

Business Cycle Synchronization and Core-Periphery Patterns in the East African Community: A Wavelet Approach

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Abstract

Optimum currency area theory suggests that various characteristics are needed for a successful monetary union, including similarities in economic structures for both shocks and business cycles. Accordingly, this study uses continuous wavelets to investigate business cycle synchronization among countries of the East African Community, which is, a region working toward the establishment of a monetary union by 2024. Wavelet decomposition is an alternative and powerful tool for analyzing the comovement of business cycles. Cross-wavelet coherency suggests that the business cycles of Tanzania and Uganda were in phase with that of Kenya's at high and medium frequencies in the early 1990s and after the establishment of the customs union in 2005. Wavelet spectra clustering shows that Kenya, Tanzania, and Uganda form the core of the monetary union, whereas Burundi and Rwanda form the periphery. Overall, the wavelet analysis highlights the significance of asymmetric shocks and the prevalence of core-periphery patterns, which casts doubts on the eventual viability of the East African Monetary Union.

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I. Introduction

The extent to which economies are affected by similar shocks is the key to determining whether a group of countries is ready for a monetary union. Optimum Currency Area (OCA) theory, which was pioneered by Mundell (1961) and later explored by McKinnon (1963), Kenen (1969), Eichengreen (1990), De Grauwe and Wim Vanhaverbeke (1993), Frankel and Rose (1998, 2005), and De Grauwe (2014), suggests that a geographical area needs four characteristics to create an optimal single currency: similarities in economic structures (for both shocks and business cycles), trade integration, factor mobility, and a strong mechanism for risk sharing. The greater the extent to which these characteristics exist, the more the partner states are likely to benefit from a common currency.

OCA literature highlights that once a monetary union is in place, the enactment of two different monetary policies will not be possible because it will be difficult for countries in a monetary union to adjust when affected by asymmetric shocks. Therefore, business cycle synchronization must be considered when making monetary policy decisions, such as creating a monetary union. Several studies have addressed this issue by assessing business cycle synchronization and examining the degree to which business synchronization has been attained by any group of countries that envisages the creation of a common currency area or by countries that are already in a monetary union. Asongu *et al.* (2017) surveyed 70 empirical papers published in the past 16 years that discussed the proposed African monetary zones including the West African Monetary Zone, the East African Monetary Union (EAMU), the Southern African Monetary Union, and the African Monetary Union. Other authors have focused on existing monetary unions, namely, the European Monetary Union (EMU) and CFA zones (Duran and Lopes 2017).

Furthermore, Aguiar and Soares (2011a) argue that although a common business cycle might be insufficient to ensure the desirability of a monetary union, it is a necessary condition. The intuition behind this condition is

straightforward: countries with similar macroeconomic shocks are good candidates for a monetary union because they are affected similarly, and there will be no need to use the exchange-rate to adjust for asymmetric shocks once they join a monetary union.

The main aim of our paper is to investigate the degree of business cycle synchronization among East African Community (EAC) member countries before their scheduled monetary union is established in 2024.

The EAC was reestablished in 2000¹ and currently comprises six countries: Burundi, Kenya, Rwanda, South Sudan, Tanzania, and Uganda. The union began with just Kenya, Tanzania, and Uganda before it was joined by Rwanda and Burundi in July 2007. South Sudan joined the EAC in April 2016.

Kenya, Tanzania, and Uganda have enjoyed a long history of cooperation under several regional integration arrangements. Kenya and Uganda signed a customs union agreement in 1917, and Tanzania (called Tanganyika at the time) joined this union 10 years later. Following the long process of ratification, the first treaty establishing the EAC was signed in 1967; however, it collapsed a decade later in 1977. These countries also tried forming a currency union at different times. In 1905, a currency board was established to create a common currency for Kenya (called the East Africa Protectorate at that time) and Uganda (called the Uganda Protectorate at that time); Tanzania joined the board after the First World War. In 1919, the three countries constituted a new currency board, and the first East African shilling was adopted. Zanzibar joined this currency board in 1936. After independence, national currencies were pegged to the pound sterling (it is worth noting that these countries were all under British rule). In 1966, the common currency became a fully convertible legal tender in Kenya, Uganda, and Tanzania. Unfortunately, the depreciation of the sterling in the 1960s and 1970s led to the disintegration of the sterling area in 1972. The East African currency area formally ended in 1977 owing to a period of divergence in both inflation targets and exchange rates (Drummond *et al.* 2014).

