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Article

China's container freight prices on the global behavior of inflation rate after COVID-19

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Abstract: The main objective of this article is to analyze the relationship between increases in freight costs and inflation in the markets due to the increases reflected in the prices of the products in some economies in destination ports such as the United States, Europe, Japan, South Africa, the United Arab Emirates, New Zealand and South Korea. We use fractionally integrated methods and Granger causality test to calculate the correlation between these indicators. The results indicate that, after a significant drop in inflation in 2020, probably due to the confinement caused by the pandemic, the increases observed in inflation and freight costs are expected to be transitory given their stationary behavior. We also find a close correlation between both indicators in Europe, the United States and South Africa.

Keywords: container freight prices; inflation rate; causality; fractional integration; FCVAR model; wavelet analysis

1. Introduction

1.1. Maritime transport and supply chain

Due to the interconnected globalization of world economies, international maritime and logistic industries have been faced with challenges and increased business opportunities. Oliveira et al. (2016) defined the supply chain (CS) "as an aggregate set of value chains linked by interorganizational relationships, both upstream and downstream of the leading company to attend all the flows involved (cash, material, goods and information), from the first supplier of the supplier to the last customer of the final customer, as well as the reverse flow of products and returnable and/or disposable products, generating value for the final consumer and for SC stakeholders", while Mentzer et al. (2001) identified supply chain management (SCM) as the coordination of the chain of events associated with the movement of goods from raw materials to the end customer. Both definitions show that the supply chain consists of a series of relationships to ensure that products and services reach the end customer as suggested by Fawcett and Magnan (2004).

Maritime logistics is considered the main means of transporting parts and finished products on a global scale. Banomyong (2005) referred to the maritime supply chain as an essential system that unites the world territory, since it is an intermediary and inter-carrier that facilitates the commercial flow in the global supply chain (Wong et al., 2011), coinciding with the statement of Cheng et al. (2015), for which maritime trade accounts for 80% in volume worldwide, an argument also defended by Kitack Lim, Secretary General of the IMO (International Maritime Organization), pointing out that it is the "most reliable, efficient mode of transport and profitable, being the main catalyst for the world economy, transporting more than 80% of world trade.".

In the maritime industry, container shipping is one of the most important aspects of the global supply chain (Heilig et al., 2017). Currently, 60% of maritime trade is moved in containers although global container shipping is inefficient and expensive (McFarlane et al., 2016). Nevertheless, it is an essential part of world trade, approximately 4 trillion dollars in goods, machinery, raw materials and food are moved in containers.

The maritime transport sector experienced a notable increase in the number of blank voyages and container ship capacity in the first part of 2020 (Xu et al., 2021). Efficient management by the main maritime transport companies was essential to avoid collapses in freight rates (UNCTAD, 2020). However, the crisis caused by the COVID-19 pandemic resulted in a significant increase in freight rates, reaching levels not previously recorded as a result of the increase in demand and the shortage of containers (Cullinane and Haralambides, 2021).

Government measures to prevent the spread of the pandemic caused great uncertainty in transportation markets. Some authors, such as Yang et al. (2023), demonstrated a broad positive correlation with import trade, but a negative correlation with export trade.

After the pandemic caused by SARS-Cov 2, maritime transport has been part of a new scenario full of changes, which in turn affected other sectors such as the financial market and supply chains. In the Capesize market, an important indicator of the industry, demand began to decline sharply in January 2020, a month before stock markets began to collapse, while demand increased in early March, roughly a month before the Capesize's stock value resumed its upward path, which indicates a strong relationship between the two markets.

In 2022 supply chains have again been put to the test by the developments in Ukraine, and the existing crisis in supply chains has been increased due to the interconnection of world economies and businesses. Dun and Bradstreet (2022) explain that there are fewer than 15,000 Tier 1 providers in Russia. Dig a little deeper, though, and it can be found 7.6 million Tier 2 supplier relationships with Russian entities worldwide. More than 374,000 businesses, 90% of which are located in the United States, rely on Russian suppliers.

1.2. Inflation and maritime transport prices

The relationship between port operations and economic activity has been investigated by authors such as Bottasso et al. (2013) and Deng et al. (2013), whose analysis of 10 European countries showed that efficiency in ports achieved an increase in growth and employment. Shan et al. (2014) focused on Chinese ports, showing that port efficiency increased growth in the country and its neighbors, while low port efficiency is considered to contribute significantly to poor economic results, coinciding with the research carried out by Sánchez et al. (2003), including that port efficiency is a determining factor in freight costs.

The possible relationship between maritime transport and the economic growth of the Caspian Sea countries was analyzed by Akbulaev and Bayramli (2020); their results verified the relationship between the development of maritime transport and the sustainability of economic development. While Khan et al. (2018) managed to demonstrate the influence of container port traffic and per capita income, the UNCTAD reported that in 2020 there was a 10% drop in world maritime trade. The Chamber of Shipping (ICS) values the losses caused by the pandemic for the industry at 350 million dollars per week. Despite this data, container transport prices have quadrupled, causing an imbalance in the market, especially at a time when transport demand exceeds supply. In their report on maritime traffic they expect an average rise of 1.5% until 2023 in relation to pre-pandemic values due to the rise in the cost of maritime transport. The United Nations emphasizes that if the problems in maritime traffic continue, world import prices will increase by 11%, citing as an example how the cost of shipping containers from Shanghai to Europe went from 1000 dollars per TEU (Twenty-Foot Equivalent Unit) to more than 8000 per TEU in mid-2021 and 10,000 by the end of the same year.

