) concluded that a negative relationship existed between the surge in COVID-19 and the Chinese Yuan rate of exchange. They conducted their studies using wavelet analysis, and it was concluded by other researchers that there existed a positive relationship between the exchange rate and the number of confirmed COVID-19 cases (Villarreal-Samaniego, 2020; Javed et al., 2021; Kinateder et al., 2021). They used ARDL and conditional value-at-risk (CoVaR) estimations to conduct their evaluation.

Various methods have been employed to evaluate the impact of COVID-19 on various securitized traded markets; e.g., the wavelet coherence method to evaluate COVID-19's ramifications on crude oil rate variance on American equity indices (Mensi et al., 2019; Mnif et al., 2020; Sharif et al., 2020) and to understand the coherence in pandemic upsurge and energy markets (futures) (Aloui et al., 2020; Sharif et al., 2020). The event study method has been used to evaluate the short-term impact of the COVID-19 surge on prominent equity market indices (J. Liu et al., 2020). As a recent investment product, a few papers evaluate COVID-19's impact on cryptocurrencies (Shahzad et al., 2019; Yarovaya et al., 2020b; Balli et al., 2020; Goodell and Goutte, 2021).

The novel coronavirus has fueled uncertainties. Hence, the above-discussed coherence analysis between the number of confirmed COVID-19 cases and its impact on numerous variables. Based on the above analysis, we chose the wavelet analysis methodology to re-assess the coherence between regional temperature, equities, Forex, and COVID-19-confirmed cases in G7 nations (Shakoor et al., 2020; Zutshi et al., 2021). The wavelet methodology, which mostly finds usage in geophysics, has recently found a place in economics and finance, environment, and meteorology studies, etc. (Bouoiyour et al., 2015; Afshan et al., 2018; Sharif et al., 2020). Not having much experience in usage in COVID-related studies in this unfamiliar terrain, we

TABLE 1 | List of Countries with COVID-19 cases

Country	Total Cases	Deaths	Recoveries
United States	3,82,54,370	6,39,103	3,76,15,267
Canada	14,68,030	26,792	14,41,238
France	66,19,611	1,13,372	65,06,239
Germany	38,88,365	92,476	37,95,889
Italy	44,84,613	1,28,751	43,55,862
Japan	12,77,439	15,596	12,61,843
United Kingdom	64,92,906	1,31,640	63,61,266

have assessed the pandemic's impact in a binary fashion: Using phase difference and wavelet coherence, we analyzed temperatures' impact on COVID-19 cases. Using PWC and phase difference, accounting for control variables, we analyzed the influence of COVID-19 surge on equity (Forex) returns in G7 markets by conditioning on Forex (equity) and temperature, respectively.

Wavelet techniques have helped us answer two key research questions, 1) assessment of the lead/lag relationship among the variables; and 2) cyclical nature between the assessed variables. We assessed the relationship between temperature (implying weather), equity markets and currency exchange rates (economy), and surge in COVID-19 cases in G7 countries (**Table 1**)—the United States, Canada, France, Germany, Italy, Japan, and the United Kingdom. Wavelet coherence methodology was used to examine the relationship between the selected variables/indicators. The idea was to arrive at a leading or lag relationship between the variables to use the naturally occurring event to predict the supporting variables, e.g., the impact of temperature on the equity markets while establishing the coherence with the daily confirmed cases of the novel coronavirus (Prata et al., 2020; Wu et al., 2020). Compared to conventional correlation and regression techniques, wavelet analysis is superior as the former only maps a comprehensive mean relationship between the entire time frame whereas in contrast, the latter tells us of microlevel interactions and co-movements in a time-frequency frame (Fareed et al., 2020; Onali, 2020; Tiwari et al., 2016). This predictive capability of the relationship between the variables using wavelet analysis can help policymakers take prophylactic measures to prevent unwarranted catastrophes when one of the indicators gives a particular signal. This can find usage even beyond the pandemic to minimize human casualties and other suffering. In this analysis of the relation of cases of COVID-19 and equity and Forex returns, we came up with profound insights on a predictive lead indicator for the financial markets. This type of study can be extrapolated to find the variation in the occurrence of various diseases in different varying weather conditions in G7 countries and their association if at all with equity and Forex returns.

Our study unfolds three prominent outputs:

a) Wavelet coherence for reported coronavirus cases and temperature shows the existence of an in-phase relationship (cyclicality). Temperature takes the lead in the relationship in the sample dataset in most of the G7 countries using biwavelet coherence (WC).

TABLE 2 | List of Forex and equity returns considered for G7 countries

S.No.	Country	Stock Exchange Index	Currency (USD)
1	United States	Dow Jones Industrial Average	Euro
2	Canada	S&P	TSX composite Index	CAD
3	France	CAC 40	Euro
4	Germany	DAX 30	Euro
5	Italy	FTSE MIB Index	Euro
6	Japan	NIKKE 225	JPY
7	United Kingdom	FTSE 100	GBP

b) There exists an in-phase (cyclical) and out-of-phase (anti-cyclical) pattern in the analyzed data of the daily confirmed cases of COVID-19 and equity returns, when conditioning for Forex yields along with temperature using the partial wavelet coherence (PWC).

c) PWC between Forex (exchange rate return) and the number of confirmed COVID-19 cases (conditioning for equity returns and temperature) indicates both an in-phase relationship (cyclicality) and out-of-phase (anti-cyclicality) relationship between the variables.

The layout of our article is as follows: data and methodology: second section; results: third section; findings: fourth section; policy implications and conclusion: fifth and final segment.

DATA AND METHODOLOGY

Data

The sample data on daily observations were collected for G7 countries, namely the United States, Canada, France, Germany, Italy, Japan, and the United Kingdom, from January 4, 2021 to July 31, 2021. The details of Forex (exchange rates) and equity (stock) returns considered in the present study are given in **Table 2**. **Table 3** gives the list of the variables and sources of data considered in the present study.

The wavelet analysis is applied to study the coherence between temperature $(T_{i,p})$, stock market returns $(SP_{i,p})$, currency exchange rates $(ER_{i,p})$, and new daily COVID-19 cases $(CV_{i,p})$ of country i at day p. The following relationships are studied in the present study:

a) Biwavelet coherence between $CV_{i,p}$ and $T_{i,p}$

b) Partial coherence between $CV_{i,p}$ and $SP_{i,p}$ conditioned for $ER_{i,p}$ and $T_{i,p}$

c) Partial coherence between $CV_{i,p}$ and $ER_{i,p}$ conditioned for $SP_{i,p}$ and $T_{i,p}$

Methodology
Biwavelet Coherence (WC)

The wavelet coherence methodology is considered an appropriate tool applicable to study the periodic phenomena in a time series, particularly in the presence of abrupt frequency changes across time. Wavelet coherence is analogous to the traditional correlation used to measure the degree and extent of co-movement between two time series but in the time-frequency (location—scale) domain. This approach was applied to measure the nature of the relationship between the two time series - temperature $(T_{i,p})$ and the daily number of new COVID-19 cases $(CV_{i,p})$, for country i at day p, which was our first objective in our study.

