Received: 11 October 2021 | Revised: 25 February 2022 | Accepted: 5 May 2022

DOI: 10.1111/imig.13026

ORIGINAL ARTICLE

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Exploring the co-movements between COVID-19 pandemic and international air traffic: A global perspective based on wavelet analysis

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Funding information
No funding was received for this work.

Abstract

The travel and tourism industry was one of the fastest-growing industries before the onset of the COVID-19 pandemic. However, to avoid COVID-19 spread, the government authorities imposed strict lockdown and international border restrictions except for some emergency international flights that badly hit the travel and tourism industry. The study explores the nexus between international air departures and the COVID-19 pandemic in this strain. We use a novel wavelet coherence approach to dissect the lead and lag relationships between international flight departures and COVID-19 deaths from January 2020 to September 2020 (COVID-19 first wave period). The results reveal that international flights cause the spread of COVID-19 spread during May 2020 to June 2020 worldwide. The overall findings suggest asymmetries between daily international flight departures and COVID-19 deaths globally at different time-frequency periods due to uncertainty surrounding the COVID-19 pandemic. The study will be conducive for the policymakers to control the upsurge of COVID-19 spread worldwide.

INTRODUCTION

The COVID-19 pandemic has been affecting billions of people around the world. It has impacted all aspects of social life, as well as the weather and environmental conditions (Ali et al., 2021; Irfan et al., 2021; Shahzad et al., 2020a, 2020b; Shuai et al., 2022). It has also significantly affected the performance of many economic sectors worldwide, such as the stock markets, insurance, banking industry, foreign exchange and crypto markets, travel and tourism industry (Iqbal et al., 2021; Shahzad et al., 2020a, 2020b; Yan et al., 2022). However, transportation is one of the sectors that has been so severely affected by the pandemic, as well as other modes of transport such as walking, driving, public transportation, aviation, taxi and cruise ships (Baker et al., 2020; Bucsky, 2020; De Vos, 2020; Hadjidemetriou et al., 2020; Ito et al., 2020; Nian et al., 2020). The restrictions laid by governments and the fear of contracting the virus as a result of a pandemic can be considered the main reasons for the huge impact of the pandemic on the transportation sector (Abu-Rayash & Dincer, 2020). Transportation is regarded as a crucial factor in supporting human civilization and commerce (Dube & Nhamo, 2020). It is also important to note that mobility at the global scale has experienced an increasing trend over the last decade, surpassing global world population growth (Abu-Rayash & Dincer, 2020). However, the aviation sector has been considered a key factor in human development as it enables people to reach each other in a short period of time (Nhamo et al., 2020). The aviation sector makes a significant contribution to the world economy as the net worth of this sector is around US$ 2.7 trillion, and more than 65 million people work in the sector (ICAO, 2019). So, the impact of the pandemic on the aviation sector has indirectly influenced other sectors, including tourism, hoteling and entertainment, besides the economic situation of many people in the society. Figure 1 shows the trend of daily COVID-19 deaths and international air departures worldwide. It is evident that the number of international air departures plummets considerably since March 2020, as the number of daily COVID-19 deaths increased. One reason for that can be the restriction towards air travelling in order to restrain the pandemic transmission.

Many studies show that restricting air travel is a useful strategy for preventing the spread of coronavirus (Chu et al., 2020; Craig et al., 2020; Daon et al., 2020; Lau et al., 2020; Linka et al., 2020; Murphy et al., 2020; Wilson

