Journal Pre-proof

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PII: S0378-4371(19)32125-9
DOI: https://doi.org/10.1016/j.physa.2019.123820
Reference: PHYSA 123820

To appear in: *Physica A*

Received date : 3 July 2019
Revised date : 18 November 2019

Please cite this article as: S.H. Kang, S. Lahmiri, G.S. Uddin et al., Inflation cycle synchronization in ASEAN countries, *Physica A* (2019), doi: https://doi.org/10.1016/j.physa.2019.123820.

Highlights

- We investigate the causality of ASEAN inflation rates across time and frequencies.
- We also analyse inflation cycle synchronization and network structure of causality.
- We measure DCCs, a wavelet cohesion, and the spillover network index.
- Evidence of time-dependent variation in the strength of co-movement is found.
- Positive network causality and inflation integration are identified.

Inflation Cycle Synchronization in ASEAN Countries

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Inflation Cycle Synchronization in ASEAN Countries

ABSTRACT

We investigate the pairwise causality of inflation rates across time and frequencies, inflation cycle synchronization and network structure of causality between five ASEAN countries: Indonesia, Malaysia, The Philippines, Singapore, and Thailand. We draw our empirical results and conclusions by implementing dynamic conditional correlations (DCCs), a wavelet measure of cohesion for inflation cycle evolution assessment, and the spillover network index model of Diebold and Yilmaz [1,2]. We find evidence of time-dependent variation in the strength of co-movement between inflation cycles across countries. Positive network causality between inflation cycles and inflation integration across the ASEAN countries are identified. The lead-lag properties of economic indicators are observed to depend on the cycle's periodicity. The inflation synchronization is particularly pronounced in Thailand.

PACS codes: 89.65.Gh

Keywords: Inflation cycle synchronization; Wavelet transformation; DCC-GARCH model; ASEAN countries

1. Introduction

Global macroeconomic developments have mainly focused on business cycle formation rather than inflation cycle formation, probably due to inflation cycle formation being easily linked with economic activity and growth [3–8]. However, given the intrinsic relationship of dependence and causality between interest rates, inflation cycles, and business cycles [9–15], the focus on macroeconomic developments has gradually shifted towards the analysis of cyclicality in macroeconomic fundamentals. Inflation cycles, in particular, due to the role inflation plays in business cycle formation and development and in causing its fluctuations, with decreasing and increasing business cycle trends varying according to investor response to market innovations, are largely perceived as opportunities for economic growth and as sources of economic risk, simultaneously. It is this complexity of inflation cycles, which underlies interwoven dynamic relationships between global, macro, micro and financial variables in the short- mid- and long runs, and a higher integration of international and regional economies via trade linkages and trade competition, what continues to draw the attention of policy makers, the private sector and the academia. Accordingly, relevant stakeholders are beginning to understand the economic and trade diversification opportunities as well as the risks behind high-long and low-short inflation cycle interdependence, in relation to regional or international trading partners. [1] In addition, interest rate determination is now seen from the perspective of inflation cycles that could be positively or negatively correlated with inflation cycles of substantial trading partners, and it is in this context where the subject of inflation cycle synchronization becomes relevant for macroeconomic decision-making and for determining regional trading agreements [16].

The concept of inflation cycle synchronicity emerges in situations where the inflation cycle of a certain country is positively correlated with or Granger-caused by that of another country, yielding a similarity effect in inflation cycle formation in both countries, and to potential advantages and disadvantages with respect to trade and sector diversification. Focusing on the importance of this research subject, our paper investigates the pairwise causality of inflation rates across time and frequencies, the inflation cycle synchronization, and the network structure of causality between five ASEAN countries: Indonesia, Malaysia,

[1] The subject of inflation cycle synchronization is also appealing as a trade-off between inflation and output in the context of growth dynamics, and their relationship with inflation continues to intrigue macroeconomic and financial regulators. This subject is, in turn, linked to the effect that financial stimulus packages have on the economy once the inflation variable is added to the equation [17].

The Philippines, Singapore, and Thailand. We draw our empirical results and conclusions by implementing dynamic conditional correlations (DCCs), a wavelet measure of cohesion for inflation cycle evolution assessment, and the spillover network index model of Diebold and Yilmaz [1,2]. [2]

Our motivations for modelling the inflation cycle synchronization between the five ASEAN countries selected are that business cycles, and inflation rate cycles by inference, in those countries may have patterns of dependence across time and frequencies of inflation rates [18]. Further, with the exception of Singapore, all other ASEAN countries considered in this study are either developing or emerging markets (i.e., low-wage countries), making them suitable candidates for large foreign direct investments that may impact local inflation levels in nearly similar ways. Furthermore, historical inflation data from those countries show fairly similar inflation rate paths through time, perhaps due to similar central bank monetary policies such as quantitative easing (QE), which increase the likelihood of inflation rate synchronization between those countries. Emerging market economies also have common financial and real sector similarities and are exposed to common regional shocks. Specifically, all five ASEAN countries considered have gone through substantial financial and industrial development, although at different time periods and in differing degrees over the last four decades, and have also had low to moderate inflation rates, relative to other emerging market economies. The same countries were exposed to financial crises of regional and international scale such as the Asian crisis of 1997-1998, which started in Thailand in early July 1997 with the collapse of the Thai baht that was under severe speculative attacks; the 2008-2009 global financial crisis that emerged from the US real state subprime market; and the 2014 oil price decline crisis, which made those countries susceptible to short-term, mid-term, and long-term convergence trends. [3]

We contribute to the relevant literature firstly by exploring the hypothesis of inflation

[2] The measurement of co-movement among macroeconomic variables is an important issue in both advanced and developing economies. Conventionally, the degree of co-movement has been assessed in the time domain. Recently, Rua [19] proposed a new measure of co-movement resorting to wavelet analysis. This approach allows one to assess simultaneously the co-movement at the frequency level and over time. Working on the continuous wavelet transform, Rua and Nunes [20] suggest a novel approach to measuring market risk based on the continuous wavelet transform. The good results they obtain from their implemented model is one of the motivations for our research study on inflation cycles.

[3] Policy makers typically use the concept of convergence to indicate the reduction of inflation/interest rate differentials between countries [21]. Interest rate convergence serves as an indicator of the degree of integration in the financial markets. On the other hand, inflation convergence serves as an indicator of the degree of integration in the goods markets. Therefore, examining co-movement between the inflation cycles of the five ASEAN countries modelled has important theoretical as well as policy implications for the analysis of issues related to monetary policy and open-economy macroeconomic models.

cycles at the regional level rather than at the local level. Secondly, we implement a robust modelling framework consisting of the DCC method that examines pairwise causality between inflation rates, a wavelet coherence method for the study of inflation cycle synchronization across different frequencies, and a spillover network index model to measure the spillover effects between inflation rates. To the best of our knowledge, this study is the first to employ the wavelet coherence method for the analysis of inflation cycle synchronization between ASEAN countries. Thirdly, we draw useful insights regarding the network structure of causality and interdependence between inflation cycles of ASEAN countries in varying market conditions. We find evidence of time-dependent variation in the strength of co-movement between inflation cycles across countries. Positive network causality between inflation cycles and inflation integration across the ASEAN countries are identified. The lead-lag properties of economic indicators are found to depend on the cycle's periodicity. Inflation synchronization is particularly pronounced in Thailand. Our economic reasoning suggests that economic policy choices and development measures strongly explain the cross-sectional variation in the relative importance of international inflation cycle influence.

The implications of the obtained empirical results related to regional co-movement of inflation suggests that may be used to improve national inflation forecasting and to develop time-varying approaches for trade diversification and regional economic co-operation. The inflation integration identified between the countries modelled suggests that it is complicated for some countries in the region to significantly diverge from the inflation cycle patterns led by other ASEAN countries, making it difficult at some points in time to maintain inflation and the price of certain traded goods at a low level. On the other hand, the inflation integration across ASEAN countries, while being an indicator of nearly similar monetary policies, also suggests that the economies of the region may display similar growth patterns, although at different time periods.

The rest of this paper is organised as follows. Section 2 reviews the relevant literature on the subject of inflation co-movements. Section 3 presents the data and justifies the data sample selected. The descriptive statistics of the data is also explained. Section 4 explains the models and methodology used. Section 5 states and discusses the empirical results. Section 6 provides concluding remarks.