The interruption of operations caused by the SARS-CoV2 pandemic would explain the negative figures with the closure of ports, crew replacement problems and changes in protocols to minimize contagions, producing a bottleneck when China rapidly increased its production due to the shortage of containers, caused by the lack of production during confinement and especially by the unexpected increase in demand in the United States and Europe, for which hundreds of containers were left waiting in these ports.

Freight prices have skyrocketed since the second half of 2020; in October 2021 maritime transport price indicators had increased by more than 500 percent compared to pre-pandemic prices, while the cost of Shipping of bulk products by sea had tripled (Carrière-Swallow et al., 2023).

This increase occurs for two main reasons: on the one hand, the increase in demand for inputs, thanks to greater manufacturing activity, increased the demand for container shipments, while on the other hand, shipping capacity was strongly affected. limited by logistical bottlenecks due to the pandemic and the shortage of containers. These issues led to increased surcharges and fees, including demurrage and detention fees (Smialek and Nelson, 2021).

The prices of the main basic products such as oil, iron, coal and cereals have begun to rise due to a gradual improvement in demand, which led to an increase in the volume of cargo in the first half of 2021. Part of the transport costs have passed on to consumers through higher prices, which produces inflationary pressures. Using a structural vector autoregressive model (SVAR), Herriford et al. (2016) estimated this effect. The analysis showed that a 50% annual increase in the Harpex (Harper Petersen Charter Rates Index) could increase PCE (Personal Consumption Expenditures) inflation by as much as 0.25 percentage points a year later.

More than 500 ships being stuck in ports around the world in the last quarter of 2021 aroused the concern of the main distribution companies. In 2022, the President's Economic Report included a chapter on supply chains, stating that product disruptions and shortages made the public painfully aware of what a production chain entails (President's Economic Report, 2022). These problems are reflected in an increase in the price of goods by sea between countries, increasing up to seven times during the pandemic.

The simultaneous increase in the price of freight transportation and import prices is examined in various studies on the relationship between the two. Swanson (2022) analyzed the statements of the United States Secretary of Transportation about how the shortage of maritime transportation would put upward pressure on prices. Some researchers view this price increase as a bubble, considering it as an important phenomenon affecting financial and commodity markets (Khan and Köseoğlu, 2020). Stiglitz (1990) defined this concept as an effect in which the market price exceeds the fundamental price. These low levels were followed by a recovery in the second half of 2020 thanks to the opening of Asian economies and the decrease in new cases, while the pandemic boosted consumption and electronic commerce as an alternative source of purchase, increasing demand of shipments (Khurshid et al., 2023).

In addition to all the above, one of the crucial factors in prices are stranded ships, which interrupt supply chains and produce pressure on freight prices (Molaris et al., 2021), this lack of availability of containers results in a higher freight cost, especially from China to the United States and Europe.

1.3. Analysis methods

Grammenos and Arkoulis (2002) applied unit roots and Auto Regressive Moving Average (ARMA) models to investigate the impact on stocks of oil prices, industrial production and inflation. To achieve this, they relied on the performance of the global stock market portfolio and innovations in a set of macroeconomic variables, including inflation. They found that oil prices and stored tonnage are negatively related to the value of transport stocks, while the exchange rate variable shows a positive relationship.

Shan et al. (2014), using data from the 41 main Chinese port cities and their local ports during the period 2003–2010, carried out an analysis on the relationship between port activity and the economic growth of the city. Başer and Açık (2018) also applied unit root tests in a study to determine the asymmetric causal relationship between the Turkish economy and freight rates in the ISTFIX (Istanbul Freight Index). As a result, although causal relationships are expected to exist between negative and positive shocks, only negative shocks matter in the ISTFIX index. These results suggested that negative news in the economy are felt directly in the maritime market, but the impact of the positive news is not quickly reflected.

To examine the impact of port performance on trade, Mlambo (2021) used the ARDL (Autoregressive Distributed Lag) model in three steps, investigating stationarity, cointegration, and the ARDL panel estimation model (Menegaki, 2019). The results showed that port unemployment has a positive effect on trade. Infrastructure investments are necessary to automate and achieve a higher degree of competitiveness.

The studies reflected in this section highlight the need to understand the behavior of freight prices with respect to the economy; for this reason, the objective of this research is to establish the relationship between the costs of maritime transport prices and inflation, especially in a post-pandemic context in which there has been great instability in the economy and maritime transport. Fractional cointegration and Granger causality techniques will allow an exhaustive analysis of the relationship and behavior of both after the pandemic. So, to the best of our knowledge, this is the first paper that proposes the use of advanced statistical and econometric methodologies for this purpose.

The remaining of the paper is as follows: Section 2 focuses on the data and the methodology used, while in Section 3, the results obtained are displayed. Section 4 concludes the paper.