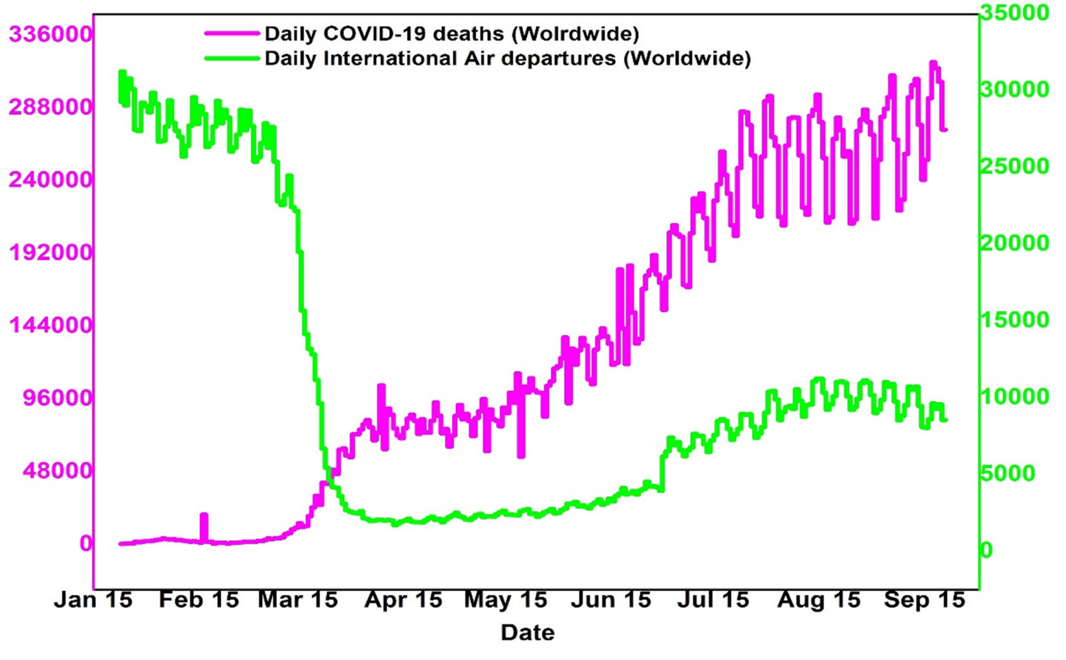

FIGURE 1 Time trend of COVID-19 and international air departures worldwide

et al., 2021; Zhang et al., 2020a), and as a result, the government has imposed restrictions on air travel to curb the spread of the virus. The other reason is the significant dependency of the air travelling industry on pandemic outbreaks in the past, like SARS and MERS in 2003 and 2015, respectively (ICAO, 2019). Besides, the aviation sector is sensitive to internal and external shocks, whether the shocks come from humans or nature (Senbeto & Hon, 2020). Accordingly, as the pandemic worsens, the aviation sector will be influenced severely, and during the coronavirus pandemic, air travel becomes a challenge for governments, travellers and airlines (Bielecki et al., 2020). More evidence of the pandemic impact on the aviation sector will be presented in the following. Air travel has been declining since March 2020 (Iacus et al., 2020; Suau-Sanchez et al., 2020). Air travel restrictions affect air passengers, airports, airlines, tourism and trade. As a result of the pandemic, passengers have decreased by 57%–61% compared to 2019. In addition, airport revenue is down 104.5 million$ in 2020 compared to 2019. Airline revenues fell by 54.7% in 2020. It is reported that airlines will bear a loss of $118 billion in 2020 worldwide. As mentioned earlier, the effects of a pandemic on the aviation sector are not limited to the aviation sector, and it has also influenced other sectors. For instance, tourism and trade are also affected by restrictions due to the coronavirus.

For example, tourism sector revenues are projected to decline by $910 billion to $1170 billion in 2020 compared to 2019, and global trade is also projected to decline by 13% to 32% in 2020. The crisis also significantly impacts the different types of active fleets. As shown in Figure 2, the number of active regional jets, single-aisle jets and twin-aisle jets has declined significantly in 2020 compared to 2019.

Figure 3 shows the commercial and total flights trend from January 2020 to March 2020. It is clear that the number of commercial and total flights declined sharply from mid-March. As it is evident from the statistics on tourism sector has also been influenced so severely by the pandemic. Many studies claim that the pandemic affects both behaviours and the mental welling of tourists (Aman et al., 2019; Bauer et al., 2021; Park et al., 2019). Accordingly, as the risk of transmission of virus soar during travel, they tend to postpone travel plans (Avery, 2017; Mamirkulova et al., 2020; Meadows et al., 2019). Besides, without an effective vaccine, tourist travel can increase the risk of infectious and worsen the pandemic (Hu & Zhang, 2014; Reynolds & Seeger, 2005; Tonsaker et al., 2014; Zhong et al., 2021). So many governments find travel restrictions effective in curbing the spread of the disease (Gössling et al., 2020; Ioannides & Gyimóthy, 2020; Kallbekken

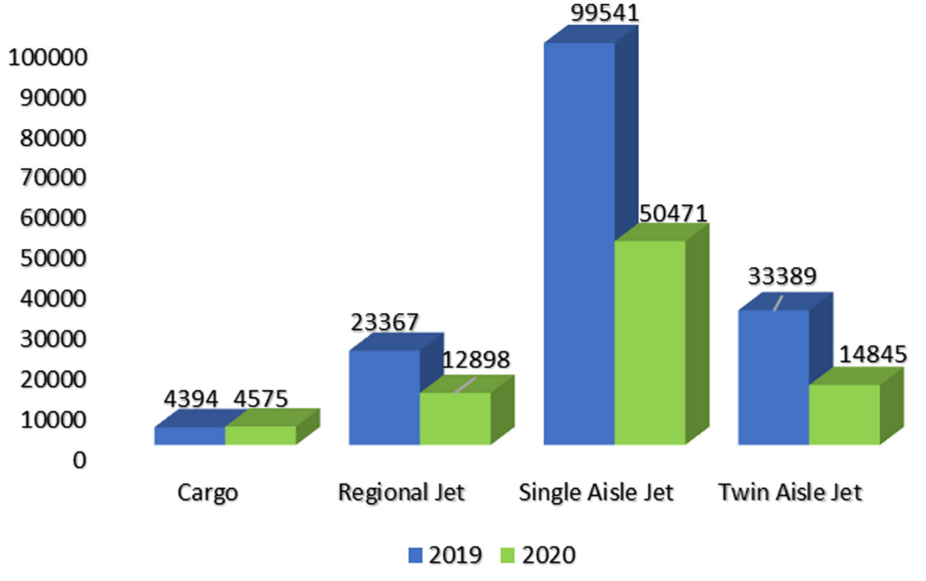

FIGURE 2 Active fleet comparisons by aircraft types due to COVID-19 *Source*: International Civil Aviation Organization (ICAO)