The EAC is a key driver of the regional integration process in Eastern Africa, and it has gone through several steps for economic integration over the years. The protocol on the establishment of the EAC customs union was signed in 2004 and was formally established the following year. The

¹The EAC project was first introduced in 1967 but collapsed in 1977 owing to political differences among participating countries. It was reestablished by the 1999 treaty and came into force in 2000.

implementation of the common market protocol in 2010 and the monetary union protocol came into force in 2014² with a clear road map for the realization of the monetary union and the circulation of a single currency in 2024.³ The former EAC Secretary General stated that these stages of integration are being implemented in a progressive manner and major strides are being made to establish a political federation (Drummond *et al.* 2014). One can argue that the current efforts in forming the EAMU are built on a long history of economic and monetary arrangements in the region, and this situation explains why the three countries form the core of the monetary union, as evidenced by the findings of the current study.

Trade has significantly expanded within the EAC region, and this improvement is attributed to the implementation of the customs union and common market protocols. For example, the total exports from intra-EAC trade amounted to 3,327.6 million US dollars in 2015 from 1,206.2 million US dollars in 2006, an increase of 176% over just 9 years.⁴ In addition to the improvement in intraregional trade, EAC countries also strived to achieve macroeconomic convergence via the harmonization of fiscal and monetary policies among partner states and by reducing major divergences (e.g., by reducing inflation, placing an 8% ceiling on headline inflation, and maintaining the fiscal deficit, including grants, below the deficit ceiling of 3% of GDP) that can threaten the monetary union once it is in place (EAC 2013).⁵

However, despite considerable progress and the political will that has been gaining momentum, empirical evidence on the feasibility of a single currency is mixed. Some studies suggest that the EAMU is not feasible (Buigut 2011, Kishor and Ssozi 2011, Rusuhuzwa and Masson 2013, Drummond *et al.* 2014), whereas others find evidence in favor of it (Mkenda 2001, Bangaké 2008, Sheikh *et al.* 2011, Asongu 2013). Asongu *et al.* (2017) provided ample literature on the proposed African monetary unions.

Our study uses annual real GDP growth over the period of 1989–2015 for the five EAC member countries to analyze the feasibility of a monetary union. Unlike previous studies, we apply wavelet analysis, which combines time and frequency domain analyses. Wavelets are localized in time and frequency;

²It is worth noting that the monetary union that was scheduled to begin in 2012 missed its targets, and the partner states decided to postpone its implementation to 2024.

³Based on the information from the EAC website (www.eac.int)

⁴East African Community Facts and Figures, 2016 (www.eac.int)

⁵Protocol on the Establishment of the East African Community Monetary Union

therefore, they are ideal tools for analyzing nonstationary (nonperiodic) and transient time series. Wavelet analysis uncovers cyclicity and structural changes in a time series and can help assess the gradual effect of economic integration on the degree of business cycle synchronization. Rua (2010, p. 690) indicated the following: The degree of comovement can change across frequencies and over time and being able to capture such evolving features is crucial for a richer comovement assessment. To the best of our knowledge, the current study is the first study to apply this type of analysis to EAC countries.