We defined the squared biwavelet coherence between two time series - Y and X, at scale (s) and location (t) as

$$C_{y,x}^2(s,t) = \frac{\overset{\leftrightarrow y,x}{d}(s,t).\overline{\overset{\leftrightarrow y,x}{d}(s,t)}}{\overset{\leftrightarrow y,y}{d}(s,t).\overset{\leftrightarrow x,x}{d}(s,t)} \quad (1)$$

where $\overset{\leftrightarrow A,B}{d}(s,t)$ is the smoothed auto-wavelet power spectra (for A = B) or cross wavelet power spectra (when A≠B) respectively. ( ) is the smoothening operator and $\overline{(\ )}$ is the complex conjugate operator (Liu, 1994).

Partial Wavelet Coherence

Partial wavelet coherence (PWC) is similar to the partial correlation coefficient employed in studying the correlation (co-movement) between two variables (time-series) while controlling (excluding) the effect of a third variable(s) (time series) but in the time-frequency domain. Our second and third objectives were to study the co-movements between.

1) COVID-19 cases $(CV_{i,p})$ and stock price index $(SP_{i,p})$ while controlling for the factors—temperature $(T_{i,p})$ and exchange rates. $(ER_{i,p})$

2) COVID-19 cases $(CV_{i,p})$ and exchange rates $(ER_{i,p})$ while controlling for the factors—temperature $(T_{i,p})$ and stock price index. $(SP_{i,p})$

The approach of partial wavelet coherence was employed.

TABLE 3 | List of variables and source of data covered in the study

| S.No	Variables	Variable Description	Source	link
1.	Cases	Daily number of new confirmed COVID-19 cases	'Our world in data'	https://ourworldindata.org/grapher/daily-cases-COVID-19
2.	SP	Stock Price Index	'Yahoo! Finance'	https://in.finance.yahoo.com
3.	ER	Currency Exchange Rates	'Yahoo! Finance'	https://in.finance.yahoo.com
4.	Temp	Daily Average Temperature collected from monitoring stations nearest to each country's capital	'National Centers for Environmental Information (NCEI)'	www.ncei.noaa.gov/access/search/data-search/global-summary-of-the-day
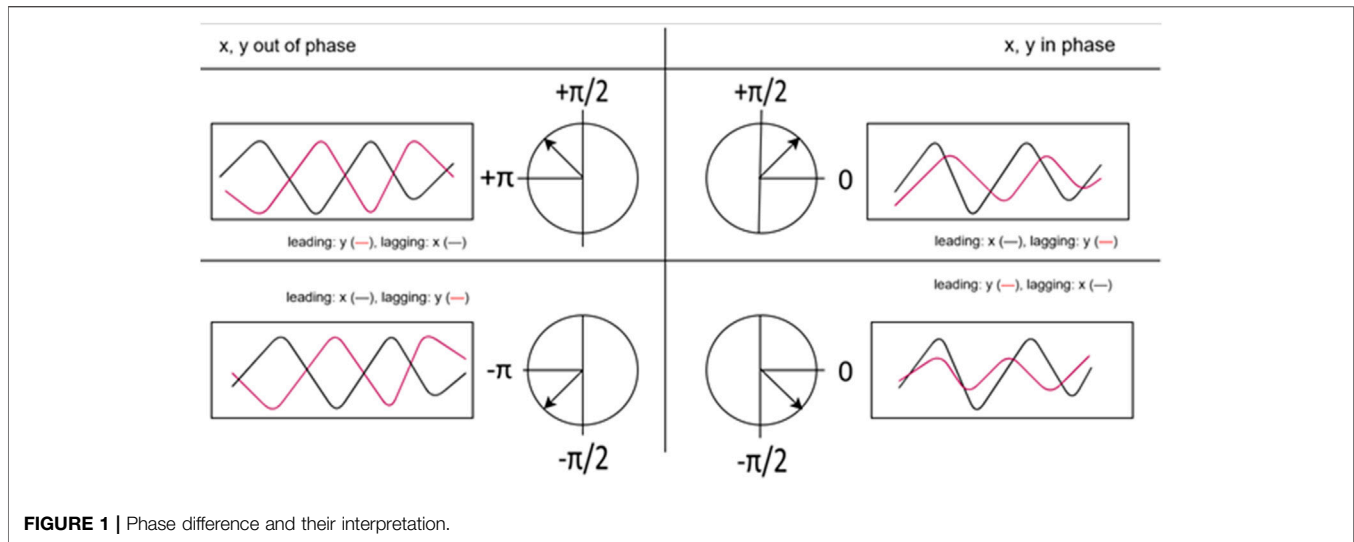
FIGURE 1 | Phase difference and their interpretation.

We defined the squared partial wavelet coherence (Hu and Si, 2021) between time series - Y and X, after excluding the effect of a pair of time series, $Z = (z_1, z_2)$ at scale (s) and location (t) as

$$C_{y,x|z}^2(s,t) = \frac{\left|1 - C_{y,x,z}^2(s,t)\right|^2 C_{y,x}^2(s,t)}{\left(1 - C_{y,z}^2(s,t)\right)\left(1 - C_{x,z}^2(s,t)\right)} \qquad (2)$$

$C_{y,x}^2(s,t)$ is the squared biwavelet coherence between time series - Y and X as defined in **Equation 1**.

Lead/Lag Relationship Between Time Series

Phase difference (PD), which equals the difference of individual phases of the time series, phase X—phase Y, was used to conceptualize the lead-lag relationship between the two time series. PD, when converted to an angle in the interval, $[-\pi, \pi]$ was defined as

$$\theta_{xy}(t,s) = arg[d^{x,y}(s,t)] = tan^{-1}\left[\frac{Im(d^{x,y}(s,t))}{Re(d^{x,y}(s,t))}\right] \qquad (3)$$

where $d^{x,y}(s,t)$ is the cross-wavelet power spectrum between X and Y at scale s and location t.

For PWC, PD between X and Y after excluding the effect of $Z = (z_1, z_2)$ converted to angle was defined as:

$$\theta_{xy|z}(t,s) = \varphi_{xy|z}(t,s) + \theta_{xy}(t,s) \qquad (4)$$

where

$$\varphi_{xy|z}(t,s) = arg\left(1 - C_{y,x,z}^2(s,t)\right)$$

If $|PD| < \pi/2$, this indicated the two time series moved in-phase (cyclical) while $|PD| > \pi/2$ indicated that they moved anti-phase (anti-cyclical) at a particular instance of time and frequency. PD equal to zero indicated the two time series moved together on a particular frequency. The sign of PD (+/-) showed which series was the leading one in the relationship. Following the Aguiar-Conraria and Soares (2011) approach, **Figure 1** illustrates the possible range and interpretation of phase differences.