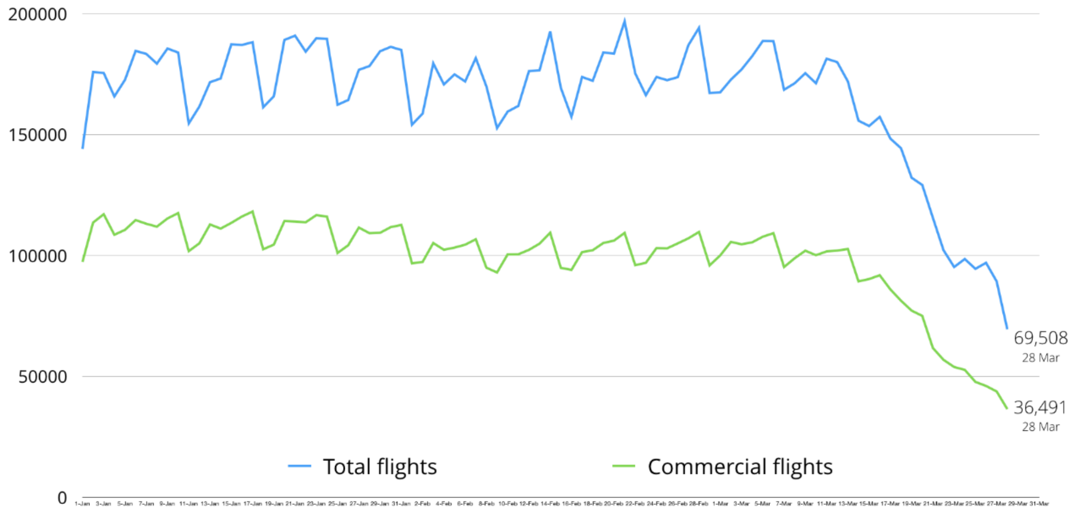

FIGURE 3 Daily time trend of commercial and total flights during Jan–mar 2020
Source: https://www.flightradar24.com/

& Sælen, 2021; Li et al., 2018). These are the reasons why the COVID-19 outbreak is wreaking havoc on the tourism industry.

It is also worth noting that Coronavirus coronavirus's impact on the aviation sector may also affect global GDP and job losses (Iacus et al., 2020; Sobieralski, 2020). Hence, the coronavirus significantly impacts the aviation sector, other related sectors and the whole economy.

Accordingly, in this paper, we aim to investigate the impact of the COVID-19 pandemic on international air travel departures using a bivariate wavelet approach. After applying the wavelet transform, we estimate the wavelet coherence between two series to understand the interdependence and possible contagion effect between the COVID-19 new death and international air travel. The results reveal the contagion effect between COVID-19 daily deaths and international air travel from May 2020 to June 2020. To the best of our knowledge, this study is the first to investigate the empirical relationship between COVID-19 pandemic and international air travel (international air departures) for the global data. The study's theoretical framework is presented in Figure 4, which tells how COVID-19 impacts the travel and tourist industry segments.

The remainder of this paper is organized as follows: Section 2 present a brief literature review on the impact of the aviation sector, Section 3 explain the methodology that is used in the study, Section 4 describes the data that is used in the study, Section 5 explain and discuss the results, and finally, Section 6 presents the conclusions and policy-making implications.

LITERATURE REVIEW

Up to this date, many studies addressed the influence of the COVID-19 pandemic on the air travelling around the world and how governments react to that, and the literature on this issue is expanding. For instance, Monmousseau et al. (2020) examined the effect of the COVID-19 pandemic on the United States airline industry by estimating indicators to show the relationship between passengers and airliners during coronavirus pandemic, and their results indicated that every airline treats their passengers differently due to coronavirus restrictions. Iacus et al. (2020) investigated the travel ban's impact due to the COVID-19 pandemic on the aviation sector and whole economy by developing a forecasting model. They found that aviation losses could negatively impact the global GDP and employment. Abate et al. (2020) explored the willingness of movements to support the air transport sector following