2. Literature review on co-movement of inflation

Inflation co-movements across countries have been extensively studied in the finance literature.[4] Hyvonen [26], using a large sample of IMF member countries, documents the convergence of inflation rates and the role played by inflation targeting in driving the convergence. Wang and Wen [27] indicate that ‘persistent and lagged’ inflation is a worldwide phenomenon and that short-run inflation dynamics are highly synchronized across countries. Cecchetti et al. [28] considering G7 countries investigate the reasons for high inflation in the 1970s and provide evidence of changes in monetary regimes playing a significant role in the rise of inflation. Ciccarelli and Mojon [29] argue that inflation has been dominated by common shocks ever since the 1960s without changing over time. Friedman and Schwartz [30] point out that after the outbreak of war in Europe in September 1939, a period of extremely high inflation followed that was comparable to the inflation levels that accompanied the Civil War in the US and World War I, overall indicating inflation converge across nations and continents on the aftermath of war events. By August 1948, wholesale prices had more than doubled. Monacelli and Sala [31], based on four Organisation for Economic Co-operation and Development (OECD) countries, estimate the contribution of international common factors to the dynamics of inflation rates across 948 consumer price index (CPI) products from these countries. Their findings indicate a strong positive and statistically significant correlation between international trade shocks and consumer inflation exposure at the sectorial level.

Hall et al. [32], using a Kalman filter technique, provide evidence of inflation convergence among European economies and conclude that a slow and protracted process of convergence is taking place within the economies in this region. Adopting a similar approach, Holmes [33] examines inflation convergence in the initial Euro countries for the manufacturing and service sectors and finds no evidence of German leadership in both the sectors. Hall [34], using data from 1980 to 2008, studies the key mediating role of interest rates in inflation fluctuations and argues that in a low-inflation economy, the room for a decline in interest rate is rather small. Further, he finds that inflation rates converge faster than the output gap.

Kočenda and Papell [35] and Lopez and Papell [36], within a European Union context, apply panel unit root tests on quarterly CPI-based inflation rates for the period from 1952 to

[4] There are some studies which explore the economic cycle or business cycle among countries [22–25], but these studies do not deal with the inflation cycle.

1994 to examine inflation convergence. Both studies find evidence of convergence in inflation rates. Holmes [37], on the other hand, using monthly CPI-based inflation data from 1972 to 1999, finds that inflation convergence was stronger during the period from 1983 to 1990, whereas the turbulence experienced within the initial Euro countries in the early 1990s conferred some degree of macroeconomic independence to certain member countries. Kisswani and Nusair [38] use CPI-based inflation rates from 1990 to 2011 to examine the nonlinear convergence of inflation rates in five ASEAN countries, relative to the U.S. and Japan. The stationary inflation differentials they find in those countries are interpreted as evidence of convergence in inflation rates. Neely and Rapach [39] utilize a dynamic latent factor model to decompose inflation rates from 64 countries and regions for the period from 1951 to 2009. Their findings indicate that the world and regional components, on average, account for 35% and 16% of annual inflation variability across countries, respectively. Moreover, international factors are said to explain just over half of the inflation variability in those countries and regions. Ciccarelli and Mojon's model [29] on inflation rates from 22 members of the OECD shows that inflation in industrialized countries is largely a global phenomenon.

Recently, Gerard's [40] application of panel vector autoregression (VAR) on G7 countries indicates that shocks to commodity prices, rather common movements in real economic activity, are more important in driving global inflation dynamics. Mumtaz and Surico [41], in the context of industrialized countries, argue that inflation rates have become more similar and less predictable across those countries since the 1960s; however, there has not been a common trend of inflation persistence. Further, they find that during the late 1980s, inflation predictability declined significantly across the industrialized world. Osorio and Unsal [42], by implementing a global VAR (GVAR) model on regional and global drivers of inflation, analyse inflation dynamics in Asia. Their results indicate that over the past two decades, the main drivers of inflation in Asia have been linked to monetary and supply shocks; however, the contribution of these shocks to inflation has fallen in recent years. In addition, money demand has emerged as an important contributor to inflation in Asia.

Jiranyakul and Opiela [43], using a AR(p)-EGARCH (1,1) model, estimate conditional variance and consider Granger causality to explore the linkage between inflation and inflation uncertainty in the five ASEAN countries, over the period from January 1970 to December 2007. The results show that increases in inflation raise inflation uncertainty, and vice versa, in all five countries. Flood and Rose [18] show that inflation targeting appears to have a small but positive effect on the synchronization of business cycles. In addition, they show that business cycles from countries in which inflation targeting is practiced move slightly more closely with foreign business cycles, showing a degree of synchronicity between them.

The study by Tiwari et al. [51] using a wavelet coherence method examines at different frequencies the relationship between oil prices and the U.S. consumer price index, and finds that their relationship changes across frequencies and over the sample period considered, with a decrease in oil price-inflation pass-through across time. Tiwari et al. [52] by employing a wavelet transform method examine the inflation-output gap relationship for France and find that the output gap can forecast the dynamics of inflation in the short and medium runs. Discrete wavelet transform shows that the variables modeled more strongly correlate in the short and medium terms, while the continuous wavelet transform suggests that output gap leads inflation in similar time frames. Ferrer et al. [53] using wavelet transform methods analyzes the relationship between measures of economic activity and U.S. financial stress indices. The authors find that the relationship between the variables considered changes according to time horizon. The financial stress caused by the global financial crisis of 2007-2008 is observed to impact U.S. economic activity and the linkage between financial stress and economic activity is more visible between one and four-years. Berument and Dincer [54] using a full information maximum likelihood method investigate the interaction between inflation and inflation uncertainty in the context of the G-7 countries and find that inflation causes inflation uncertainty for all G-7 countries considered. They also find that in some countries increasing uncertainty lowers inflation, while in one country the opposite occurs. Sun and Xu [55] using wavelet coherence analysis examine the comovements and lead-lag effects between stock market indices from Asia (Japan, Singapore, Hongkong, China) and identify strong comovements among the equity markets considered in the long run. They also identify the Japanese market as the leader of the other markets in the long run. Rohit and Mitra [56] using DCCA cross-correlations model the comovements of monetary policies for advance and emerging economies. Their findings indicate stronger comovements among the monetary policies of advanced economies, relative to those of emerging economies. Also, for emerging economies the comovements are more noticeable in the short term. Kang et al. [57] by employing dynamic conditional correlations and wavelet coherence analyze the hedging and diversification properties of gold for Bitcoins. Their results show phase difference between the prices of gold and Bitcoins. The European sovereign debt crisis is acknowledged as a source of contagion and comovements are identified between gold and Bitcoins for the 8-

16 weeks frequency band. Huang et al. [58] using cointegration and Grange causality tests, as well as, wavelet coherence analyze the relationship and comovements between the Chinese stock market and the prices of crude oil and gold. Their findings indicate cointegration in the long term between the variables considered. Gold and crude oil strongly correlate with the stock market under high (1-14 days) and medium frequency (14-128 days) bands.

3. Data

The data sample consists of monthly frequency CPIs from five ASEAN countries: Indonesia, Malaysia, The Philippines, Singapore, and Thailand. The CPI series span from March 1983 to March 2017. The inflation rates of the five ASEAN countries are calculated as the first difference of the logarithmic transformation. All the data has been obtained from Thomson Reuters Datastream International. We use CPI data in our analysis because it is a reliable indicator of increases or decreases in the average price, and thus can be used as a measure of inflation in the economy. We use monthly frequency data because it is the smallest time frequency in which CPI measurements are available.