2. Data and methodology

2.1. Dataset

To carry out this research, we use data from Thomson Reuters Eikon. To reflect an accurate price of shippers that have signed long-term contracts with shipping lines that leave from all major ports in China, we use the China Containerized Freight Index (CCFI). This index is a composite of spot rates and contractual rates. Finally, we take the 15 reference ports of this index to study globally how the cost of transport affects the inflation rate in Europe, the United States, the Arab Emirates, New Zealand, South Africa, Japan and South Korea. To study the inflation rate we use the Consumer Price Index (CPI) of each country. We use quarterly data from October 2011 to April 2021. The time series are represented in **Figure 1**.

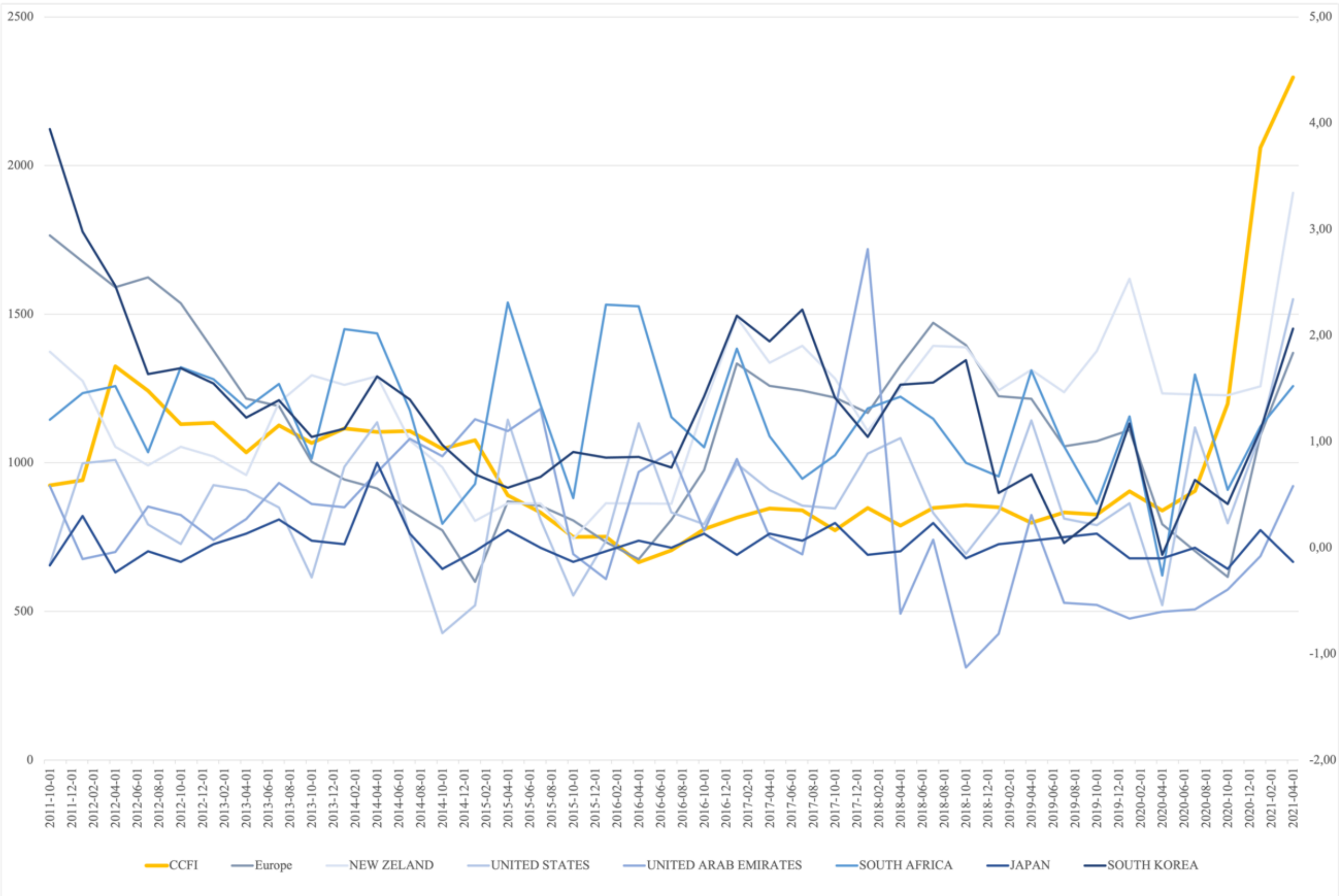

Figure 1. CCFI vs. CPI.

We observe in **Figure 1** that, following a widespread drop in CPIs in 2020 due to the Coronavirus pandemic, demand for goods increased in the second half of 2020 and in 2021, as consumers spent their money on goods during closures and restrictions, according to the report by UNCTAD (2021).

The mismatch between increased demand and reduced supply capacity led to a record rise in freight prices from China. This increase in transport rates is reflected in an increase in consumer prices in the receiving ports, which might have caused a slowdown in national economies with an increase of 1.2% in the United States and of 1.4% in China (UNCTAD, 2021).