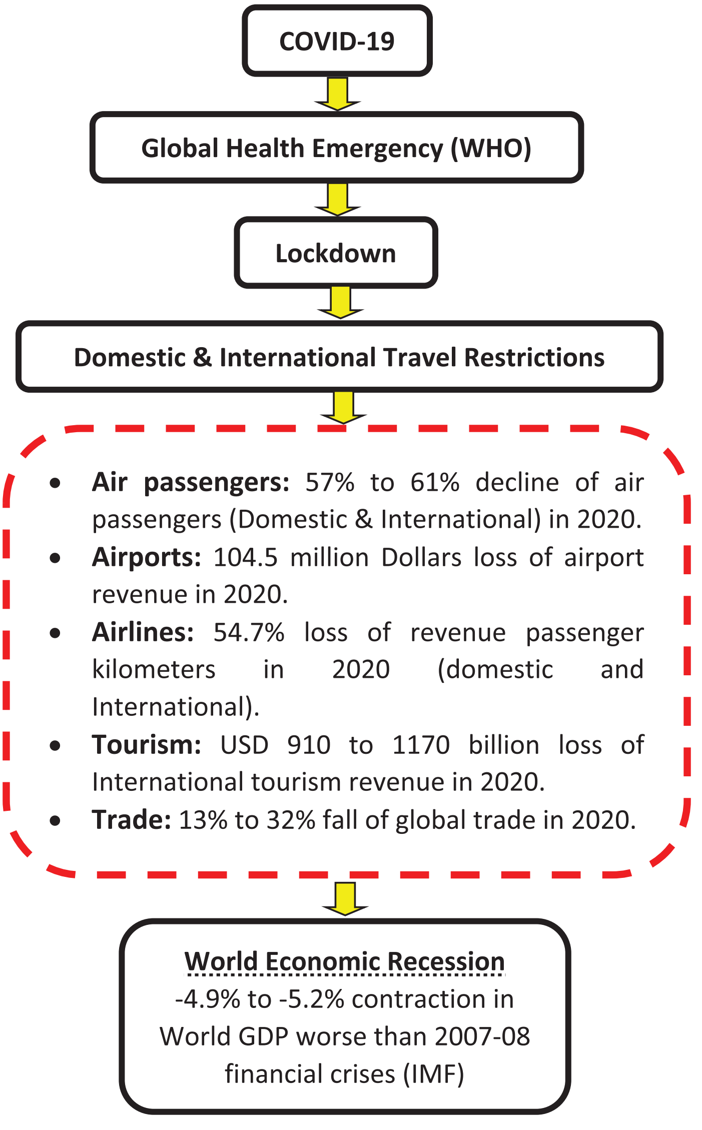

FIGURE 4 Theoretical framework: COVID-19 economic impact due to international travel restrictions

the COVID-19 pandemic and which factors affect that support. They found that some factors like GDP and the number of employees is essential in the willingness of the government to support this sector. Besides, they found that most governments are willing to support the air transport sector. Lamb et al. (2020) investigated how the COVID-19 pandemic affects the business and air travellers' willingness to fly by conducting the survey. The results indicated that fear from the COVID-19 threat negatively affects the willingness to fly. Santos et al. (2021) investigated the impact of the COVID-19 pandemic on the air travel demand by employing a two-step regression methodology, and their results indicated that short and low-density routes are influenced the most in the airline market. In addition, the business routes are also impacted more intensely than leisure routes. Besides, their results indicated that the market with higher social inclusion experienced a greater decline in demand during the COVID-19 pandemic.

Warnock-Smith et al. (2021) explored the effect of the COVID-19 pandemic on Chinese air passenger markets through time in terms of offered airline seats, airline revenues and airport frequencies. Their results indicated that air carriers had been influenced differently by the COVID-19 pandemic. The results indicated that the airlines that are less well-financed and their network focus on international markets and discretionary leisure travel had been influenced the most by the COVID-19 pandemic. Suau-Sanchez et al. (2020) investigated the impact of COVID-19 on the aviation sector using the interview method. They found that this crisis makes the aviation sector smaller. The recovery from the crisis is slow for full-service network carriers. In addition, large airports are the big winners, and regional and secondary airports are the big losers of the crisis. Lau et al. (2020) investigated the interaction between domestic COVID-19 cases and domestic and international passenger volume; their results indicated that there is a strong linear correlation between international COVID-19 cases and passenger volume worldwide. Besides they argue that along with volume of passenger's number of routes should be considered a risk factor for the spread of coronavirus.

Nhamo et al. (2020) examine the impact of the COVID-19 pandemic on the aviation sector employing critical document analysis, and their empirical results indicated that COVID-19 impacts the sector severely and costs its billions of dollars worldwide. Pandemic also led to job losses across aviation sectors and related sectors due to some reasons, including a reduction in revenues, fixed costs increased costs. In addition, some policies are perused to mitigate the impact of the pandemic on the aviation sector, including giving bailout funds, tax deferment, provision of grants and offering low-interest loans.

Hotle and Mumbower (2021) investigated the impact of COVID-19 on domestic U.S. air travel operations. Their results indicated a 71.5% decrease in performed departures in May 2020 compared to May 2019. Besides, they found that the reduction in domestic air services is not the same amongst airlines. Airlines reduced their departure operation at non-primary airports less than larger airports. In general, large airports and airports in multi-airport cities suffer more severely from the crisis.

Choi (2021) investigated the impact of the COVID-19 pandemic on airport operating procedures. He claims that as a result of the crisis aviation industry faces changes in the management environment. He also mentions that airport operation changes are inevitable as safety will be the top priority after the COVID-19 crisis.