Table 1. Descriptive statistics and unit root tests for inflation rates of ASEAN-5 countries

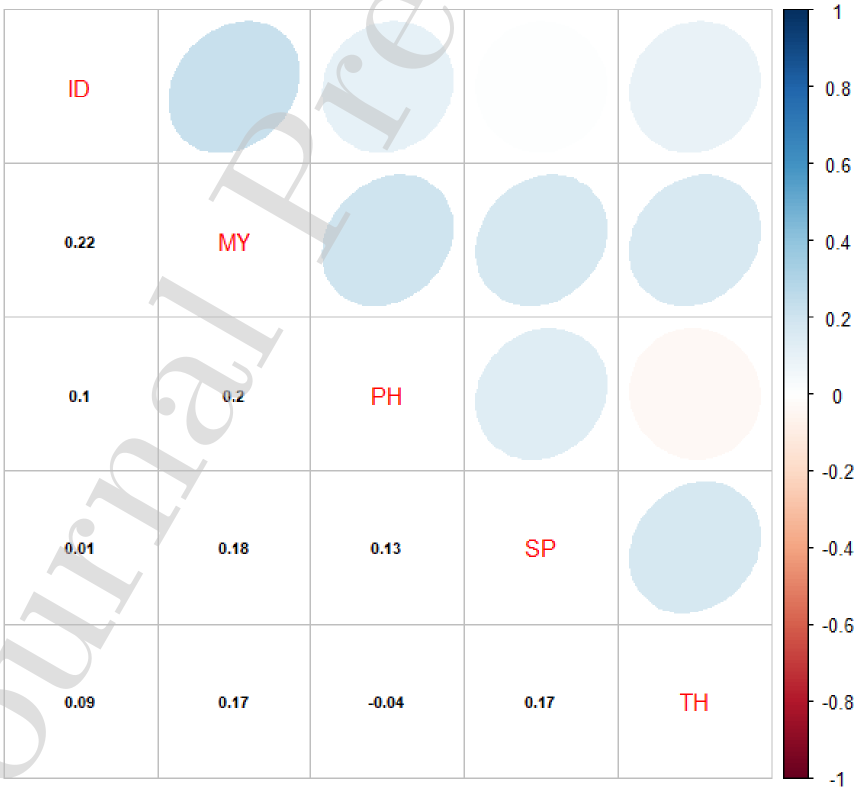
	Indonesia	Malaysia	Philippine	Singapore	Thailand
Mean	0.00723	0.00216	0.00628	0.00135	0.00254
Maximum	0.11898	0.03889	0.08604	0.01988	0.02658
Minimum	-0.01059	-0.01538	-0.01956	-0.01620	-0.02982
SD	0.01170	0.00403	0.01006	0.00435	0.00502
Skewness	4.5919	1.9188	4.2465	0.1992	-0.1685
Excess kurtosis	30.829	18.211	23.965	1.9815	6.0532
Jarque-Bera	17634.***	5902.9***	11016.***	69.617***	626.37***
ADF	-5.6459***	-7.9927***	-6.2663***	-7.6234***	-7.7547***
PP	-11.322***	-15.756***	-11.399***	-23.020***	-14.771***

Notes: SD denotes the standard deviation. ADF and PP are the empirical statistics of the augmented Dickey-Fuller and the Phillips-Perron unit root tests, respectively. *** denotes the statistical significance at the 1% level.

Table 1 provides the descriptive statistics of inflation rates and the unit root tests. Indonesia has the highest average inflation rate, which corresponds to the largest standard deviation from the mean. With the exception of Thailand, each inflation rate series has positive skewness, with the rates in Indonesia being the most skewed. The kurtosis values for all the rates are above three, an indication of fat tails in the inflation rates' distributions. The Jarque-Bera test results confirm the identified fat tails and the absence of the normal distribution in the time series. All inflation rate time series are found to be stationary based on two unit root tests (i.e. the ADF and PP tests).

Fig. 1 displays the heat map of Pearson's correlation matrix among ASEAN inflations. Note that the color indicates the strength of the correlation, from blue (positive) to red (negative). Except for the Thailand and the Philippines pair, the inflation rates have a positive correlation, indicating the synchronization of inflations.

Fig. 1. Heat map of the correlation matrix



Note: This figure shows a visual correlation matrix across ASEAN inflations. The color boxes indicate the strength of the correlation. Blue indicates a positive correlation, while red indicates a negative correlation.

4. Methodology

In order to analyse the synchronization of ASEAN inflation cycles, we implement three methods to capture the comovement and spillover across inflation cycles. First, we study the volatility of the inflations using a multivariate GARCH framework. In particular, the Dynamic Conditional Correlation (DCC) model is applied to capture the time-varying conditional correlations between inflation cycles. Second, we apply a wavelet coherence approach to analyse the co movement effects in different time scales (short-term, intermediate-term, and long-term horizons). The wavelet approach provides the causality of co movement between inflations. Finally, we investigate the direction of spillover across inflations using the spillover index of Diebold and Yilmaz [1,2]. We identify the net-transmitter or net-recipient of inflation spillover using the causality network of inflations. By employing DCC GARCH, Wavelets and spillover network, we expect to provide a comprehensive analysis that explains the nature of synchronization of inflations.

4.1. Dynamic conditional correlation

The dynamic conditional correlation generalized autoregressive conditional heteroscedasticity (DCC-GARCH) model by Engle [44] is used to estimate the time-varying correlations across the five ASEAN countries' inflation rates. The analytical structure of the DCC-GARCH model is as follows. Assume that $E_{t-1}[\varepsilon_t] = 0$ and $E_{t-1}[\varepsilon_t \varepsilon_t'] = H_t$, the conditional expectation at time t of the available set of information is given by $E_t[\cdot]$. An equation of the conditional variance-covariance matrix (H_t) is:

$$H_t = D_t^{1/2} R_t D_t^{1/2}, \tag{1}$$

In Eq. (1) $R_t = [\rho_{ij,t}]$ stands for the conditional correlation matrix, while the matrix parameter $D_t = diag(h_{1,t}, \cdots, h_{n,t})$ accounts for the conditional variances organized in diagonal matrix form. By directly modelling the right-hand side of Eq. (1) instead of H_t, the following dynamic correlation structure is suggested, along with Engle [44]:

$$R_t = \{Q_t^*\}^{-1/2} Q_t \{Q_t^*\}^{-1/2}, \tag{2}$$

$$Q_t^* = diag[Q_t], \tag{3}$$

$$Q_t = [q_{ij,t}] = (1 - a - b)S + \alpha u_{t-1} u_{t-1}' + bQ_{t-1}, \tag{4}$$

where $u_{i,t} = \varepsilon_{i,t}/h_{i,t}$ are the standardized residuals drawn from the univariate GARCH model. The parameter $S = [s_{ij}] = E[u_t u_t']$ is the $n \times n$ unconditional covariance matrix of u_t, while a and b are non-negative scalars that satisfy $a + b < 1$. Maximizing the log-likelihood of the model, we perform the final estimation as follows:

$$\mathrm{L} = \left(\frac{1}{2}\right)\sum_{i=1}^{T}(n\ln(2\pi) + \ln|D_t| + \varepsilon_t' D_t^{-1}\varepsilon_t) - \left(\frac{1}{2}\right)\sum_{i=1}^{T}(\ln|R_t| + \varepsilon_t' R_t^{-1}\varepsilon_t - \varepsilon_t'\varepsilon_t). \quad (5)$$

The resulting model is called the DCC-GARCH model. Although the DCC correlation sheds little light on the scale-dependent characteristics of the ASEAN inflation cycle synchronization, it is evident that the correlation structure is highly dependent on the point in time assessed. This provides support for the use of the wavelet-based measure of synchronization in simultaneously identifying the calendar time and scale characteristics of the ASEAN countries' inflation rates.

4.2. Wavelet-based measure of synchronization

Wavelet analysis is suitable to examine the co-movement of the inflation cycles because it estimates the spectrum as a function of time, revealing how the different periodic components of the time series change over time. The wavelet measure of synchronization is applied to examine the co-movements of the inflation rates across the five ASEAN countries. Wavelet analysis estimates the spectral characteristics of a time series and its different periodic components that change over time. To study business cycle synchronization, wavelet-squared coherence analysis is fitted to the data. The wavelet transform decomposes a time series in terms of a wavelet function, $\psi_\sigma(t)$, which helps to retrieve dynamics at different time scales and to decompose the time series of interest into different time scales. Based on Rua and Nunes [45], we use a continuous-time Morlet wavelet function $\psi_\sigma(t)$ with Morlet set to 6,[5]. The continuous wavelet transform, $W_t^X(r)$, of a discrete sequence, x_m $(m = 1, \cdots, M - 1, M)$, that has uniform time steps δ_t, is defined as the convolution of x_m with a scaled and normalized wavelet (Torrence and Compo 1998). The continuous wavelet transform can be expressed as follows:

$$W_t^X(r) = \sqrt{\frac{\delta_t}{r}}\sum_{t=1}^{M} x_{m'}\,\psi_\sigma\left[(m' - m)\frac{\delta_t}{r}\right]. \quad (6)$$

[5] Grinsted et al. [50] suggested that the 6 wavelet frequencies provide a good balance between time and frequency localization and also simplifies the interpretation of the wavelet analysis as the wavelet scale in inversely related to the frequency.