2.2. Granger causality tests

To examine the direction of causality between two stationary series x_t and y_t, the Granger causality test is performed after estimating the VAR model. The Granger test consists of a vector autoregressive representation (VAR) consisting of the two series:

$$x_t = a_1 + \sum_{i=1}^{k} a_i x_{t-i} + \sum_{i=1}^{k} \beta_i y_{t-i} + \epsilon_{1t},$$

$$y_t = a_2 + \sum_{i=1}^{k} \gamma_i x_{t-i} + \sum_{i=1}^{k} \delta_i y_{t-i} + \epsilon_{2t}.$$

K represents the lag length of the variables x_t and y_t. The null hypothesis can be tested "*x* is not a consequence of *y*", which can be described as $H_0^1 = \gamma_1 = \cdots = \gamma_k = 0$. The result reflects that the causality goes from y_t to x_t when the null value is rejected; in the same way, in the second case $H_0^2 = a_1 = \cdots = a_k = 0$, the causality from x_t to y_t occurs when the null value is rejected. Both hypotheses can be rejected. The Chi-square distribution has been chosen to perform the statistical tests.

2.3. Unit roots

To carry out the objectives set forth in this research work, the ADF tests are used following the line in Fuller (1976) and Dickey and Fuller (1979) to determine if the time series used are stationary as well as their characteristics. In addition, other methods with higher power will also be employed (Elliot et al., 1996; Kwiatkowski et al., 1992; Ng and Perron, 2001; Phillips, 1987; Phillips and Perron, 1988).

2.4. ARFIMA (*p*, *d*, *q*) model

To study the statistical properties of time series, we follow a mathematical notation where a time series $x_t,\ t = 1, 2, \ldots$ follows an integrated order process d (and denoted as $x_t \approx I(d)$) if:

$$(1 - L)^d x_t = u_t, t = 1, 2, \ldots \tag{1}$$

where any real value is represented by *d*, lag-operator ($Lx_t = x_{t-1}$) is represented by L and I(0) covariance stationary process is represented by u_t and it occurs when the spectral density function is positive and finite at the zero frequency, displaying potentially a type of time dependence in its weak form. So, if u_t is ARMA (*p*, *q*), x_t is then said to be fractionally integrated ARMA, or ARFIMA (*p*, *d*, *q*).

According to the value of the parameter d we can conclude that x_t is anti-persistence, that is when the series exhibiting zero spectral density at the origin and switching signs more frequently than a random process (see Dittmann and Granger

(2002)), when $d < 0$;

x_t is short memory or I(0) when $d = 0$ in (1) because $x_t = u_t$.

x_t is long memory ($d > 0$) when we find a high degree of association which is far distant in time. Related to this latter assumption we say that the process is still covariance stationary if $d < 0.5$ and the interpretation of the result will be related to mean reversion when d has a value less than 1; it represents that it is a temporary effect derived from the shock; on the contrary, when d is equal to or higher than one, it will be a permanent effect.

Geweke and Porter-Hudak (1983), Phillips (1999, 2007), Sowell (1992) carried out different techniques for calculating the degree of long memory and fractional integration.

To carry out the representation of the results, Sowell (1992) and his likelihood technique have been used, while in order to choose the most appropriate ARMA orders (p and q) for the analysis, the Akaike information criterion (Akaike, 1973) and the Bayesian Information Criterion (Akaike, 1979) are used.

2.5. FCVAR model

The Fractional Cointegrated Vectorial Auto Regressive (FCVAR) methodology was studied by Johansen (2008), and later Johansen and Nielsen (2010, 2012) carried out an extension of this research, being the evolution of the model described by Johansen (1996) of the Cointegrated Vector Auto Regressive (CVAR), which has the ability to admit integrated time series of order d and that cointegrate with order $d - b$, with $b > 0$.

Let Y_t, $t = 1, \dots, T$ be a p-dimensional I(1) time series. The CVAR model is:

$$\Delta Y_t = \alpha\beta' Y_{t-1} + \sum_{i=1}^{k} \Gamma_i \, \Delta Y_{t-i} + \varepsilon_t = \alpha\beta' L Y_t + \sum_{i=1}^{k} \Gamma_i \, \Delta L^i Y_t + \varepsilon_t \qquad (2)$$

Δ^b and $L_b = 1 - \Delta^b$, that are the difference and lag operator, is used to derive the FCVAR model. We then obtain:

$$\Delta^b Y_t = \alpha\beta' L_b Y_t + \sum_{i=1}^{k} \Gamma_i \, \Delta L_b^i Y_t + \varepsilon_t \qquad (3)$$

Which is applied to $Y_t = \Delta^{d-b} X_t$ such that:

$$\Delta^d X_t = \alpha\beta' L_b \Delta^{d-b} X_t + \sum_{i=1}^{k} \Gamma_i \, \Delta^b L_b^i Y_t + \varepsilon_t \qquad (4)$$

where ε_t is a term with mean zero and variance-covariance matrix Ω that is p-dimensional independent and identically distributed. As in the CVAR model, the parameters can be interpreted as follows. α and β are $p \times r$ matrices, where $0 \le r \le p$. The relationship in the long-run equilibria in terms of cointegration in the system is due to the matrix β. Control the short-run behavior of the variables depends on the parameter Γ_i. Finally, the deviations from the equilibria and their speed in the adjustment depends on the parameter α.

MATLAB is a programming language widely used in the literature for the development of different mathematical developments such as the FCVAR model (Nielsen and Popiel, 2018); Some of the investigations that have made use of MATLAB are the following: Jones, Nielsen and Popiel (2014) to analyze the relationship between macroeconomic conditions and political support; Baruník and Dvořáková (2015) for the study of the relationship between the maximum and minimum prices of shares; Maciel (2017) also used this approach to forecast and modeling the Brazilian stock market; Aye et al. (2017) to examine hedging of gold inflation in the UK; Dolatabadi et al. (2018) used FCVAR to forecast commodity prices, while Gil-Alana and Carcel (2018) investigated the relationship between five exchange rates to the US dollar.