In addition, many studies also investigate the impact of the COVID-19 crisis on the tourism sector (Abbas et al., 2021; Bakar & Rosbi, 2020; Baum & Hai, 2020; Del Valle, 2020; Foo et al., 2021; Jaipuria et al., 2021; Korinth & Ranasinghe, 2020; Kumar & Nafi, 2020; Kuqi et al., 2021; Sah et al., 2020; Škare et al., 2021). For instance, Bakar and Rosbi (2020) investigated the effect of COVID-19 on the tourism industry worldwide using supply and demand analysis, and their result indicated that COVID-19 lowered demand in the tourism industry because of the implemented lockdowns. They claim that lower demand resulted in lower demand prices affecting the tourism industry negatively based on the supply–demand equilibrium. Škare et al. (2021) investigate the impacts of the COVID-19 pandemic on the tourism industry worldwide by employing the panel structural vector auto-regression (PSVAR) approach. Their results indicated that the impact of the COVID-19 pandemic crisis on the tourism industry is different and more destructive than the former pandemic crises. Besides they claim that the recovery of the industry will take more time than what has been expected. They also suggest that tourism managers should consider new risk management methods and precisely evaluate the impact of COVID-19 crisis to deal well with the pandemic.

METHODOLOGY

The Wavelet methodology is developed in engineering sciences. It has applied to other fields of science like finance and economic and environmental studies (Fareed et al., 2020; Fareed & Iqbal, 2020; Habib et al., 2021; Iqbal et al., 2020; Madaleno & Pinho, 2012; Matar et al., 2021; Saiti, 2012; Vacha & Barunik, 2012) to investigate the comovement and contagion in time series. This method is an alternative to time series and frequency domain methods (Saiti et al., 2016). This method converts the data into data frequency components with a resolution fitted to its scale. This method is useful in dealing with nonstationary series. There are both discrete and continuous versions of the wavelet method; however, we focus on the continuous wavelet method in this study. Accordingly, in this study, we apply the wavelet coherence method under continuous wavelet transform that is developed by (Grinsted et al., 2004; Torrence & Compo, 1998) to study the comovement between COVID-19 death and international air travelling. The continuous wavelet transform of time series is a function of time and scale, and it is obtained by projecting a mother wavelet ψ onto the examined time series. The continuous wavelet transform $W_x(\tau, s)$can be defined as follows:

$$W_x(\tau, s) = \int_{-\infty}^{\infty} x(t)\, \psi \frac{1}{\sqrt{s}}((t-\tau)/s)\mathrm{d}t \tag{1}$$

s shows the position of the wavelet in the frequency domain, whilst τ shows the position of the wavelet in the time domain. $x(t) \in L^2(R)$. $\frac{1}{\sqrt{s}}$ is the normalization factor. Finally, ψ is the mother wavelet. The most common choice for choosing the mother wavelet is the Morlet wavelet. Furthermore, it can be defined as follows:

$$\psi_{w0}(t) = \pi^{(-1/4)e^{jw0t}} e^{\left(-\frac{t^2}{2}\right)} \tag{2}$$

After transforming the time series, we can find the wavelet power spectrum for variables. The wavelet power spectrum can be defined as follows:

$$(\mathrm{WPS})_x(\tau, s) = \left|W_x(\tau, s)^2\right| \tag{3}$$

The wavelet coherence is a bivariate framework that the interaction between two time series, and it can be defined as follows:

$$R_n^2 = \frac{\left|S\left(s^{-1}W_n^{xy}(s)\right)\right|^2}{S(s^{-1}\left|W_n^x(s)\right)\right|^2 \times S(s^{-1}\left|W_n^y(s)\right)\right|^2} \tag{4}$$

R_n^2 is ranging from 0 to 1. As R_n^2 is getting closer to one (zero), the comovement becomes stronger (weaker). s is wavelet scale, W_n^y and W_n^x are the continuous wavelet transform of the time series x and y. $W_n^{xy}(s)$ is a cross wavelet transform of the two-time series x and y and finally $S$is a smoothing operator (Grinsted et al., 2004; Madaleno & Pinho, 2012; Ranta, 2013; Torrence & Compo, 1998). The smoothing operator can be defined as follows:

$$S\,(W) = S_{\mathrm{scale}}\left(S_{\mathrm{time}}\left(W_n(s)\right)\right) \tag{5}$$

S_{scale} and S_{time} are the smoothing along the wavelet scale axis and time, respectively (Grinsted et al., 2004; Madaleno & Pinho, 2012).

In addition, we can find the wavelet coherence phase differences that can give us some information about the lead /lag relationship between two variables. The wavelet coherence phase difference can be defined as follows:

$$\phi_{xy} = \tan^{-1}\frac{\mathrm{imag}\left[S\left(s^{-1}W_n^{xy}(s)\right)\right]}{\mathrm{real}\left[S\left(s^{-1}W_n^{xy}(s)\right)\right]} \tag{6}$$

The arrows on wavelet coherence plots indicate the phase differences. If the arrows are pointing to the right (left), it indicates that variables are in phase (anti-phase), implying that two variables have a positive (negative) correlation. In these situations, both variables none together. If arrows are pointing to down (up), it indicates that variable x (y) leads to variable y (Czerny et al., 2021).

DATA SPECIFICATION

In this study, we employ daily data of COVID-19 new death and international air departures worldwide. The COVID-19 daily data is obtained from the Bing COVID-19 tracker,[1] whilst daily data of international air departures is manually collected from the official website of the International Civil Aviation Organization[2] (ICAO). The data ranges from January 2020 to September 2020. The summary statistics of the data are shown in Table 1. We use a sample of 243 daily observations. The kurtosis and skewness values for data show that the data is not normally distributed. The results of Jarque-Bera and Shapiro–Wilk statistics that are rejected the null hypothesis of normality at a 1% level of significance.