Based on Eq. (6), the wavelet power is defined as $|W_t^X(r)|^2$. Because our intention is to measure the extent to which two time series of inflation rates synchronize, we focus on determining the presence of coherence between them. Fourier spectral approaches define wavelet coherency (WTC) as the ratio of the cross spectrum to the product of each series' spectrum; thus it can be thought of as a local correlation between two time series of inflation rates in both, time and frequency. Given two countries' rate of inflation time series X_m and Y_m that have wavelet transforms $W_t^X(r)$ and $W_t^Y(r)$, respectively, we can define their corresponding cross-wavelet spectrum as $W_t^{XY}(r) = W_t^X(r) * W_t^Y(r)$. Along with Torrence and Webster [46], the wavelet coherence of the two time series of inflation rates can be expressed as follows:

$$R_t^2(r) = \frac{\left|Q\left(r^{-1}W_t^{XY}(r)\right)\right|^2}{Q\left|\left(r^{-1}\left|W_t^X(r)\right|^2\right)\right|.Q\left|\left(r^{-1}\left|W_t^Y(r)\right|^2\right)\right|}. \quad (7)$$

In Eq. (7) Q is a smoothing operator applied to both time and frequency [20], while the expression in the numerator is the smoothed cross-wavelet spectrum in its absolute value squared form. On the other hand, the expression on the denominator stands for smoothed wavelet power spectra [45,46]. The values of $R_t^2(r)$, the wavelet-squared coherency, fall in the interval [0,1]. The closer those values are to 1 the stronger is the co-movement between the time series inflation rates or business cycles of two countries, and conversely. Unlike the standard correlation coefficient, the wavelet-squared coherency parameter only takes positive values. Also, by means of the graphical representation of Eq. (7) it is possible to observe the location of co-movement between time series inflation rates according to time and frequency, simultaneously. In testing for the significance of wavelet coherence estimates we employ Monte Carlo simulation method [47]. Along with Aguiar-Conraria and Soares [48] our fitted model targets WTC rather than the wavelet cross spectrum. Table 2 reports the relationship between frequency scale and time horizon in Fig. 3 and Fig. 4.

Table 2. Corresponding relationship between scale and time horizon

scale	0.25	0.5	1	2	4	8
frequency	1-3 months	3-6 months	6-12 months	12-24 months	14~48 months	48-96 months

4.3. Directional spillover index

In analysing the inflation spillovers across ASEAN countries, we implement the spillover index method of Diebold and Yilmaz [1,2]. This spillover index approach measures the total, net, and directional spillover index across inflation rates and their embedded cycles. Evolution of the inflation rate series' first-order differences is assumed to follow a covariance stationary VAR(p) of the following form:

$$y_t = \sum_{k=1}^{p} \psi_k \, y_{t-k} + \varepsilon_t \tag{8}$$

where the variable y_t refers to an $N \times 1$ vector inflation rate, and ψ_k refers to an $N \times N$ matrix of autoregressive coefficients indicating the effects of past inflation rates on the evolution of y_t. The term ε_t accounts for the effects of variables not included in the evolution of the process, and it is assumed to be serially uncorrelated. A moving average representation of Eq. (8) is $y_t = \sum_{l=0}^{\infty} \Theta_l \, \varepsilon_{t-l}$, where $\Theta_l = \psi_1 \Theta_{l-1} + \psi_2 \Theta_{l-2} + \cdots + \psi_p \Theta_{l-p}$. In implementing the GVAR, the effects of variable j on the H-step-ahead generalized forecast error variance of variable i are accounted for by the following relationship:

$$c_{ij}^{g}(H) = \frac{\sigma_{jj}^{-1} \sum_{h=0}^{H-1} \left(e_i' \Theta_h \Sigma \, e_j\right)^2}{\sum_{h=0}^{H-1} \left(e_i' \Theta_h \Sigma \, \Theta_h' e_i\right)} \tag{9}$$

where Σ refers to a non-orthogonalized covariance matrix of errors corresponding to the vector autoregressive (VAR) system. The term σ_{jj} is a vector of the standard deviations of the error term for the j^{th} equation, and e_i is an $N \times 1$ vector, which has one as the i^{th} element and zero otherwise. The term Θ_h accounts for the coefficients that scale the h-lagged error in the infinite moving-average representation of VAR.

Pairwise directional spillovers from inflation rates j to inflation rates i are estimated as follows:

$$C_{i \leftarrow j}^{H} = C_{ij}^{g}(H) \tag{10}$$

The total directional spillovers from all other inflation rate series to series i are calculated as the sum of off-diagonal values from the resulting connectedness matrix:

$$C_{i\leftarrow\cdot}^{H} = \sum_{\substack{j=1 \\ j\neq i}}^{N} C_{ij}^{g}(H) \quad (11)$$

The total and off-diagonal sums of the columns represent the total directional connectedness to others from j, as follows:

$$C_{\cdot\leftarrow i}^{H} = \sum_{\substack{i,j=1 \\ j\neq i}}^{N} C_{ij}^{g}(H) \quad (12)$$

We can also define net total directional connectedness as

$$C_{i}^{H} = C_{\cdot\leftarrow i}^{H} - C_{i\leftarrow\cdot}^{H} \quad (13)$$

Finally, the total (system-wide) connectedness is the ratio of the sum of the to-others (from-others) elements of the variance decomposition matrix to the sum of all elements:

$$C^{H} = \frac{1}{N}\sum_{\substack{i,j=1 \\ j\neq i}}^{N} c_{ij}^{g}(H) \quad (14)$$

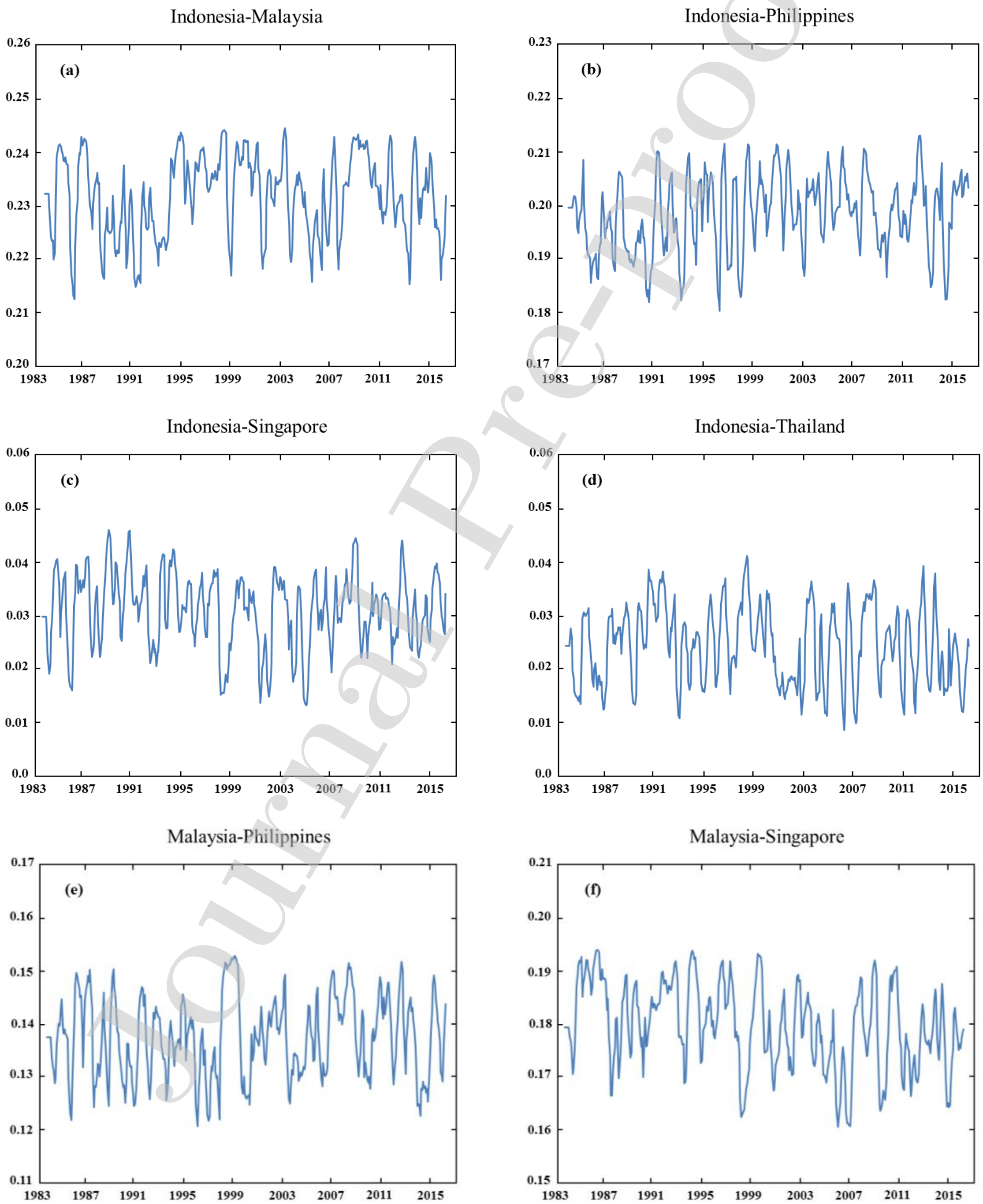
To develop the network topology of all market connectedness, Diebold and Yilmaz [1,2] interpreted the variance decomposition matrix as the adjacency matrix of a weighted directed network. Elements of the adjacency matrix include our pairwise directional connectedness, $C_{i\leftarrow j}^{H}$; sums of the rows of the adjacency matrix (node in-degrees) indicate our total directional connectedness 'from', $C_{i\leftarrow\cdot}^{H}$; and sums of the columns of the adjacency matrix (node out-degrees) indicate our total directional connectedness 'to', $C_{\cdot\leftarrow i}^{H}$.