2.6. Continuous wavelet transform (CWT)

Time series are an aggregation of components operating on different frequencies. So, the most outstanding information is hidden in the frequency content of the signal. For this reason, this methodology makes a lot of sense.

Wavelet coherence and wavelet phase difference have been used to deepen this research in the time-frequency domain. It allows to analyze the interaction of the time series in the time domain and revealing structural changes without the need for it to comply with the stationarity characteristic.

Based on the analysis carried out by Kyrtsou et al. (2009) on the energy markets and nonlinear dependencies, several authors have used nonlinear methods to analyze the impact of oil shocks using wavelet analysis. Other authors such as Aguiar-Conraria and Soares (2014) and Crowley and Mayes (2009) have used wavelets to test and to study business cycle synchronization.

To identify hidden patterns and/or information, we use the wavelet coherency plot that measures the correlation between the time series in the time-frequency domain. To get this result, we calculate the $WT_x(a,\tau)$ that is the wavelet transform of a time series $x(t)$, projecting the mother wavelet ψ to map the original time series onto a function of τ and a:

$$WT_x(a,\tau) = \int_{-\infty}^{+\infty} x(t)\frac{1}{\sqrt{a}}\psi^*\left(\frac{t-\tau}{a}\right)dt \tag{5}$$

We choose Morlet wavelet as the mother wavelet because it is a complex sine wave within a Gaussian envelope, so it permits us to measure the synchronism between time series (Aguiar-Conraria and Soares, 2014).

Taking into account the results that we get using Wavelet Transform, Wavelet Coherence helps us understand how one time series interacts with respect to the other. We can define this term as:

$$WCO_{xy} = \frac{SO\left(WT_x(a,\tau)WT_y(a,\tau)^*\right)}{\sqrt{SO(|WT_x(a,\tau)|^2)SO\left(\left|WT_y(a,\tau)\right|^2\right)}} \tag{6}$$

where the SO parameter represents the smoothing operator in time, being relevant since if it were dispensed with, the wavelet coherence for all scales and times would be one (Aguiar-Conraria et al., 2008). It is possible to find the codes developed with Matlab for the CWT solution on the Aguiar-Conraria website (Aguiar-Conraria, 2011).

3. Empirical results

3.1. Unit roots tests

The statistical properties of the series under study and their differences are analyzed using the Augmented Dickey-Fuller test (Dickey and Fuller, 1979), Phillips and Perrron (1988) and Kwiatkowski et al. Alabama (1992) with the aim of achieving robust results.

Table 1 displays the results, which suggest that CCFI and inflation rates of the series for Europe, New Zealand, South Korea follow a nonstationary pattern. These results suggest that since the hypothesis about the existence of a unit root or nonstationarity behavior is not rejected, the shocks in these cases are permanent. The rest of the variables already have a stationary behavior and therefore shocks will be transitory.

Table 1. Unit roots tests.

	ADF			PP		KPSS	
	(i)	(ii)	(iii)	(ii)	(iii)	(ii)	(iii)
China Containerized Freight Index	0.7798	−0.6807	0.298	0.3715	1.4531	0.1894*	0.1911
CPI_Europe	−1.5965	−2.5192	−2.1732	−2.3867	−1.9094	0.2069*	0.1559
CPI_United States	−2.5507*	−5.1789*	−5.5007*	−4.5945*	−4.7425*	0.3408*	0.0897*
CPI_Arab Emirates	−2.8121*	−3.1144	−3.5442*	−4.0184*	−4.2206*	0.3737*	0.1374*
CPI_New Zealand	−0.1367	−1.6636	−2.7477	−1.7759	−2.6151	0.47	0.1316*
CPI_South Africa	−1.2688	−5.089*	−6.1237*	−6.1002*	−6.9813*	0.4543*	0.0751*
CPI_Japan	−4.3373*	−4.5728*	−4.6087*	−6.5133*	−6.6119*	0.1407*	0.0772*
CPI_South Korea	−1.7972	−3.3118*	−2.7294	−3.985*	−3.3263	0.3915*	0.1088*

(i) Refers to the model with no deterministic components; (ii) with an intercept, and (iii) with a linear time trend. * Denotes a statistical significance at the 5% level.

3.2. Results of long memory tests

Given the low power of the unit root methods under fractional alternatives (Diebold and Rudebusch, 1991; Hassler and Wolters, 1994; Lee and Schmidt, 1996) and in line with the aforementioned methodology, the ARFIMA (p, d, q) models are used in order to analyze the persistence of bunker fuel, the prices of raw materials premiums and indices related to shipping and the market and their prices. To select the AR and MA orders in the models (Note, however, that according to Beran et al. (1998) and Hosking (1981), the AIC and BIC criteria might not be the best criteria under the assumptions of fractional models.), the AIC (Akaike, 1973) and BIC (Akaike, 1979) criteria have been used.

Table 2 shows the estimates obtained for d following the maximum likelihood approach of Sowell (1992). Various ARFIMA specifications (p, d, q) have been considered with all combinations of $p, q \leq 2$ for each time series.