RESULTS AND DISCUSSIONS

Figures 5a,b indicate the continuous wavelet power spectrum of daily COVID-19 death and international air travel, respectively, from scale one (represent 1 day) to scale six (represent 64 days). These figures show the volatility of the time series. The vertical axis shows the frequency component, and the horizontal axis represents the time component. The black contours designated by the thick black line represent a 5% significance level estimated from Monte Carlo simulations. The cone shape represented by a black lining separating dark colour inside to light colour outside is also known as 'Cone of Influence.' COI gives a significant 'edge effect' within its borders. The results that are out of the cone of influence should not be considered. The colour ranges from blue to red, which shows low frequency to high frequency. The blue area (low frequency) in high scales shows the long-term structure of the data, whilst the red area (high frequency) in low scales indicates the short-term structure of the data (Abu Bakar & Masih, 2014).

The time scale decomposition of COVID-19 death shows significant high variations in the frequency ranges (0–4) periods during mid-April to 1st May 2020 and 1st July to 15th September 2020.

The pattern for international air travel is different. We can see very weak variations in the frequency ranges (0–4) and (4–8) during mid-May and from end-June to 15th September. However, a prominent dark red colour inside the black lining shows a significant variation during the (32–64) cycle period from Mid-March to end-March 2020. Again, the findings come from the fact that during March 2020, the COVID pandemic was at its peak, and international flights of more than 20 airlines were suspended worldwide for an uncertain period.[3]

TABLE 1 Summary statistics

Variable	COVID-19	IAT
Obs.	243	243
Mean	127,000	10586.4
SD	101,000	9476.479
Skewness	0.306	1.024
Kurtosis	1.739	2.536
Min	265	1712
Max	318,000	31,267
JB	19.89***	44.72***
Shapiro–Wilk	0.907***	0.786***

***Significance at the 1% level. COVID-19 is the daily new death worldwide. IAT denotes daily international air departures worldwide.