Another strength of wavelet analysis is its ability to uncover core and periphery groups among potential monetary union members. The core forms a coherent group of countries that are characterized by synchronous business cycles, whereas countries in the peripheral group are less strongly advised to participate in the monetary union because their business cycles are less correlated with those of the core. This idea, which originated with Bayoumi and Eichengreen (1993) and was explored in other studies (Aguiar and Soares 2011a), stresses that the existence of core and periphery patterns is detrimental to a monetary union. Accordingly, we take it a step further and apply wavelet cluster analysis to uncover core-periphery patterns in the EAC. Overall, our wavelet analysis results show significant asymmetric shocks that affect economic activities in EAC countries and show the prevalence of core-periphery patterns. Kenya, Tanzania, and Uganda form the core, whereas Burundi and Rwanda tend to cluster together into a peripheral group. Taken together, our findings cast doubts on the readiness of EAC countries for a common monetary policy.

The remainder of this paper is organized as follows. Section 2 briefly reviews the related literature. Section 3 describes the wavelet methodology. Section 4 presents and discusses our empirical findings. Section 5 concludes.

II. Related Literature

Several studies have focused on cyclical comovements in a region that seeks the establishment of a common currency. The main focus of these studies is on developed countries, particularly countries in Europe. For instance, before the establishment of EMU, various studies analyzed

business cycle synchronization among EU countries. Artis and Zhang (1997) investigated the effects of the exchange-rate mechanism (ERM) of the European Monetary System on the international business cycle in terms of both linkages and cyclical fluctuation synchronization between countries. They found evidence of strong correlations between the business cycles of European countries after they started ERM, whereas the correlations of these countries' cycles with those of the United States and other nonparticipating ERM countries were weak. Angeloni and Dedola (1999) presented empirical evidence on the increase in the cyclical correlations of European countries with Germany before the EMU; this finding indicates a tendency toward the fulfillment of one of the OCA conditions. Dickerson *et al.* (1998) found that prior to the formation of the EMU, there was a huge difference in business cycles between European countries, thus leading them to conclude that there were two groups in existence: core countries (the Netherlands, France, Belgium, Luxembourg, and Germany) and the periphery (Greece, Ireland, Italy, Portugal, Denmark, the United Kingdom, and Spain).

To examine business cycle synchronization for the Czech economy and the 12 economies in the euro area, Slanicay (2013) applied a two-country DSGE model, decomposed the observed variables into contributions of structural shocks, and computed conditional correlations. He further examined how these correlations evolved over time by using quarterly data for 2000~2011. His findings suggest that productivity shocks in the tradable sector were the driving force behind the different business cycle behaviors, whereas investment efficiency shocks contributed to the symmetric behavior of the two economies.

Empirical literature on the feasibility of the EAMU differs in terms of the criteria of interest, the methodology, and the sample period. Mkenda (2001) used the generalized purchasing power parity (G-PPP) method to investigate the cointegration between the real exchange rates of EAC countries (excluding Rwanda and Burundi) for 1981~1998. Her findings suggest that EAC countries tended to be affected by similar shocks. Hence, she concludes that the EAC is an OCA. However, Buigut and Valev (2005) argue that the G-PPP method does not distinguish shocks from responses. Following Xu (2006), Kishor and Ssozi (2011) argue that if market prices and nominal exchange rates are often controlled by governments, the long-term exchange rates are unlikely to reflect common trends in market forces as expected in an

OCA. Hence, inferences based on G-PPP should be interpreted with caution.

By using the vector autoregressive methodology, Buigut and Valev (2005) investigated the similarity of underlying shocks in all five EAC countries. Their results indicate that supply and demand shocks were generally asymmetric. However, they found that the speed and magnitude of adjustment to shocks was similar across the countries. Therefore, they concluded that the further integration of EAC economies might lead to more favorable conditions for EAMU.

In light of the OCA criteria, Rusuhuzwa and Masson (2013) investigated the business cycle correlation and macroeconomic convergence among other aspects in EAC countries. They report that EAC member countries differ in several respects, namely, responses to asymmetric shocks and production structures. They further argue that these countries have had difficulties meeting the convergence criteria, particularly when it comes to fiscal deficits. The authors conclude that there is no clear evidence that the EAC is an OCA.