We observe in **Table 2** that the estimates of d in CCFI and inflation rates for several regions are fairly heterogeneous, observing I(0), I(d, $0 < d < 1$) and I(1) patterns across the series. Except for the case of Europe, the values of the parameter d for the time series analyzed are below 1, which might suggest that these variables have mean reversion behavior, with transitory shocks. However, a more exhaustive analysis of the results indicate that the confidence intervals in CCFI and inflation rate in Europe and South Africa include the value of 1, and therefore, we cannot reject the hypothesis of I(1) so the shocks might be permanent in these cases.

Table 2. Results of long memory tests.

Long memory test						
Data analyzed	**Sample size (weeks)**	**Model Selected**	***D***	**Std. Error**	**Interval**	**I(*d*)**
China Containerized Freight Index	39	ARFIMA (2, *d*, 1)	0.54	0.41	[−0.13, 1.22]	I(0), I(1)
CPI_ Europe	39	ARFIMA (0, *d*, 0)	1.14	0.17	[0.86, 1.42]	I(1)
CPI_ United States	39	ARFIMA (0, *d*, 2)	0.18	0.20	[−0.15, 0.52]	I(0)
CPI_ Arab Emirates	39	ARFIMA (0, *d*, 0)	0.27	0.12	[0.07, 0.47]	I(d)
CPI_ New Zealand	39	ARFIMA (0, *d*, 1)	0.18	0.18	[−0.12, 0.48]	I(0)
CPI_South Africa	39	ARFIMA (0, *d*, 1)	0.70	0.19	[0.39, 1.01]	I(1)
CPI_ Japan	39	ARFIMA (0, *d*, 2)	0.22	0.22	[−0.15, 0.59]	I(0)
CPI_ South Korea	39	ARFIMA (0, *d*, 2)	0.46	0.12	[0.26, 0.66]	I(0)

3.3. Results of granger causality test

Once we have studied the statistical properties of each time series, we use the Granger causality test to examine the interactions between containerized freight rates and inflation rates in various regions of the world.

The Granger causality test results are displayed in **Table 3**. The results suggest that there are three regions in which the containerized freight rates from China have caused inflation. These are Europe, United States and South Africa.

Table 3. Results of granger causality test.

Direction of Causality	**Lags (We have used Akaike Information Criterion to detect the number of lags)**	**Prob.**	**Decision**	**Outcome**
d_CCFI → d_CPI_{Europe}	10	0.0317	Reject Null	Freight rates cause inflation
d_CCFI → $CPI_{United\ States}$	10	0.0001	Reject Null	Freight rates cause inflation
d_CCFI → $CPI_{Arab\ Emirates}$	1	0.9328	Do not reject null	Freight rates do not cause inflation
d_CCFI → $d\_CPI_{New\ Zealand}$	9	0.4214	Do not reject null	Freight rates do not cause inflation
d_CCFI → $CPI_{South\ Africa}$	10	0.0000	Reject Null	Freight rates cause inflation
d_CCFI → CPI_{Japan}	11	0.1555	Do not reject null	Freight rates do not cause inflation
d_CCFI → $d\_CPI_{South\ Korea}$	9	0.7014	Do not reject null	Freight rates do not cause inflation

3.4. Results of FCVAR

To study the relationship between time series in the long-run and their co-movements, we use the fractional cointegration VAR model (see Johansen and Nielsen, 2012). The results summarized in **Table 4**.

Following Jones, Nielsen and Popiel (2014) regarding the lag value, we choose k = 3. Also, we consider deterministic components and cointegration rank (r) to get our results. In **Table 4**, we report the results assuming that the coefficients for d and b are supposed to be different. Some evidence of a low order of cointegration is found in the case of the United States ($d = 1.351$ and $b = 1.248$). So, in the US case we cannot reject the hypothesis where the shock duration is mean-reverting in the long-run. For the remaining cases, d is equal to b ($d = b$) supporting the standard cointegration in the sense that the long run equilibrium is $\mathrm{I}(0)$, assuming that the shock duration has a short-lived duration due to its short-run stationary behavior.

Table 4. Results of the FCVAR model.

Series	$\boldsymbol{d = b}$	$\boldsymbol{\beta}$	$\boldsymbol{\alpha}$	$\boldsymbol{\mu}$
Europe	$d = b = 1.412$ (0.173)	Var 1 = 1.000 Var 2 = −1110.236	Var 1 = 0.057 Var 2 = 0.000	-
United States	$d = 1.351$ (0.180) $b = 1.248$ (0.200)	Var 1 = 1.000 Var 2 = −2377.668	Var 1 = −0.005 Var 2 = 0.001	-
Arab Emirates	$d = b = 0.982$ (0.271)	Var 1 = 1.000 Var 2 = −2637.499	Var 1 = 0.036 Var 2 = 0.000	-
New Zealand	$d = b = 1.666$ (0.176)	Var 1 = 1.000 Var 2 = −793.728	Var 1 = −0.003 Var 2 = 0.001	-
South Africa	$d = b = 0.948$ (0.168)	Var 1 = 1.000 Var 2 = −778.193	Var 1 = 0.124 Var 2 = 0.001	-
Japan	$d = b = 0.945$ (0.189)	Var 1 = 1.000 Var 2 = −8539.154	Var 1 = 0.039 Var 2 = 0.000	Var 1 = 747.696 Var 2 = 0.030
South Korea	$d = b = 0.974$ (0.230)	Var 1 = 1.000 Var 2 = 234.175	Var 1 = −0.241 Var 2 = −0.001	Var 1 = 586.645 Var 2 = 2.784

3.5. COVID-19 and continuous wavelet transform

To identify the dependence over time and to study the behavior of the structural change caused by COVID-19, we have calculated the wavelet coherency and phase difference between CCFI and the CPI of Europe, United States and South Africa, which are the regions where inflation has been affected by the containerized freight prices (according to the Granger test). The results are displayed in **Figure 2**.