FINDINGS

The biwavelet and partial wavelet coherence analyses were applied between the reference variables on daily observations for the sample period of January 4, 2021 to July 31, 2021. The results are presented in **Figures—2** to **8**.
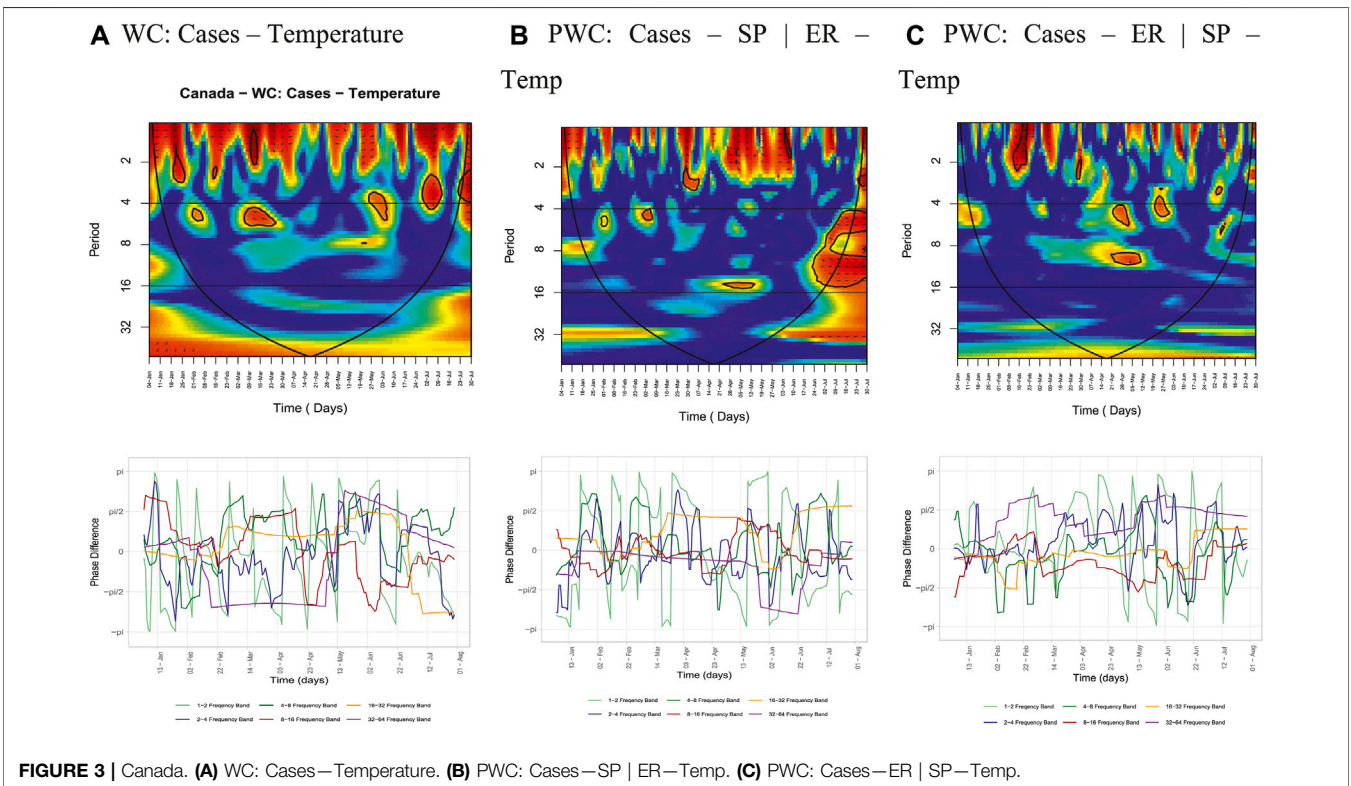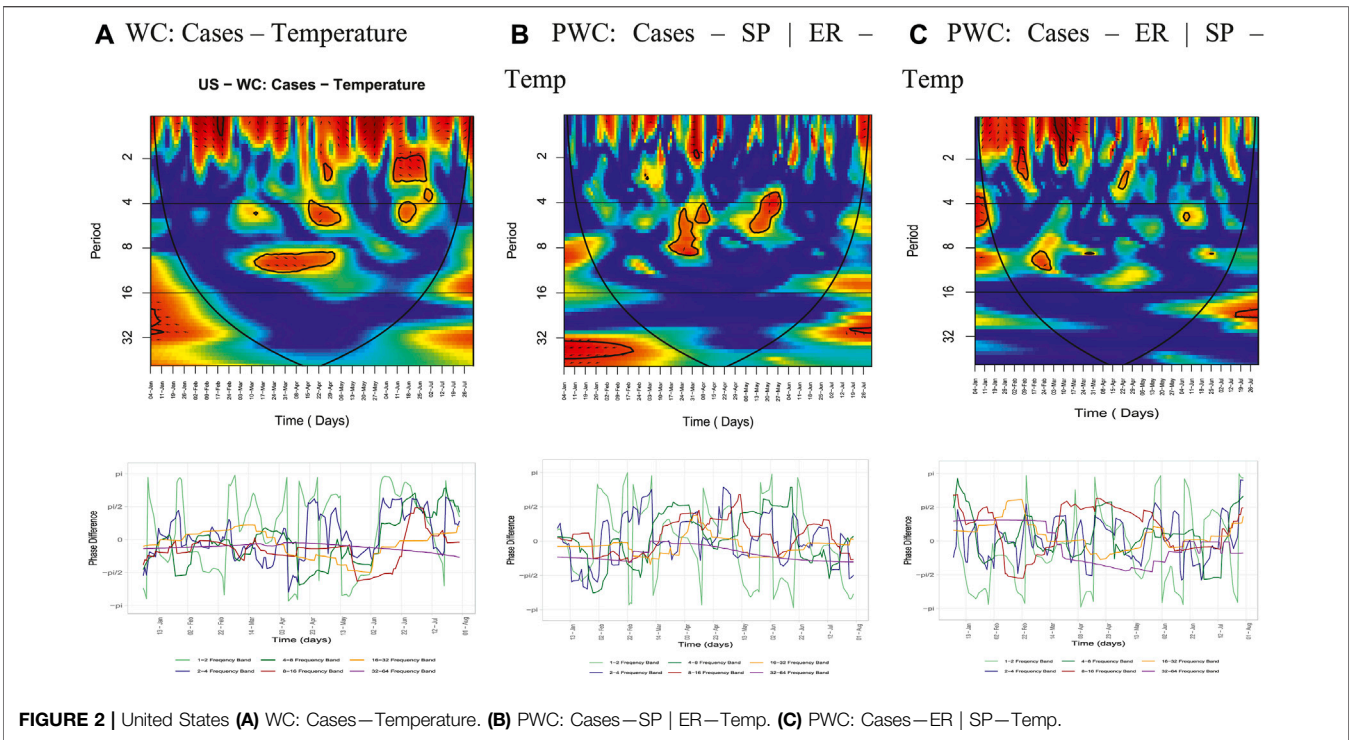
The horizontal axis (X-axis) represents the time points (days), while the vertical axis (Y-axis) represents the frequency domain. For the present analysis, six frequency cycles were considered—1–2, 2–4, 4–8, 8–16, 16–32, and 32–64 days bands. The first two cycles (1–2 and 2–4 days bands) are indicative of the short-run or high-frequency bands, and the remaining four cycles (4–8.8–16.16–32 and 32–64 days bands) are indicative of the long-run or low-frequency bands.
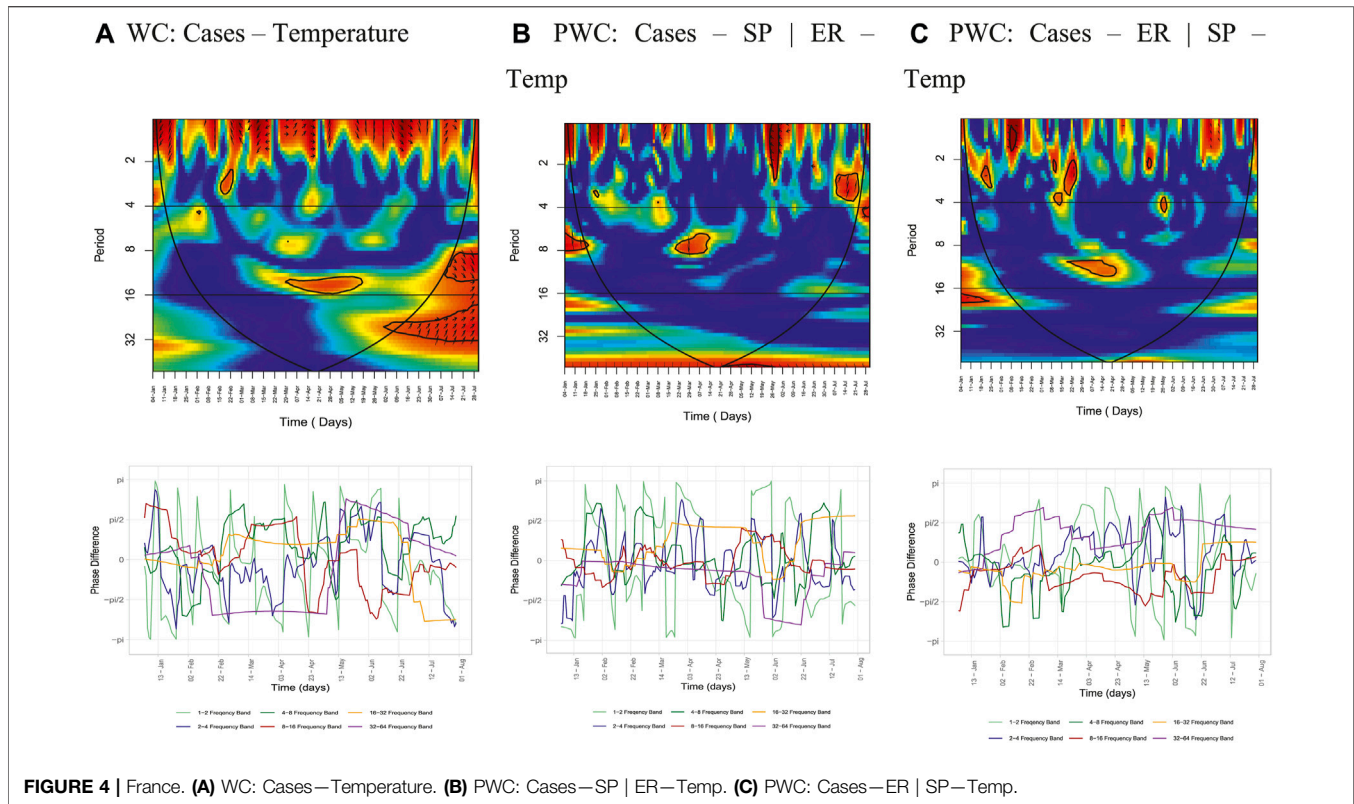
The color spectrum indicates the intensity of the interrelation (co-movement) between the series under study. The warmer color (red) signifies regions with significant co-movement, while a colder color (blues) signifies lower dependence (co-movement) between the series. The regions beyond the black line cone or the cone of influence (COI) which represents the 5% level of significance are not considered as the estimates of wavelet coefficients and are not statistically significant.