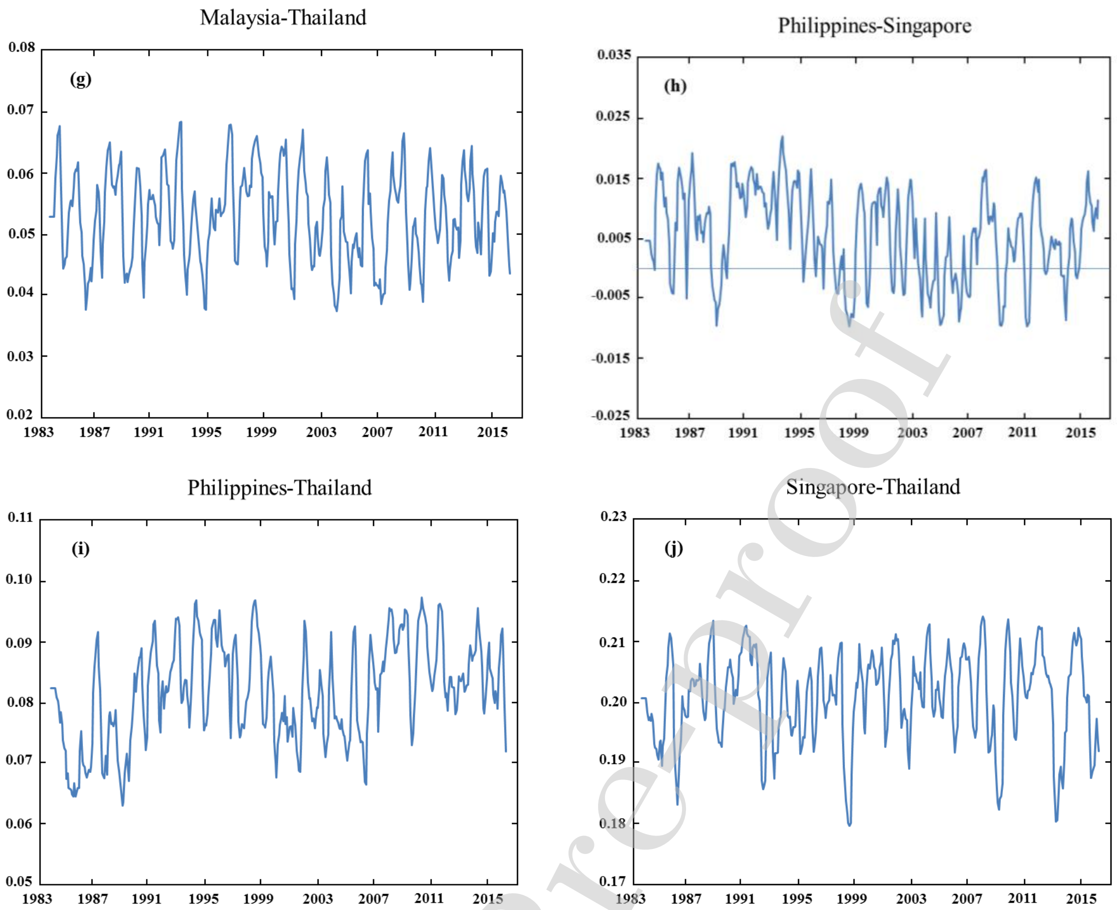
5. Results and discussion

5.1. Evidence of inflation integration

In this section, we discuss the measurements of inflation co-movement between series of inflation rates as a proxy of their integration. Fig. 2 shows the evolution of the conditional correlation obtained from the implemented DCC model. The plots clearly show that the correlations do not remain constant over time, but rather significantly fluctuate, indicating time-varying dependence between them. Most of the DCC estimates show a similar pattern and positive correlations over time, an indication of inflation integration across the five ASEAN countries. Nevertheless, short time periods of negative correlation are observed in the Philippines-Singapore pair of inflation rates (refer to Fig. 2(h)), suggesting that the Philippines and Singapore have a weak economic relationship.

Fig. 2. Multivariate GARCH dynamic conditional correlation (DCC)