Panel (a) shows the wavelet coherence that represents the interrelationships between CCFI and the inflation rate of each region. The results reflect how strong the relationship is and how often it occurs. The value 1 represents a quarter, while 4 is the representation of a year, these frequencies are shown on the vertical axis while the analyzed period is represented on the horizontal axe.

Monte Carlo simulations are used in order to identify the high frequency and high coherence with statistical significance of the local correlations in the time-frequency domain, with the black outline showing the regions with significant values at 5%. The time series studied have an understandable relationship through the frequency band represented in panel (b), which reflects the frequency band 1–4.

Focusing on the data from the beginning of the pandemic outbreak in China in December 2019, we observe from **Figure 2** statistically significant coherency in the three results obtained. We observe in the pandemic outbreak a high degree of coherence in the low frequency (short-term) that corresponds to cycles 0.5 to 1.5 quarters.

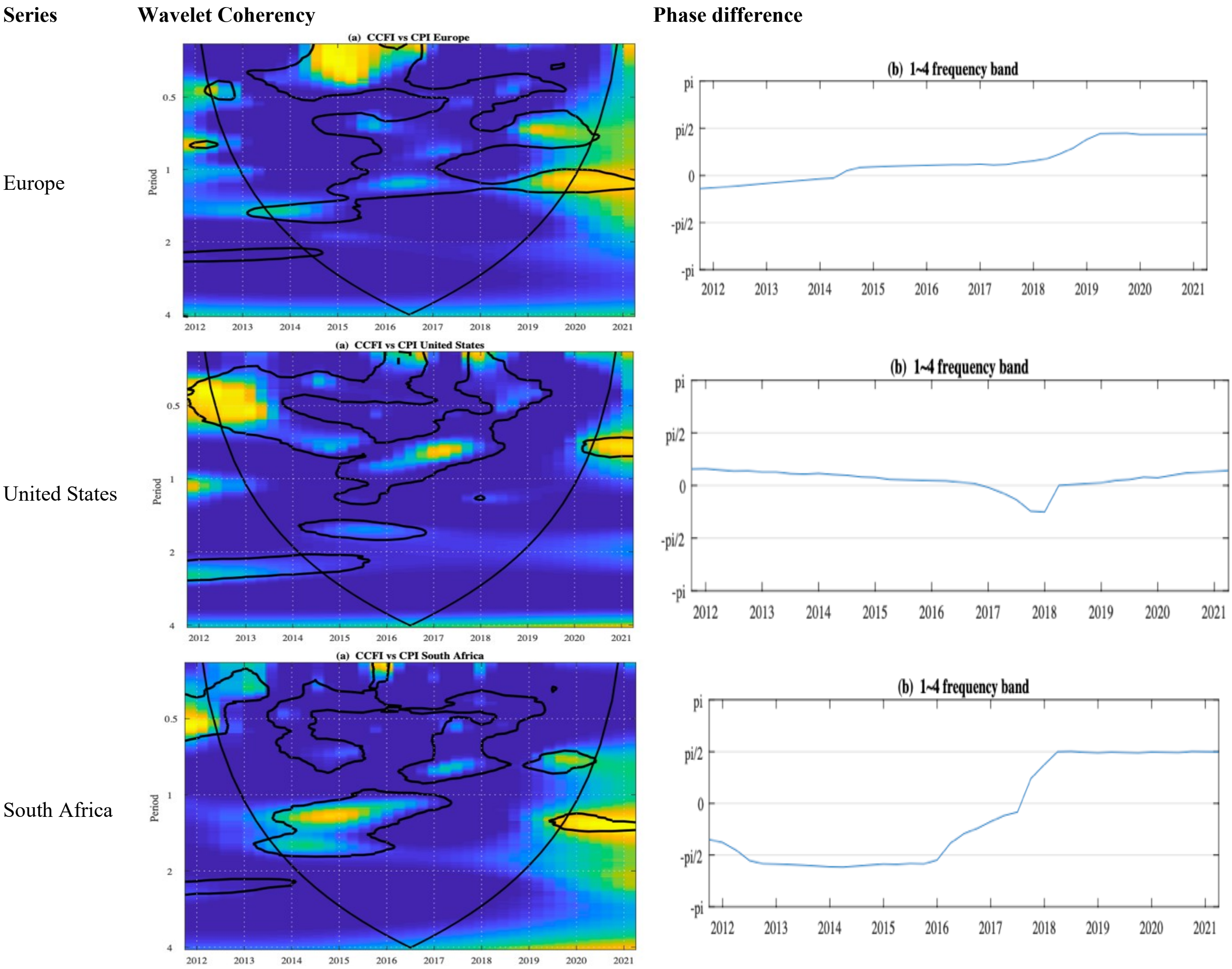

Figure 2. Wavelet coherency and phase difference results.