The area of arrows depicts the phase differences chosen at a 5% level of significance for the present analysis. The arrows are indicative of lead/lag phase relations between the series under consideration in the diagram. Arrows pointing to the right (left) mean that the series is in-phase (out-phase) while the arrows pointing right-down or left-up indicate the second series is leading while arrows pointing left-down or right-up indicate the first series is leading.

Wavelet Coherence: Cases—Temperature

The wavelet coherence and phase difference (PD) plots for cases vs temperature for the G7 countries are presented in **Figure 2A**, **3A**, 4(a), 5(a), 6(a), 7(a), and 8(a) with interpretations given in Table—4.

FIGURE 2 | United States (A) WC: Cases—Temperature. (B) PWC: Cases—SP | ER—Temp. (C) PWC: Cases—ER | SP—Temp.

FIGURE 3 | Canada. (A) WC: Cases—Temperature. (B) PWC: Cases—SP | ER—Temp. (C) PWC: Cases—ER | SP—Temp.

FIGURE 4 | France. **(A)** WC: Cases—Temperature. **(B)** PWC: Cases—SP | ER—Temp. **(C)** PWC: Cases—ER | SP—Temp.

For the United States, a small significant coherence was found in the two to four band around april 22–29, and a large island was depicted between June 11–25 where cases and temperature were out of phase (cases leading temperature). Further, two huge islands of significant coherence were found in the four to eight band between april 22—May 6 where cases and temperature were out of phase (temperature leading cases) and June 11–25. For the 8–16 days band, a significant coherence was located between March 12—april 30 with temperature leading cases.

For Canada, small islands with significant coherence could be seen in the one to two band between January 18–28 (out of phase) and March 5—20 (in-phase), where temperature was leading cases. In the two to four band, a huge island of significant coherence could be seen between June 20—July 10 with cases leading temperature and a small significant coherence could be seen between June 18–25 and February 8–16. For the four to eight band, islands with significant coherences could be seen between January 20 -February 8, March 2–31 (out of phase with cases leading temperature) and May 20—June 3.

For France, islands of significant coherences were located between February 15—March 1 (two to four band), March 29 -May 19 (8–16 band), and June 2–15 (16–32 band).

For Germany, significant coherence could be seen between January 15–31 with temperature leading cases in the two to four and 4–8 days bands.

For Italy, in the two to four band, islands of significant coherences were located between January 15—31 and June 15–25 where cases and temperature were in-phase with