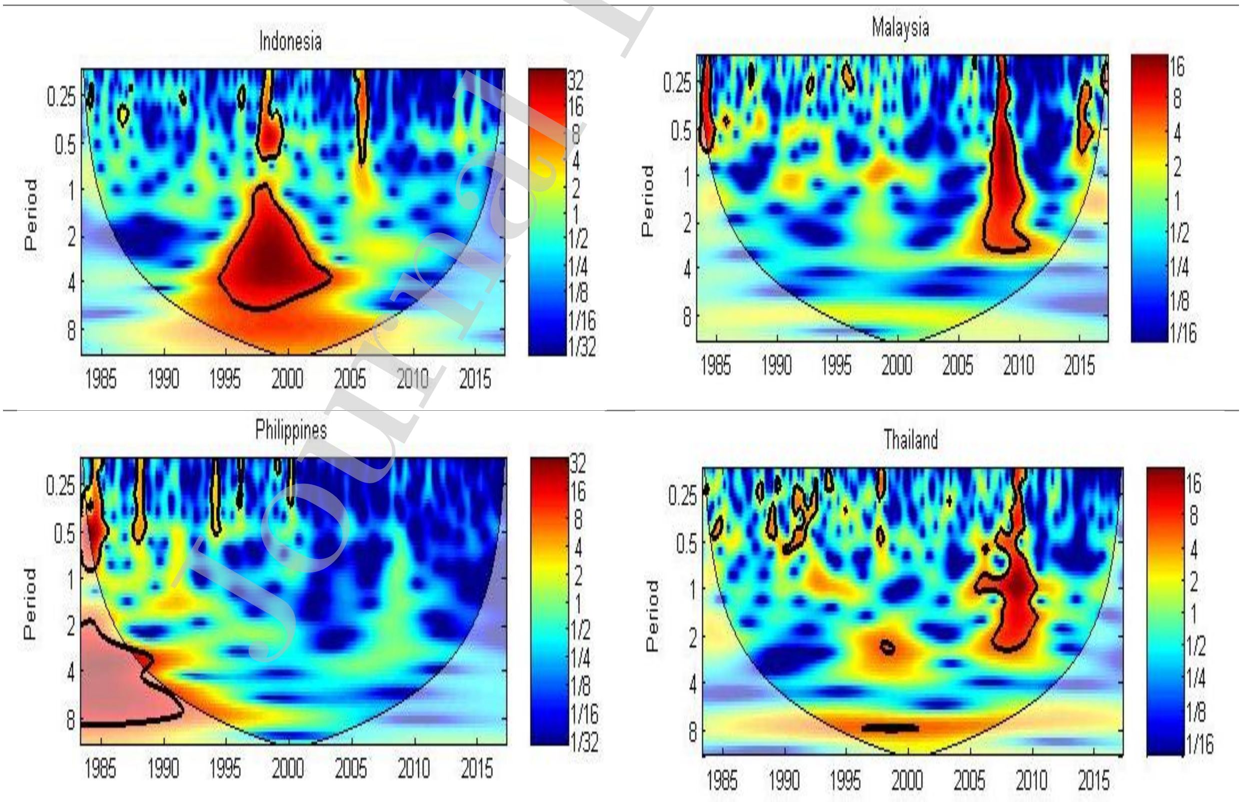


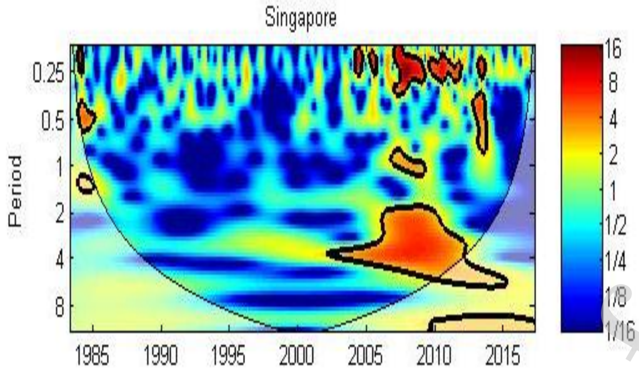
5.2. Evidence of wavelet-based measure of synchronization

Fig. 3 displays the continuous wavelet power spectrum of the inflation cycle for Indonesia, the Philippines and Singapore (left-hand side) and Malaysia, as well as the time period scale (right-hand side) for the monthly data series. In the wavelet process, we identify higher power in the data at different frequencies and time scales. Indonesia has the highest power (higher volatility) on the 16~64 month scale (frequency), which corresponds to the time and sample period ranging from 1995 to 2004. On the other hand, Malaysia has the highest power on the short- to medium-term scale (frequency), i.e. the 4~40 month scale, which corresponds to the time and sample period ranging from 2006M07 to 2010M04. The Philippines displays high power characteristics slightly on the short-run scale (frequency), which corresponds to the time and sample period ranging from 1983M04 to 1986M07. Thailand displays a higher power on the short- to medium-term scale (frequency), i.e. the 8~32 month scale, corresponding to the time and sample period ranging from 2006M07 to 2009M12. Singapore has a higher power on the 20~42 month scale (frequency), corresponding to the time and sample period ranging from 2001M07 to 2012M05. It is evident that the high-power region for the data series is above the 5% significance level.

In our research paper, WTC is used to identify both frequency bands and time intervals within which the pairs of indices co-vary. The results of the cross-wavelet coherency are presented in Fig. 4. As shown in this figure, the phase relationship between inflation cycles is present in all areas. The area of the time frequency plot below the 95% confidence level is not a reliable indication of causality. It is possible for two time series to perfectly correlate on one specific scale if the scales are approximately weighted for averaging; however, the area of significant correlation might be less than the 5% significance level. The result from WTC give us a very interesting scenario of the causality between the five ASEAN countries considered. In Fig. 4, arrows indicate the phase differences as follows: arrows pointing right (→) in-phase (positive relationship); left (←) anti-phase (negative relationship) ; right and up (↗) – first series lagging; right and down – second series lagging; left and up (↙) – first series leading; and left and down – second series leading.

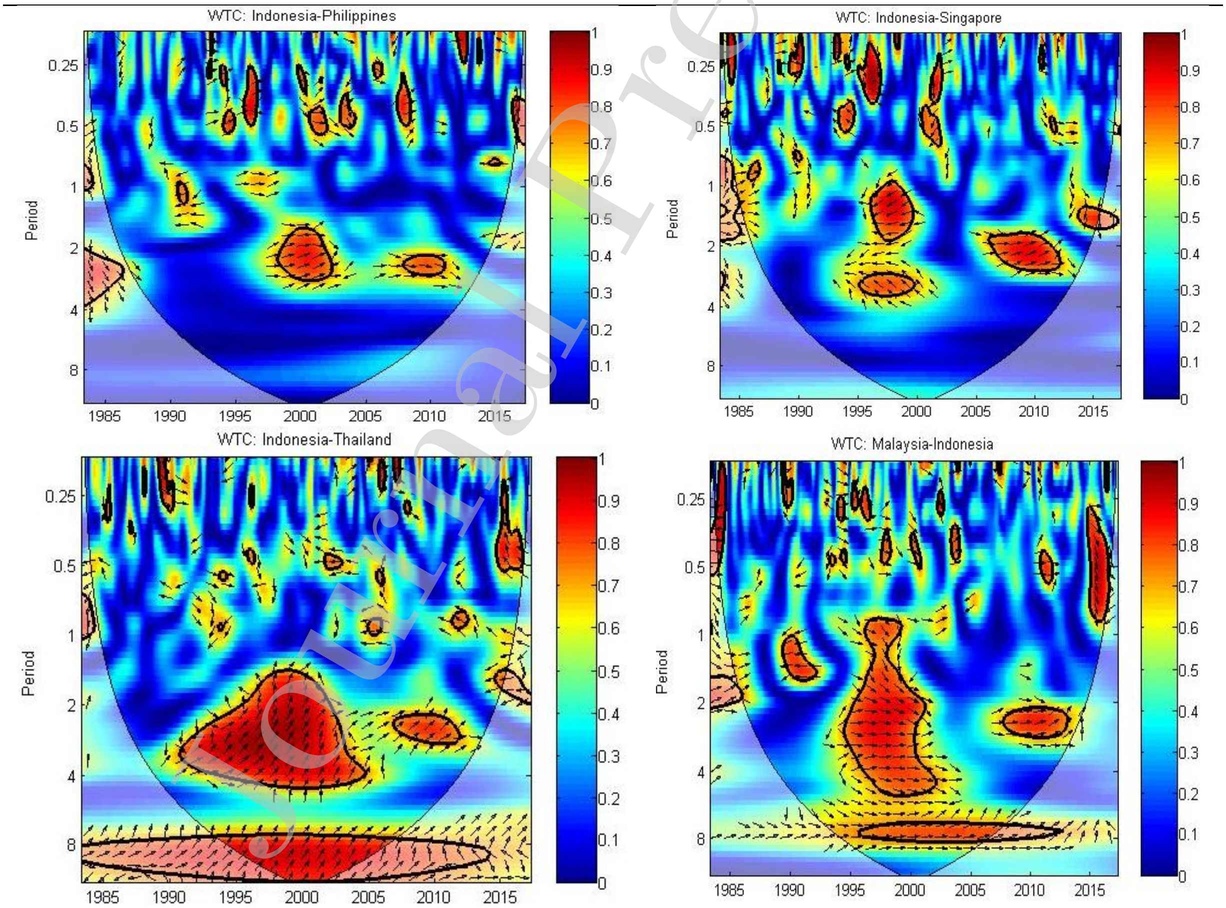
Fig. 3. The wavelet power spectrum of the inflation cycle