Wavelet coherency and phase difference results. **(a)** Wavelet coherency. **(b)–(c)** Phase difference. The contour designates the 5% significance level. Coherency ranges from blue (low coherency) to yellow (high coherency).

If we focus on the phase-difference, we observe that the high coherency mentioned before for the pandemic episode stay between 0 and $-\pi/2$, which means that containerized freight prices are negatively correlated with consumer price index of Europe, the United States and South Africa. Thus, the demand shock represented by CCFI has led the inflation rate since the beginning of the pandemic in the case of Europe and later in the case of the United States and South Africa.

The statistical analysis reveals that the China Containerized Freight Index (CCFI) and inflation rates in Europe, the United States and South Africa show non-stationary behaviors, indicating permanent shocks in these cases, while other variables show stationary patterns with transitory shocks. The ARFIMA models suggest that, except in Europe, there is mean-reverting behavior with transitory shocks. Increases in freight costs, according to the Granger causality test, affects inflation in the aforementioned regions. Furthermore, the FCVAR model shows fractional cointegration, indicating long-term reversible effects in the United States and short-term effects in other regions. The continuous wavelet transform reveals that the COVID-19 pandemic caused a high short-term coherence between the CCFI and the Consumer Price Index (CPI) in all three regions, suggesting a significant impact on inflation due to the increase in prices of freight during this period.

4. Conclusions

The main objective of this paper has been to analyze how freight costs, using the CCFI from Thomson Reuters Eikon, might affect inflation in some economies in destination ports such as those in the United States, Europe, Japan, South Africa, the United Arab Emirates, New Zealand and South Korea.

The importance of this research is given by the need to know the possible relationship between the increase in freight costs and inflation in the markets due to the increase reflected in the prices of the products. In 2020, due to the SARS-CoV-2 pandemic, there was a collapse in maritime trade produced by the slowdown in trade caused by sanitary restrictions and increased docking time in ports due to contagion prevention measures. The situation was aggravated by the conflict in Ukraine, raising inflation to figures far above those forecast. These circumstances led to an increase in prices, which together with the increase in demand for products produced an increase in costs that is reflected in the general price index of the main economies.

To carry out this research, we started from the analysis of the statistical properties of the time series of the CCFI and inflation rates from the 15 reference ports of this index to study globally how the cost of transport affects the inflation rate in Europe, the United Sates, Arab Emirates, New Zealand, South Africa, Japan and South Korea. To study the inflation rate we used the US Consumer Price Index (CPI), using quarterly data from October 2011 to April 2021.

The analysis started with several unit root methods, including ADF (Dickey and Fuller, 1979), KPSS (Kwiatkowski et al., 1992) and PP (Phillips and Perron, 1988). The results suggested that the CCFI and the series of inflation rates for Europe, New Zealand and South Korea follow a non-stationary behavior. Therefore, for these time series, we have to take first differences, while the rest of the variables show a stationary pattern with shocks having then a transitory nature. The use of Granger causality test to examine the interactions between container freight rates and inflation rates in various regions of the world, resulted in only three of the regions being affected by an increase of inflation, namely, in Europe, the United States and South Africa.

The FCVAR model of Johansen and Nielsen (2012) made possible to verify the persistence of long-term shocks in the series, verifying that in the United States, we cannot reject the hypothesis where the duration of the shock is reverting to the long-term average.

To identify the dependence on time and to study the behavior of the structural change caused by COVID-19, the wavelet coherence and the phase difference between the CCFI and the CPI of Europe, the United States and South Africa were calculated; these being the three regions where inflation was affected by the increase in freight prices as observed in the Granger test. Focusing on the start of the SARS-CoV-2 pandemic in China in December 2019, a high degree of coherence was observed in the low frequency (short term) in all three results. The demand shock represented by the CCFI has led the inflation rate since the beginning of the pandemic in the case of

Europe and later in the case of the United States and South Africa.

The results obtained confirm that the increase in freight costs can lead to an increase in inflation, especially in Europe, the United States and South Africa, reflected in the increase in product prices in destination markets. The SARS-CoV-2 pandemic caused a significant slowdown in maritime trade due to health restrictions and increased docking time at ports to prevent infections, which, combined with an increase in demand for products, raised costs of freight and, therefore, the price indices in the main economies. Using the FCVAR model, it was found that in the United States long-term shocks tend to revert to the long-term mean, indicating that although freight costs can cause temporary increases in inflation, these effects are not permanent. Furthermore, the coherence and phase difference analysis between the CCFI and the CPI revealed a high degree of short-term coherence since the start of the pandemic in China, showing that demand shocks, represented by the increase in freight costs have led the inflation rate in Europe and subsequently in the United States and South Africa since the beginning of the pandemic. Although there was a persistent rise in inflation in the second half of 2021, data from the end of that year showed a decline in freight rates, suggesting a short-term stabilization of inflation indicators. However, new blockades in Shanghai and the impact of the conflict between Russia and Ukraine present additional risks that should be studied in future research. The results of this study are of great use to investors and portfolio managers, providing a detailed understanding of how freight costs can influence inflation, valuable information to anticipate investment decisions and design policies that promote stability in the affected markets. for maritime transportation costs.

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