temperature leading cases. Two huge islands were located in the two to four and four to eight bands between January 15–25 (in-phase) with cases leading temperature and March 1–22 with temperature leading cases. Further, small islands of significant coherences could be seen between May 10–20 (four to eight band) and February 8–22 and april 1–30 (8–16 band).
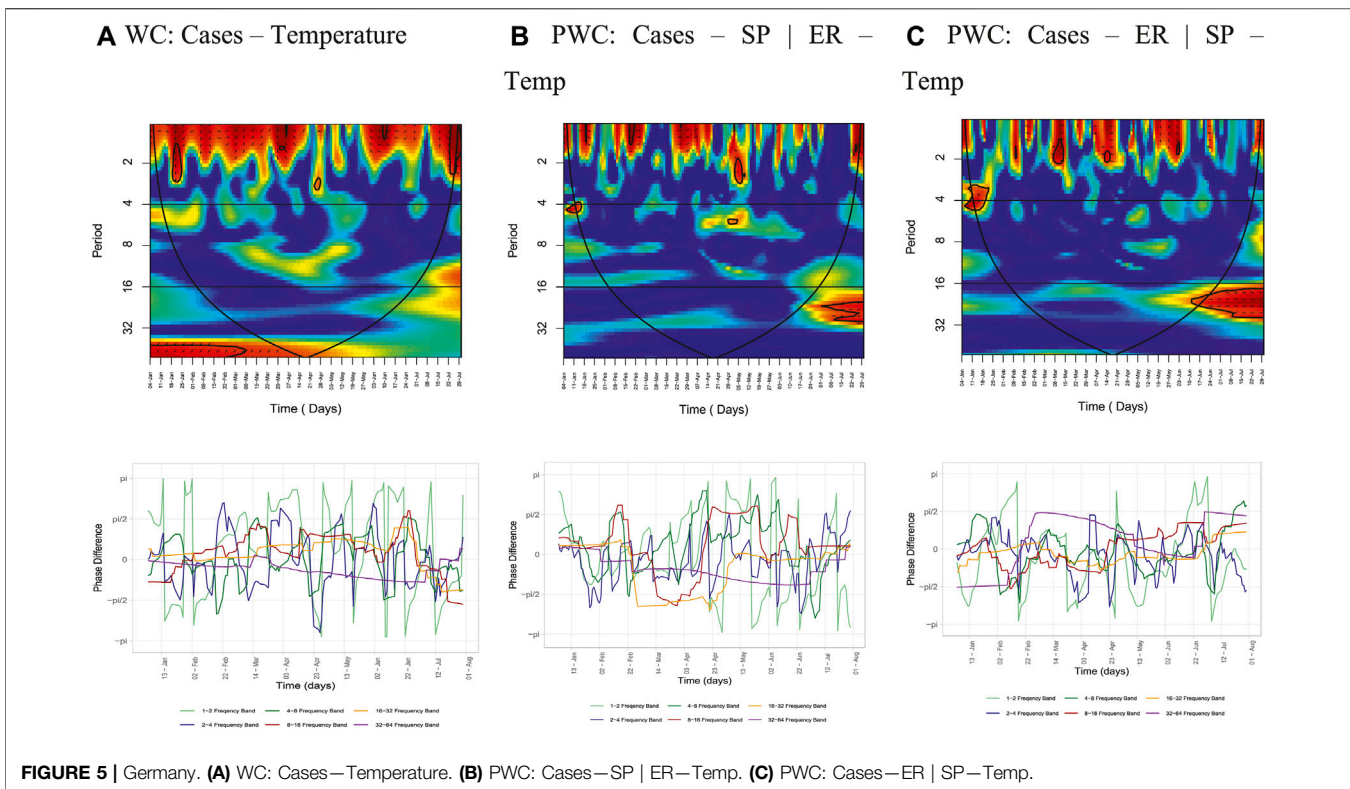
For Japan, islands of significant coherences could be seen between april 10–20 where cases and temperature were out of phase and april 25—May 20 with cases and temperature in-phase in the one to two and two to four bands with temperature leading cases. A huge island of significant coherence could be seen in the 16–32 band between May 15-June 30 (in-phase) with temperature leading cases.

For the United Kingdom, significant coherences could be seen between February 20–28 (two to four band) and april 1 -May 15 (8–16 band).

Partial Wavelet Coherence: Cases—Stock Price Index | Exchange Rates—Temperature

The partial wavelet coherence and phase difference (PD) plots for COVID-19 cases $(CV_{i,p})$ and stock price index $(SP_{i,p})$ while controlling for the factors—temperature $(T_{i,p})$ and exchange rates for the G7 countries are presented in **Figures 2(b)**, **3(b)**, **4(b)**, **5(b)**, **6(b)**, **7(b)**, and **8(b)** with interpretations given in Table—5.

For the United States, cases and stock prices were in-phase depicted by islands of significant coherence located between

FIGURE 5 | Germany. **(A)** WC: Cases—Temperature. **(B)** PWC: Cases—SP | ER—Temp. **(C)** PWC: Cases—ER | SP—Temp.

March 15—april 15 (4–8 & 8–16 bands) with cases leading stock prices and between May 5–30 (two to four and four to eight bands).

For Canada, a huge island of significant coherence was seen between June 20—July 20 where cases and stock prices were out of phase (stock price leading cases) for the majority of days in the four to eight and 8–16 bands.

For France, significant coherence was seen in the one to two and two to four bands between May 18–31, where cases and stock prices were out of phase with cases leading stock prices. In the two to four band, an island was located between June 30-Jul 20 with cases and stock prices in-phase with cases leading stock prices. In the four to eight and 8–16 bands, significant coherence was found between March 20-April 15, where cases were seen leading stock prices.

For Germany, cases and stocks were in-phase in the one to two band between January 15–20 and February 20–25. In the two to four band, cases and stock prices were seen to be out of phase with cases leading stock prices between april 28—May 10.

For Italy, cases and stock prices were seen to be out of phase in all islands of significant coherence. In the two to four band, cases were seen to be leading stock prices between February 1–7 and april 30–May 10. For June 20–30, stock prices were observed to be leading cases. A huge island of significant coherence could be seen between June 16-July 15 with stock prices leading cases in the 8–16 band.

For Japan, an island of significant coherence was observed in the one to two band around February 25 -March 5 with cases leading stock prices (out of phase) and april 25–30 with stock
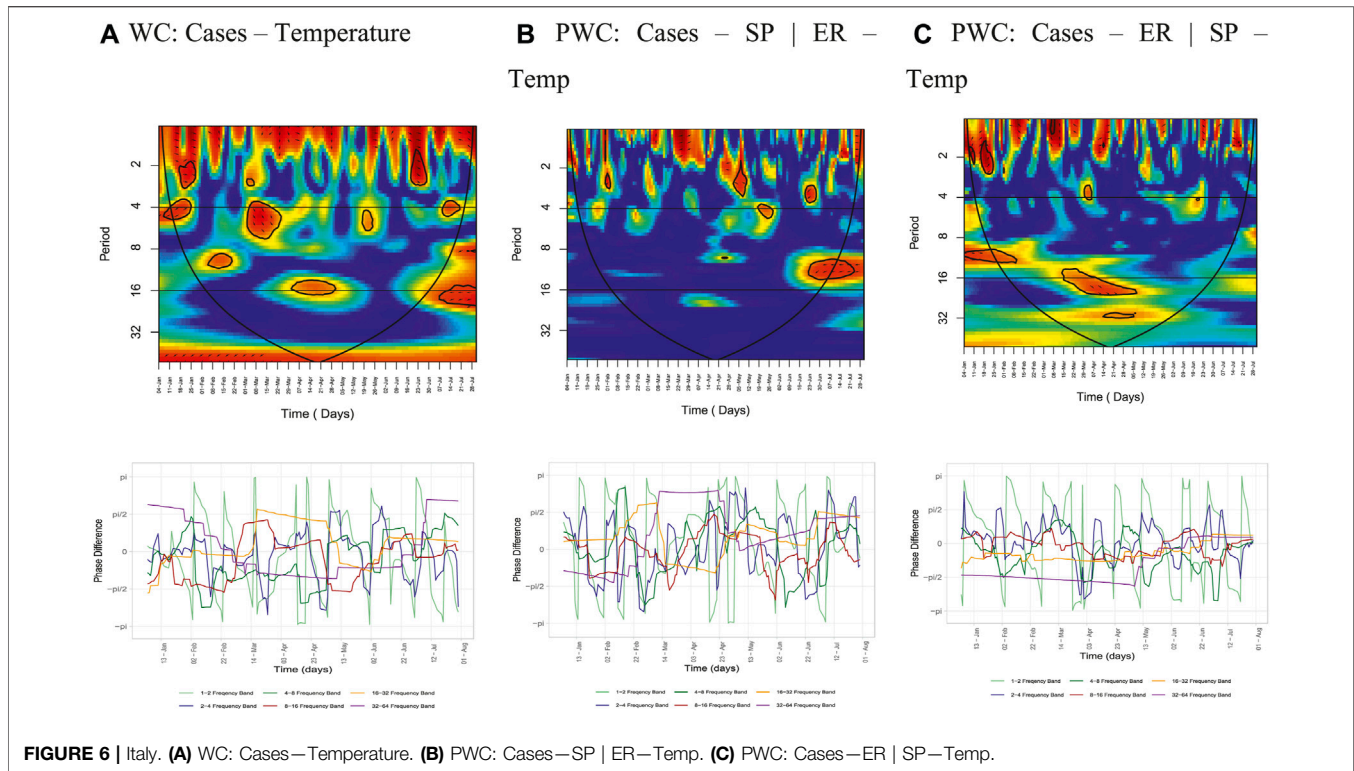
prices leading cases (out of phase). In the two to four band, stock prices were observed to be leading cases in islands of significant coherence observed between February 10–28 (out of phase) and March 15–25 (in-phase). Further, significant coherence was seen between February 5–28 with stock prices leading cases (out of phase). In the 8–16 band, stock prices were seen to be leading cases (in-phase) between april 25 -May 20.