Kishor and Ssozi (2011) used an unobserved component model to measure business cycle synchronization as the proportion of structural shocks that are common across EAC countries. They also employed a time-varying parameter model to examine the evolution of business cycle synchronization. They found that although the degree of synchronization has increased since 2000 (when the reestablished treaty of the EAC came into effect), the proportion of shocks common across countries is still small, thus implying weak synchronization.

Buigut (2011) applied multivariate cointegration analysis to determine whether the EAC member countries would form a successful monetary union. The author covered a short period from 1997 to 2010 and analyzed comovements with respect to four variables: nominal and real exchange rates, monetary base, and real GDP. He found only a partial convergence of policies in EAC member countries. The author argues against a fast-track EAC monetary union process. On the basis of the evidence, he suggests that EAC member countries allow for a period of monetary policy coordination to promote further convergence and improve the chances of a credible and sustainable monetary union.

Thus far, we have discussed previous studies that were conducted in the time domain. We now present a review of studies that were conducted in the time-frequency domain by using wavelets. Aguiar and Soares (2011a)

argued that wavelets are suitable for analyzing the degree of business cycle synchronization because they reveal how the different periodic components of a time series evolve over time by estimating the spectral characteristics of a time series as a function of time. Accordingly, by comparing the wavelet spectra of two countries, one can check for a similarity in cycles and identify when and at what frequencies the cycles are synchronous. These authors used wavelets to study the degree of business cycle synchronization across EU-12 countries (countries already in the euro zone) and EU-15 countries (including the United Kingdom, Denmark, and Sweden). They found that the strength of business cycle synchronization varied across countries: France and Germany were the most synchronized with the rest of Europe, whereas Portugal, Greece, Ireland, and Finland did not show statistically relevant degrees of synchronization with Europe.

They further computed the wavelet spectra distance matrix and derived a euro-core and a euro-periphery in terms of business cycle synchronization. They argued that France and Germany form the core of the euro zone, whereas Portugal, Greece, Ireland, and Finland form the periphery.

Aloui *et al.* (2016) examined business cycle synchronization among the Gulf Cooperation Council (GCC) countries. Their time-frequency analysis showed that the business cycles were asynchronous not only among the existing GCC countries but also between existing and potential country members. Albulescu (2017) employed wavelets to investigate business cycle synchronization among the United Kingdom, the United States, and Germany. He found that the United Kingdom was more synchronized with the United States than with Germany. His wavelet analysis showed strong medium and long-term comovements between the United Kingdom and the United States and short-term comovements between the United Kingdom and Germany.

Unlike business cycle synchronization, relatively fewer studies have investigated the core-periphery patterns in monetary unions. Artis and Zhang (1998) applied cluster analysis to a dataset comprising ten countries joining the first wave of EMU and countries with prospective membership to the EMU; they added Canada, the United States, and Japan as controls. Their analysis divides the countries studied into two groups: the core (Germany, France, Austria, Belgium, and the Netherlands) and two peripheral groups (northern group: the Scandinavian countries, the United Kingdom, and Ireland; southern group: Greece, Spain, Italy, and Portugal).

Ferreira-Lopes and Pina (2011) used fuzzy clustering techniques to analyze the core periphery patterns and their evolution over time in a wide and long sample. On the basis of annual data for 1950~2005 and three monetary unions (comparing Europe with the United States and Canada on business cycle synchronization and core-periphery patterns), they found that European countries have progressed more toward a viable monetary union than the United States.

In summary, the literature discussed in this section highlights the importance of investigating the (*ex ante*) degree of business cycle synchronization and core-periphery patterns for an eventual well-functioning monetary union, as suggested by OCA theory. Our study is a contribution to this strand of literature because, to our knowledge, this is the first study to uncover the core-periphery patterns among EAC countries by using time-frequency analysis.