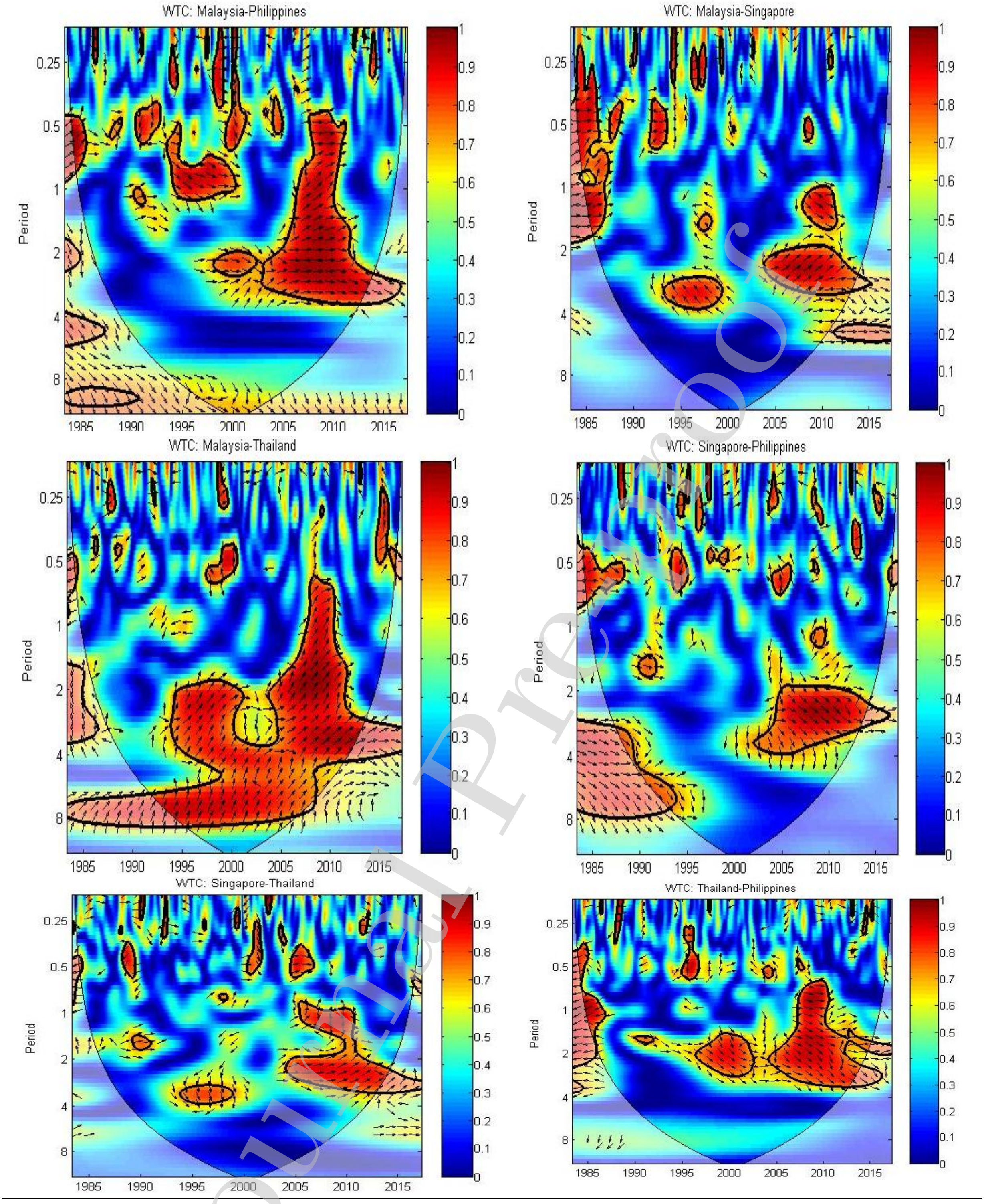




Notes: The continuous wavelet power spectrum of the inflation cycle for Indonesia and Philippines (left), Malaysia, Thailand (right), and Singapore (middle) for the time period scale series are shown in the figure. The 5% significance level is indicated by the thick black contour. In estimating it we implement Monte Carlo simulations according to phase-randomised surrogate series. The lighter shaded black line indicates the area influenced by the edges that is identified by the cone of influence. The powers are identified by the colours blue (low power) and red (high power). Measurements of frequency or scale are account for in the Y-axis, while the timeline of the selected sample series is on the X-axis. Data Range: 1983M03~2017M03; Source: Datastream International.

Fig. 4. Wavelet coherency of the inflation cycle in selected ASEAN countries





Notes: The 95% confidence level is indicated by the thick blue contour. In estimating it we implement Monte Carlo simulations according to phase-randomised surrogate series. The lighter shaded black line indicates the area influenced by the edges that is identified by the cone of influence. The powers are identified by the colours blue (low power) and red (high power). The arrows indicate the phase difference between two series. We interpret that two variables are in phase when the arrows pointing to the right. If arrows are pointing right-up, we interpret that country 2 is leading the inflation cycle of country 1. On the contrary, if the arrows pointing right-down country 1 is leading the inflation cycle of country 2. We say that two inflation cycles are out of phase if the arrows pointing leftwards. Country 1 is leading country 2 if the arrows are pointing left-up, and vice versa. If two countries display a cyclical effect on each other we say they are in-phase. On the contrary, if two countries have an anti-cyclical effect on each other we say they are out-of-phase. Data Range: 1983M03-2017M03; Source: Datastream International.

The inflation cycle co-movement between Indonesia and the Philippines is evident in the mid-term period. The inflation cycles of the Philippines marginally lead the ones from Indonesia on the short-run scale, i.e. the 12~18 month scale, from 1990M04~1992M05, while the inflation cycles of Singapore lead those of Indonesia at the same frequency scale, corresponding to the 15~19 month scale. Interestingly, this scenario is the opposite in the medium-term case, i.e. arrows on the 32~40 month scale (frequency) that correspond to the period 1995M04~1999M06 are pointing left-up, indicating that the inflation cycles of Indonesia lead those of Singapore. On the 20~32 month scale (frequency) that corresponds to 2007M05~2010M04, the arrows are pointing right-up, indicating that the inflation cycles of Singapore lead those of Indonesia. More specifically, in the case of Indonesia and Thailand, the arrows are pointing right-up, indicating that the inflation cycles of Thailand lead in the frequency band of 18~60, i.e. the 30~35 month scale (frequency) for periods 1991M02~2004M01 and 2007M05~2008M08. However, on the long-run scale (72 and above), the inflation cycles from Thailand also lead those of Indonesia and correspond to 1993M08~2009M08.

On the short-run scale (frequency), the inflation cycles of Malaysia are leading those of Indonesia, which corresponds to a scale between 15 and 20 months. Interestingly, both Malaysia and Indonesia also display a strong co-movement without any lead-lag relations as most of the arrows are pointing rightwards. On the short-run to long-run scale (frequency), the arrows are pointing rightwards and right-up, and the co-movement indicates that the inflation cycles of the Philippines are leading for the 1999M11~2008M03 period. In the short run, both Malaysia and Singapore co-move, whereas in the medium term, the inflation cycles of Malaysia lead those of Singapore on the 31~40 month scale (frequency), corresponding to 1993M03 and 1998M03. The reverse situation occurs on the 30~38 month (frequency) scale during the period 2004M01~2008M03, showing that the inflation cycles of Singapore lead those of Malaysia.

From the short-run to the long-run scale, the inflation cycle co-movement between Malaysia and Thailand occurs on the 8~64 month scale and above the frequency scale, which corresponds to 1991M07~2012M11. This finding indicates that the inflation cycles of Thailand are leading those of Malaysia. The inflation cycles of Singapore are leading those of the Philippines in the short-, medium-, and long-term scales (frequencies). The short-term (5~10 months), mid-term (1~34 months), and long-term (64 and above months) frequency scales correspond to periods 1983M08~1987M05; 2004M11~2009M01; and 1991M02~1992M05, respectively. The arrows are pointing leftwards and downwards. The inflation cycle co-movement between Singapore and Thailand is in the high-power region as the arrows are pointing rightwards, implying that the inflation cycles between them are in co-movement. On the short-run frequency scale, the inflation cycles of Singapore are leading those of Thailand and correspond to 2007M05~2012M06 period.

The inflation cycle co-movement between Thailand and Philippines is also in the high-power region as the arrows are pointing leftwards. This implies that their inflation cycles are in anti-phase (reverse directionality). During 260~330s, 2004M11~2010M09, and 1996M07~2000M09 time periods, on the monthly frequency band scales of 14~60 and 32~40, most of the arrows are pointing right-down, indicating that the inflation cycles of Thailand are leading those of the Philippines.