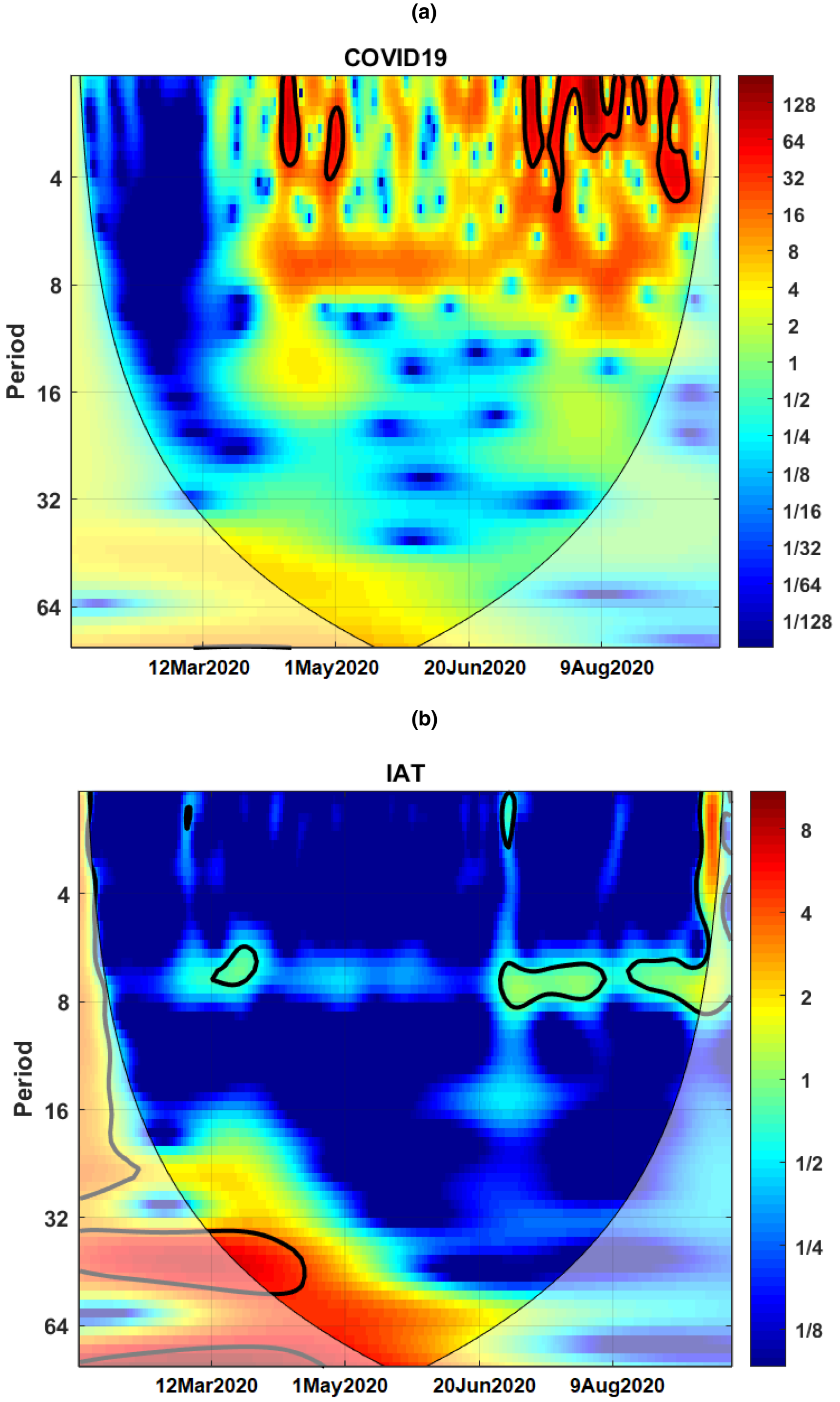

FIGURE 5 Continuous wavelet transforms between COVID-19 and IAT

Figure 6a shows the estimated wavelet coherence and phase difference between worldwide COVID-19 new death and international air travel from scale one (represent 1 day) to scale six (represent 64 days). Contour plots designated by thick black lines show the 5% significance level. The coherency ranges from 0, shown by blue colour

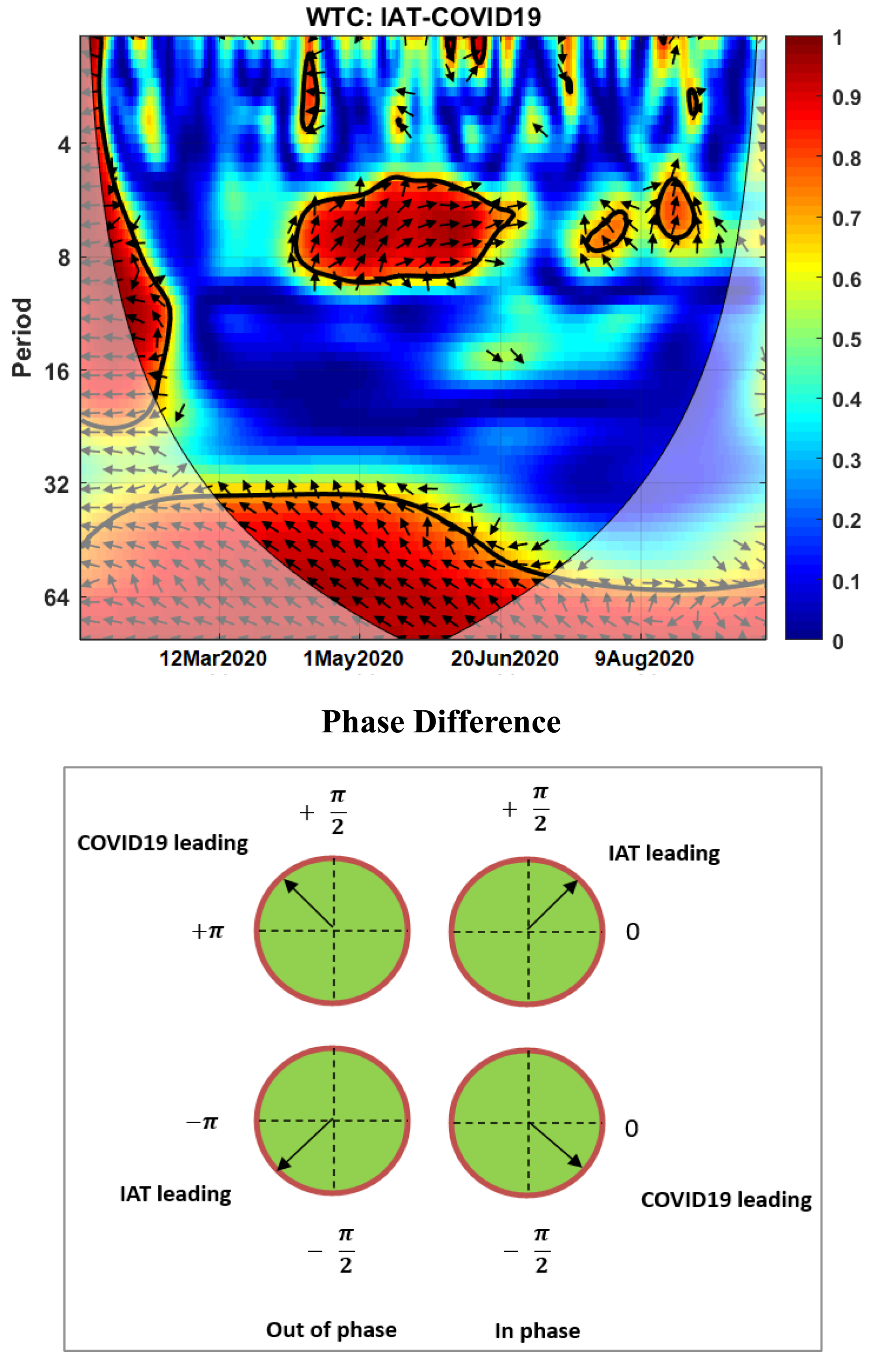

FIGURE 6 Wavelet transforms coherence between COVID-19 and IAT

(low coherency), to 1 (high coherency), represented by red colour. A black line also shows the cone of influence. At lower times scales, the high wavelet coherence between two series can be a sign of contagion.