For the United Kingdom, in the one to two and two to four bands, an island could be seen with cases leading stock prices (out of phase) between May 18–June 2. In the two to four band, an island of significant coherence could be seen between July 1–15 with cases and stock prices in-phase and cases leading stock prices. For the four to eight and 8–16 bands, an island could be seen between March 20 -April 15 with cases leading stock prices (in-phase).

Partial Wavelet Coherence: Cases—Exchange Rates | Stock Price Index—Temperature

The partial wavelet coherence and phase difference (PD) plots for COVID-19 cases ($CV_{i,p}$) and exchange rates ($ER_{i,p}$) while controlling for the factors—temperature ($T_{i,p}$) and stock price index ($SP_{i,p}$) for the G7 countries are presented in **Figures 2(c)**, **3(c)**, **4(c)**, **5(c)**, **6(c)**, **7(c)**, and **8(c)** with interpretations given in Table—6.

For the United States, significant coherence could be observed between March 31—april 7 in the one to two band with exchange rates and cases in-phase. In the two to four and four to eight

FIGURE 6 | Italy. **(A)** WC: Cases—Temperature. **(B)** PWC: Cases—SP | ER—Temp. **(C)** PWC: Cases—ER | SP—Temp.

bands, cases and exchange rates were seen in-phase with cases leading exchange rates between May 6—31. Also, significant coherence was observed in the four to eight and 8–16 bands around March 20 -April 15 with cases leading exchange rates in the 8–16 band.

For Canada, an island of significant coherence could be seen between February 15–25 with cases and exchange rates in-phase and exchange rates leading cases in the one to two and two to four bands. In the two to four band, cases were observed to be leading exchange rates (out of phase) between March 28—april 7. In the four to eight and 8–16 bands, significant coherence was depicted by islands seen around april 21 -May 12 and around May 20—June 4 in the two to four and four to eight bands. Cases and exchange rates were in-phase with exchange rates leading cases in the 8–16 band.

For France, significant coherence was seen between February 5–15 with cases leading exchange rates (out of phase) in the one to two band. In the two to four band, exchange rates and cases were in-phase between January 18–31 (exchange rates leading cases) and March 10–25. Further, significant coherence could be seen in the 8–16 band between March 17 -April 15.

For Germany, cases and exchange rates were observed to be in-phase for all significant areas. In the one to two and two to four bands, cases leading exchange rates were observed between March 1–10 and significant coherences were seen between april 10–15 and May 27—June 3. In the two to four band, cases were leading exchange rates from January 10–25, and in the 8–16 band, cases were leading exchange rates from June 10–25.

For Italy, cases were seen to be leading exchange rates (in-phase) in the one to two band, and in two to four band, islands of significant coherence were observed between January 11–25 and March 1–8. For the 8–16 band, an island was observed between January 25—February and between March 15 -May 12 for the 8–16 and 16–32 bands. In the 16–32 band, exchange rates were observed leading cases and were in-phase.

For Japan, cases were seen leading exchange rates and in-phase for all significant coherent islands. Islands of significant coherence were observed between april 30–May 20 (one to two and two to four bands), March 20—april 10 (two to four band) and May 20—June 10 (four to eight band).

For the United Kingdom, cases were leading exchange rates in all areas of significant coherence. In the one to two band, cases and exchange rates were out of phase between February 1–15 while in the two to four band, they were in-phase between January 18–30 and March 10–25. An island of significant coherence was observed between March 15—april 20 in the 8–16 band.