5.3. Evidence of inflation causality network

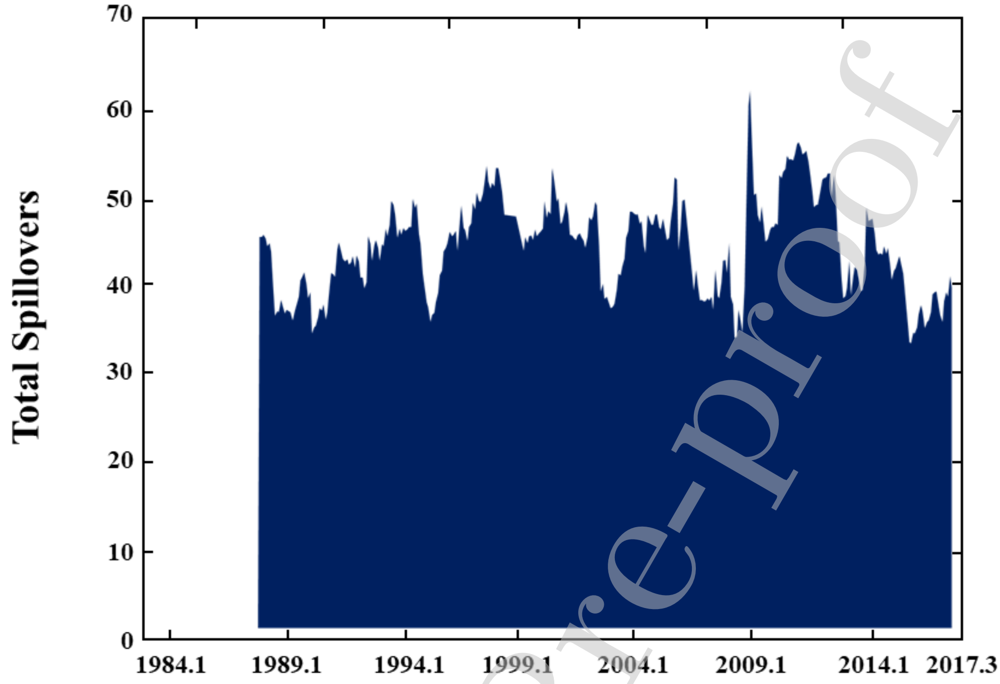
Fig. 5 plots the time-varying total spillover index across ASEAN inflations using a rolling window approach (Diebold and Yilmaz [1,2]). As shown in Fig. 5, the total spillover index varies maximum 60% and minimum 30% levels over the time. It highlights significant variation in the spillover index, which is corresponding to the various financial and economic events. For example, we identify the total spillovers attain their maximum level during 2008–2009 and 2010-2012, corresponding to the global financial crisis and European debt crisis. Therefore, the financial crises intensify the total spillovers across ASEAN inflations.

Fig. 6 presents the inflation causality network of the ASEAN countries that is estimated according to the spillover index of Diebold and Yilmaz [1,2].[6] Note that the red (green) colour of a node illustrates the strongest net transmitter (recipient) of spillovers.[7] The edge size represents the magnitude of the pairwise spillover. The magnitude is also indicated by the colour (green (weak), light blue and blue (medium), and red (strong)). As seen in Fig. 5, the red-coloured nodes of Thailand (TH) and The Philippines (PH) are the net transmitters of inflation spillovers, while the green-coloured nodes of Indonesia (ID), Malaysia (MY), and Singapore (SG) are the net recipients of inflation from others. In particular, TH has the strongest influence (red-edged arrow and thickness) on its counterparts, indicating that

[6] To save space, the estimation results of the spillover index are not reported here. They are available on request.
[7] We use the open-source Gephi software to visualise network graphs (https://gephi.org).

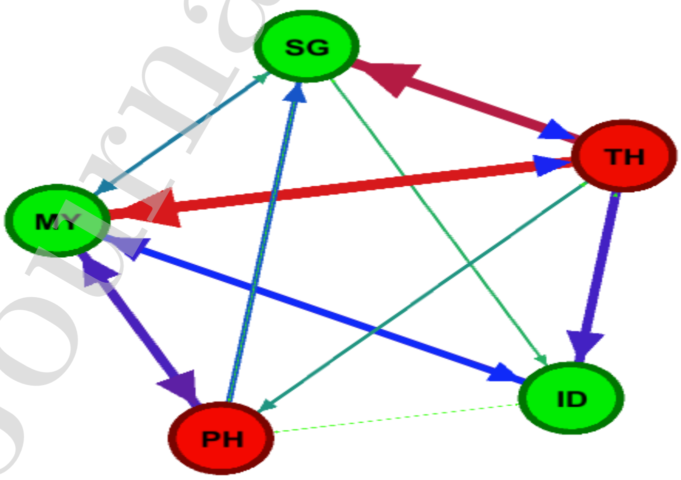
Thailand is the hub node of the inflation synchronization network across the ASEAN countries.

Fig. 5. Total spillovers across ASEAN inflations



Notes: The time evolution of spillovers indices is estimated using 50-month rolling windows.

Fig. 6. Inflation causality network



Notes: The red and green nodes correspond to the net transmitter and net recipient of spillovers, respectively. The edge size represents the magnitude of the pairwise spillover, and the magnitude is also reflected through various colours (green (weak), light blue and blue (medium), and red (strong)). The edge arrow indicates pairwise directional connectedness. ID, MY, PH, SG, and TH stand for Indonesia, Malaysia, The Philippines, Singapore, and Thailand, respectively.

6. Conclusion

Studies on inflation synchronization and inflation causality networks are important in that they reveal the interaction between business cycles, interest rates, and inflation rates. Economic theory indicates that decreases in interest rates generally lead to increases in inflation rates and to the creation of inflation cycles, as increasing money supply stimulates consumption and spending, and price increases in goods (combined with short-term shortages in supply) [49]. This negative relationship of dependence between interest rates and inflation rates gives rise to inflation cycles that in the mid- and long-terms shape country business cycles and their economic behaviour. Hence, understanding whether inflation cycle causality and inflation cycle synchronization take place across countries is of high importance in determining interest rate changes and money supply. Moreover, considering the increasing interdependence between regional economies via trade competition it is possible to predict inflation increases or decreases in one country by understanding how the inflation cycles of another country Granger cause the inflation cycles of the latter country. Policy makers from a certain country having identified positive led-lag inflation cycle dependence with another nation's inflation cycle may in advance take adequate measures to manage and mitigate inflation spillover influence from abroad. Information on positive inflation cycle synchronization could also be a motive to foster international trade diversification and regional economic co-operation, in cases when no inflation cycle synchronization is identified between countries.

Aware of the aforementioned importance inflation synchronization and inflation causality have for macroeconomic forecasting within a certain region, this paper examines the pairwise causality in inflation rates across time and frequencies, inflation cycle synchronization, and the inflation causality network for five ASEAN countries: Indonesia, Malaysia, The Philippines, Singapore, and Thailand. We draw our empirical results and conclusions by implementing dynamic conditional correlations (DCCs), a wavelet measure of cohesion for inflation cycle evolution assessment, and the spillover network index model of Diebold and Yilmaz [1,2]. We find evidence of time-dependent variation in the strength of co-movement between inflation cycles across countries. Positive network causality between inflation cycles and inflation integration across the ASEAN countries are identified. The lead-lag properties of economic indicators are observed to depend on the cycle's periodicity. The inflation synchronization is particularly pronounced in Thailand.

The implications of the obtained empirical results related to regional co-movement of inflation suggests that may be used to improve national inflation forecasting and to develop time-varying approaches for trade diversification and regional economic co-operation. The inflation integration identified between the countries modelled suggests that it is complicated for some countries in the region to significantly diverge from the inflation cycle patterns led by other ASEAN countries, making it difficult at some points in time to maintain inflation and the price of certain traded goods at a low level. On the other hand, the inflation integration across ASEAN countries, while being an indicator of nearly similar monetary policies, also suggests that the economies of the region may display similar growth patterns, although at different time periods.

Acknowledgments

We are grateful to the faculty members of the Economics Division at Linköping University for their valuable comments and helpful discussions. The third author (G. S. Uddin) is thankful for the financial support provided by the Jan Wallander and Tom Hedelius Foundation. The fifth author (S.-M. Yoon) is grateful for the financial support obtained from the Ministry of Education of the Republic of Korea and the National Research Foundation of Korea (NRF-2017S1A5B8057488).

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*Declaration of Interest Statement

November 18, 2019

Eugene Stanley
Editor
Physica A

Title: "*Inflation Cycle Synchronization in ASEAN Countries*"

Submitted to *Physica A*.

Dear Editor:

This manuscript has not been published or presented elsewhere in part or in entirety, and is not under consideration by another journal.

We have read and understood your journal's policies, and we believe that neither the manuscript nor the study violates any of these.

There are no conflicts of interest to declare.

I hope you will find it worthy of consideration.

Sincerely,

Seong-Min Yoon

(Pusan National University)