In contrast, at higher times scales, the high wavelet coherence between two series can be a sign of a fundamental theoretical relationship between two series (Saiti et al., 2016). The results show high coherency amongst COVID-19 and international air travel from January 2020 to September 2020 at a scale of 32–64 days. There seems to be no dependency from January 2020 to September 2020 at scale bands of 8 days to 32 days during whilst sampling period.

On the whole, the wavelet coherence dependency is higher after May 2020. The high wavelet coherence from May 2020 to June 2020 at the scale bands of 4–8 days can be a sign of contagion between COVID-19 death and international air travel. Since May 2020, the international air departures have plummeted significantly, and COVID-19 deaths have increased.

In addition, the phase difference between the two variables can be seen by arrows. The phase difference can help us understand the lead–lag relationship between the two series. Figure 6b represents very useful information about the interpretation of the direction of arrows in terms of describing the lead–lag relationship between variables. We found significant in-phase and out-of-phase coherence between COVID-19 cases and international flight departures in the short, medium and long run. Firstly, we can see some left upward arrows in the frequency ranges (0–4) and (4–8) during the second week of March 2020, which shows out-of-phase coherence (negative relationship) between COVID-19 and international flights departures. In this case, X variable (COVID-19 cases) is leading. In other words, the significantly increasing number of COVID-19 cases cause an unprecedented decline in international air traffic during the second week of March (as Figure 4 also shows the same decline trend). Secondly, many arrows pointing upward in a small island indicate in-phase coherence (positive relationship) between international flight departures and COVID-19 cases at frequency band (4–8) from April to mid-June 2020. In this case, the y variable (International flight departures) is leading, which means that international flights significantly increase COVID-19 cases in the mid-run. The verdicts are similar to the findings of Hanson et al. (2020) and Lau et al. (2020). Thirdly, in the same way, a large number of arrows pointing left upward indicates a significant out-of-phase coherence (negative relationship) between COVID-19 cases and international flight departures in the frequency band (32–64) (long run) during April to mid-June 2020. Finally, we observe two other small islands with very few arrows pointing left upward and right upward, indicating a negative/positive relationship between COVID-19 and IAT during the second and third week of August 2020. The overall findings depict the asymmetric relationship between COVID-19 daily deaths and daily international flight departures at different time-frequency periods due to uncertainty surrounding the COVID-19 pandemic.

CONCLUSION

In the past decade, the tourism industry was booming with continued growth, and it had become one of the fastest-growing industries in the world. However, the global historical growth was severely affected in 2020 due to lockdown, border restrictions and fear of transmitting the virus amid the COVID-19 pandemic. Therefore, to reduce the COVID-19 spread, the government imposes strict criteria to limit the international air departures/arrivals. In this scenario, the study investigates the nexus between daily international air departures and COVID-19 daily deaths between January 2020 and September 2020 (boom time of COVID-19 pandemic). We use a novel wavelet coherence approach to check the lead and lag relationship between international air departures and COVID-19 daily deaths. The results reveal significant coherence between international air departures and COVID-19 deaths. Specifically, the results indicated high coherency between COVID-19 death and international air travel at a scale of 32–64 days from January 2020 to September 2020, implying significant coherency amongst COVID-19 death and international air travel in the long term. Besides, evidence of wavelet coherence dependency between COVID-19 death and international air travel in the short run is found from May 2020 to June 2020.

In addition, the result indicated the negative impact of COVID-19 on international flights departures in the frequency ranges (0–4) and (4–8) during the second week of March 2020, implying that an increasing number of COVID-19 cases lead to an unprecedented decrease in international air traffic (Suau-Sanchez et al., 2020). Furthermore, results show a positive impact of international flight departures on COVID-19 death at frequency band (4–8) during April to mid-June 2020, implying that international flights significantly increase COVID-19 death since in-flight transmission is a typical occurrence (Yang et al., 2020; Zhang et al., 2020a; Zhang et al., 2020b). The overall findings suggest that international air departures cause the spread of COVID-19 deaths asymmetrically at different time-frequency bands in the destination countries. This study provides some useful policy implications for the destinations countries; first, the international border restrictions are the best way to reduce the spread of COVID-19 worldwide. Second, if countries allow some emergency flights, they must adopt strict criteria for scrutinizing international passenger departures and arrivals at airport points. Finally, international passengers should only be allowed to board flights if they are fully vaccinated against COVID-19. Future research can consider other wavelet methods such as partial and multiple wavelet coherences by adding a third variable.

CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

The datasets used during the current study are available on request from the corresponding or first author.

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ENDNOTES

1. https://bing.com/covid
2. https://www.icao.int/
3. https://www.statista.com/statistics/1111989/flights-cancelled-airlines-worldwide-covid-19/

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How to cite this article: Fareed, Z., Ghaemi Asl, M., Irfan, M., Rashidi, M.M. & Wang, H. (2022) Exploring the co-movements between COVID-19 pandemic and international air traffic: A global perspective based on wavelet analysis. *International Migration*, 00, 1–16. Available from: https://doi.org/10.1111/imig.13026