DISCUSSION

Wavelet coherence observed within the dataset of daily temperature and the number of confirmed COVID-19 cases in the G7 nations indicated significant co-movements in both the near-term and longer-term between the two variables. In most countries, the interconnection was led mostly by temperature and showed both in-phase and out of phase relationships indicating both cyclical and anti-cyclical movements in near and long terms.
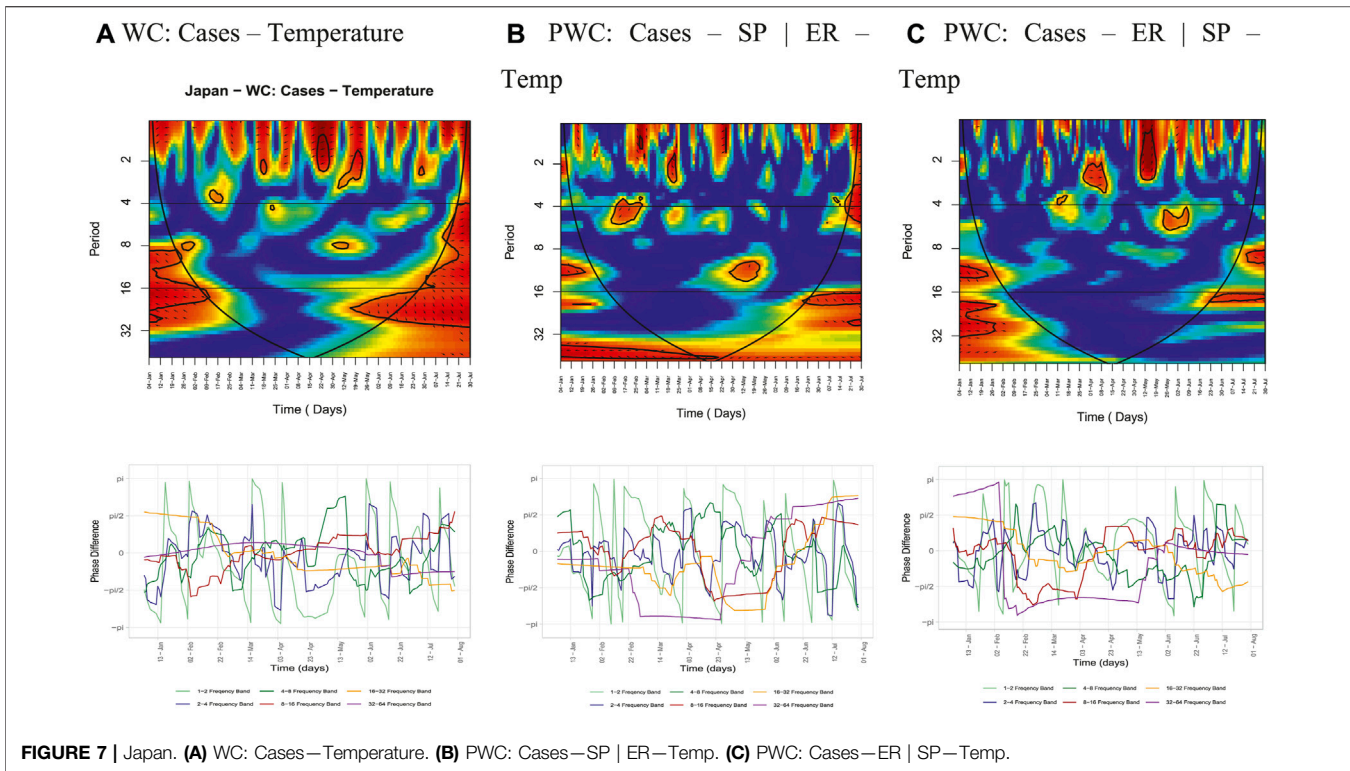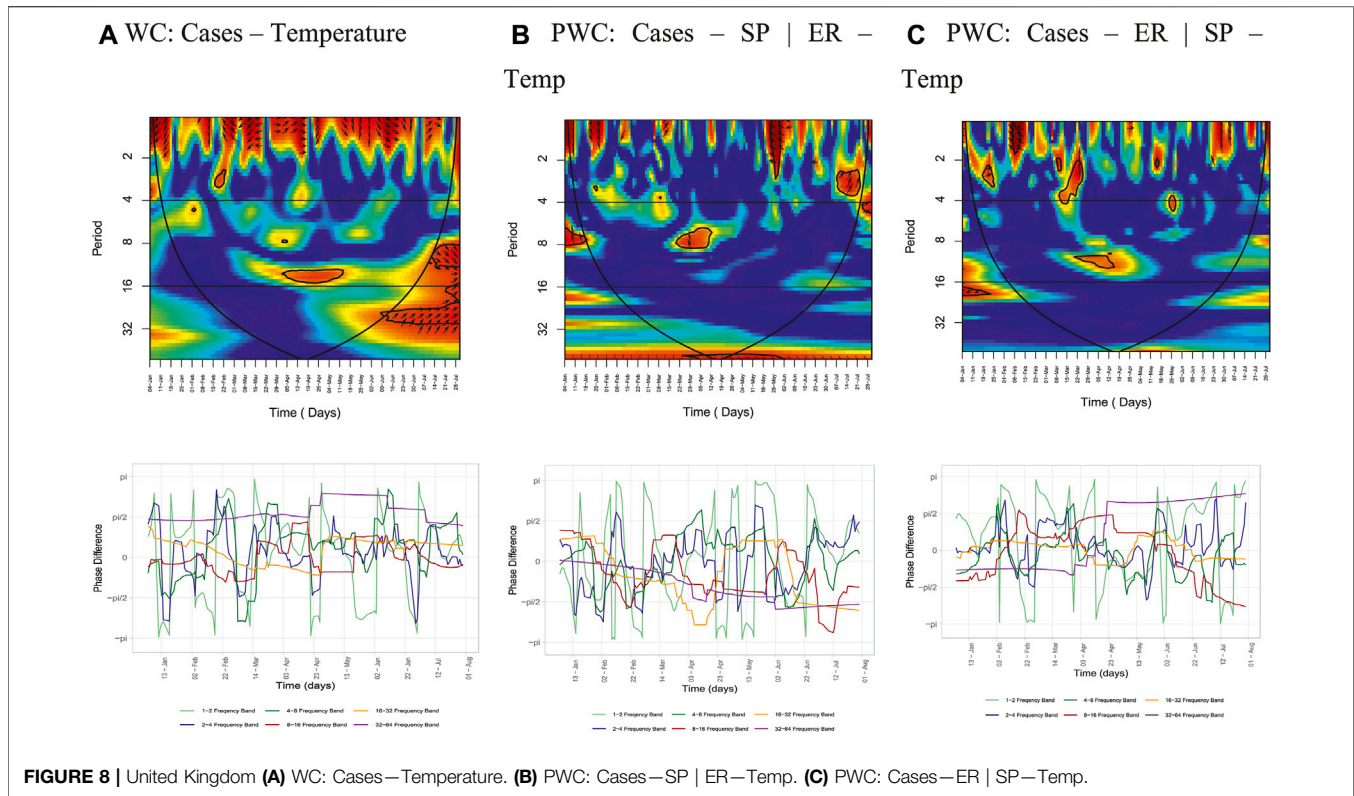
FIGURE 7 | Japan. **(A)** WC: Cases—Temperature. **(B)** PWC: Cases—SP | ER—Temp. **(C)** PWC: Cases—ER | SP—Temp.

As a result, we infer that the spread of COVID-19 had a significant correlation with the temperature of the region/country. However, the directionality of correlation varied in different regions. This aligns with most of the literature reviewed on the same subject (Prata et al., 2020; Tobías and Molina, 2020; Wu et al., 2020). Similarly, co-movements were observed both in the near-term and longer-term between the confirmed coronavirus cases and equity returns in the PWC between the two while conditioning for Forex yields and temperature. Anti-cyclical and cyclical patterns between the variables were evident, and COVID-19 had prolonged ramifications on equity returns in G7 nations. This is supported by material connectedness shown at low frequencies. Further, we infer that the confirmed coronavirus-infected cases and the equity indices of G7 nations showed an out of phase relationship indicating that the surge in the confirmed coronavirus-infected cases resulted in G7 investors estimating a long global lockdown to curtail the spread. This, in turn, slowed down investment and capital infusions resulting in slowing down or stopping otherwise self-sustaining economic cycles. The G7 countries constitute 39% of the global market cap. Like the rest of the world, the stock markets of these G7 nations fell as lockdowns were announced globally.

The volatility, measured as beta, experienced during this time frame was much higher than usual, as opined by many other authors (Narayan et al., 2020; Narayan et al., 2021; Zhang et al., 2021). The numerous reasons that exacerbated the higher volatility triggered by COVID-19 included nationwide lockdowns, increasing unemployment, plummeting consumption, unavailability of blue-collar workers, artificial clogging of the supply chain channels, and the mellow financial markets (Sharma et al., 2020). The equity stock markets (Harvey, 1989) mirrored the ground conditions and fluctuations of the real economy during the pandemic. Nonetheless, our empirical results are contradicted by a few authors who opine that the impact of COVID-19 is a short-term one (H. Liu et al., 2020), and it will reverse on its own. Assuming January 1 to be the start date, the leading indices of the G7 nations fell close to 35% by March 23, 2020. On an annualized CAGR basis from January 1, 2020 to August 24, 2021, these indices have given a return of ~10% (Yahoo, 2021). Our results agree with the findings of a few authors (H. Liu et al., 2020). The importance of the negative impact of the surge in coronavirus infections on equity market movements in G7 nations is emphasized in these findings. In line with a few others, we observed that short-term correlation among confirmed COVID-19 cases in the United States and the S&P 500 was significant in all-time frequencies (Sharif et al., 2020). Ever since the major drop in March 2020 in the equity markets and the American Federal Reserve, USFED's expansionary quantitative easing policies led to a major reversion in equity prices (Thorbecke, 2020). The rally in the indices of G7 nations was fueled due to the easy money and liquidity in the markets instead of the improvement in the fundamentals in the underlying trades (Rebucci et al., 2020). A few have stated that the variation in returns in each country has been directly correlated with the intensity of the outbreak in the respective country (J. Liu et al., 2020). By March 23, 2020 YTD, the S&P 500 was down by 37%,

FIGURE 8 | United Kingdom **(A)** WC: Cases—Temperature. **(B)** PWC: Cases—SP | ER—Temp. **(C)** PWC: Cases—ER | SP—Temp.

the S&P/TSX Composite Index for Canada had lost 34%, the French CAC was down by 35%, the German DAX was down by 34%, and the Italian IT40 had lost 34% in line with the other G7 nations while the Nikkei 225 of Japan was down 28% YTD. The fall in equity markets resonated with the gloomy investor opinion, plummeting by greater margins than the United States Sub-Prime financial crisis of 2008 (Mazur et al., 2021). It has been projected that the recovery in the economy will be slow in the G7 nations as it will be for the rest of the world. The impact of the COVID-19 pandemic has been forecasted to be very persistent and negative (Foroni et al., 2020; UNCTAD, 2020). The slowdown in commercial activities results in large-scale unemployment rendering a multiplier impact on the consumption and other wings of the economy. This has a negative bearing on the financial and commodity markets and a similar impact on private capital formation as well (Ruth Lea, 2021).

PWC between the exchange rate return and the number of confirmed COVID-19 cases in G7 nations after conditioning for temperature and equity market returns points towards the fact that there is a positive correlation in both short and long term in the sample period amongst COVID-19 cases and the Forex yield. Both anti-cyclicality and cyclicality are observed between the variables. The COVID-19 pandemic has resulted in huge swings in the currency markets as well. Since the beginning of the pandemic in 2020, the dollar has strengthened, and despite the central banks speaking to soften their QE plans, the USD is expected to strengthen further after a short pause (Reuters, 2021; Salisu et al., 2021). The instability of the Euro exchange rate can be reversed by the currency revival and a revival of the economic

activities in the Euro-zone (Neykov and Robert, 2021). Material connectedness at low frequencies shows a prolonged correlated impact on the G7 currency exchange markets with confirmed COVID-19 cases. A global foreign direct investment where the G7 nations have a major share fell to a third at $1 trillion of its earlier value. Further, it is estimated that the economic losses behest global disasters was estimated to be at $200bn in 2020 versus $150bn in the previous year (UNCTAD, 2020, 2021).

Small and developing economies gain from the depreciation of their currencies against the USD, impacting United States exports and domestic production (Bruno and Shin, 2020). Authors evaluating the Forex pairs of the United States dollar and the Great Britain pound, the United States dollar and the Turkish Lira, and the United States dollar and the Brazilian real concerning COVID-19 state that correlation between the scare of the pandemic as shown in the media and the currency exchange markets is less than 1 (Goodell, 2020; Gunay, 2020). Our results elucidate the effect of a continual rising number of cases of COVID-19 in the G7 nations impacting the volatility in currency exchange markets. The appreciation of the United States dollar during the beginning of the novel coronavirus pandemic may adversely impact the already fragile international trade (Aizenman et al., 2021). The currencies of advanced economies (United States dollar, Japanese Yen, Euro) are appreciated over the emerging economies' currencies (OECD, 2020; AsadUllah et al. 2021). The lockdowns over this period exacerbated the situation. The severely impacted European nations of Italy (G7) and Spain were impacted the worst (Dillon, 2020).

In March 2020, the United States infections began to increase, a similar situation can be observed right now. Earlier, the scare induced increased cash withdrawals from banks in the United States to tide rising uncertainty and movement limitations. This coupled with a weakened consumption level led to the Yen's USD appreciation (Koichi Hamada, 2020). With the rising cases in the current scenario, ceteris paribus, an encore of a similar round of appreciation can be envisaged.

CONCLUSION

To investigate the relationship amongst the number of confirmed cases of COVID-19, stock market return, currency exchange rates, and temperature, we applied methodologies of biwavelet and partial wavelet coherence. Lead-lag interactions were easier to find in the time-frequency domain using the wavelet-based technique. Additional support for the claims presented in the paper is now provided by this study, which incorporates the wavelet coherence approach to examine the unpredictable repercussions of the pandemic on currency exchange rates, temperature, and stock market returns in G7 countries.

The current research is a distinct evaluation of the economic effect of COVID-19 in the G7 countries. The significance, relevance, and need for such evaluation research are accentuated by Goodell (2020) and Villarreal-Samaniego (2020). We arrived at the following results, 1) temperature levels and confirmed COVID-19 cases are cyclically correlated: Indicating daily temperatures have a material bearing on propagating the novel coronavirus in G7 nations; 2) the noteworthy correlation at truncated frequencies shows that a material long-term impact has been observed on exchange rates and stock markets returns of G7 countries and confirmed COVID-19 cases; 3) accounting for the influence of temperature and equity market returns, a more robust co-movement is observed between the exchange rate returns of the respective nations and the surge in COVID-19 cases; and 4) accounting for the influence of temperature and exchange rate returns, the increase in the confirmed number of coronavirus-infected cases and equity returns' co-movements are more pronounced.

We have some important novel policy and implementation implications to provide. Society, governments, financial institution professionals, and individual investors are concerned about the fiscal and economic repercussions of the COVID-19 epidemic. The portfolio administrators must adjust the portfolios they manage to minimize the volatility and methodical risk of the COVID-19 spread. When compiling a time-frequency chart of the COVID-19 outbreak, oil prices, geopolitical risk, economic uncertainty, and the stock markets of G7, it is demonstrated in the article written by Sharif, Aloui, and Yarovaya (2020) that the key source of uncertainty for United States policymakers is the likelihood of the pandemic outbreak. To meet this global challenge, organizations like the World Bank, the World Trade Organization, and all national governments and their corresponding central banks and other government officials will need to collaborate at the national and global level.

This paper has significant potential for future research since it is beginning to consider the pandemic issue. Temperature data are only gathered for the capital city of each country, and this may not accurately represent the country's climate trends. Future studies will conquer this shortcoming. For a specific set of observed motions, substantial co-movements are usually present. The factors that explain these co-movements are identifiable. The findings can be applied to many microeconomic factors, such as fiscal policy, gross domestic product (GDP) progress, industrial production, national income, and employment.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: https://ourworldindata.org/grapher/daily-cases-COVID-19 https://in.finance.yahoo.com www.ncei.noaa.gov/access/search/data-search/global-summary-of-the-day.

AUTHOR CONTRIBUTIONS

SS conceptualizes the idea of the paper, analyzed the data, and interpreted the result. PB Analyzed the data and written the methodology part of the manuscript. NB Written the introduction and Literature review. AA has written the discussion and conclusion.

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