III. A Wavelet Analysis

Economic time series are often nonstationary (Harvey 1985, 1989). A major issue in the study of business cycles is finding appropriate techniques to isolate the cyclical components of macroeconomic time series. In a seminal paper on business cycles, Burns and Mitchell (1946) estimated the cycle by taking average monthly data. Stock (1987) indicated that the logic was to estimate the value that a variable would attain if it were observed at regular intervals in a business cycle time. This approach was subsequently criticized by Koopmans (1947), who referred to it as measurement without theory. The search for better techniques to decompose macroeconomic time series intensified in the 1980s. Several filtering techniques have been developed since the development of interalia high-pass filters (Hodrick and Prescott 1997) that block the lower-frequency components of stochastic cycles and band-pass filters (Baxter and King 1999, Christiano and Fitzgerald 2003) that let the components pass in a given frequency range. However, Pedersen (2001) indicated that it is an impossible task to devise an ideal filter in the presence of finite observations because filters inevitably entail distortionary effects (Caraianni 2012).

The application of wavelet tools for analyzing business cycles is very

recent in economic literature (Hallet and Richter 2006, Yogo 2008, Aguiar-Conraria and Soares 2011a, Fidrmuc *et al.* 2014). Wavelet analysis is an alternative and suitable tool for analyzing signals such as business cycles whose frequencies change with time. This is because it provides time-frequency localization and allows researchers to decompose nonstationary time series and uncover structural changes. Moreover, it is possible to identify leading or lagging relationships among the series. In the current study, we mainly follow the methodology of Aguiar-Conraria *et al.* (2008) and Aguiar-Conraria and Soares (2011a, 2011b). We then introduce wavelet transform and describe the different tools that we use wavelet power spectra (WPS), cross-wavelet coherency, phase differences, and wavelet spectra distances.

According to Rouyer *et al.* (2008), wavelet transform is an interaction between the time series and a mathematical function, which is called a daughter wavelet, which is derived from a mother wavelet $\psi(t)$. The latter is assumed to be a function of time with zero mean and satisfies a decaying property (Aguiar-Conraria and Soares 2011a). Hence, for a given set of parameters s and τ , the wavelet function is defined as follows:

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{|s|}} \psi\left(\frac{t-\tau}{s}\right), s, \tau \in \mathbb{R}, s \neq 0 \tag{1}$$

where τ is the translation parameter that controls the location of the wavelet, and s is the scaling parameter that controls its width. To ensure the comparability of the continuous wavelet transform (CWT) in time and in frequency, we apply the normalization factor $\frac{1}{\sqrt{|s|}}$. Thereafter, by using Equation (1), the CWT of a time series $x(t) \in L^2(\mathbb{R})$ is given by the following:

$$W_x(\tau, s) = \int_{-\infty}^{+\infty} x(t)\psi_{\tau,s}^*(t)dt = \frac{1}{\sqrt{|s|}} \int_{-\infty}^{+\infty} x(t)\psi^*\left(\frac{t-\tau}{s}\right)dt \tag{2}$$

where $*$ denotes the complex conjugate, and $L^2(\mathbb{R})$ denotes a set of square integrable real-valued functions. Several types of wavelets can be used for CWT. In line with previous studies, we opt for the Morlet wavelet (Goupillaud *et al.* 1984) for its advantages and its popularity as the mother wavelet over other wavelets such as the Paul, Mexican Hat, and derivative of

Gaussian wavelets. The Morlet wavelet is a complex-valued wavelet whose corresponding transform contains information on both amplitude and phase; this property is essential for studying business cycle synchronism between different time series (Aguiar *et al.* 2008, Rouyer *et al.* 2008, Aguiar-Conraria and Soares 2011b). The Morlet wavelet is defined as follows:

$$\psi_{\omega_0} = \pi^{-\frac{1}{4}} e^{i\omega_0 t} e^{-\frac{t^2}{2}} \quad (3)$$

where $\omega_0 = 6$ is the most common choice for achieving the optimal time-frequency balance by minimizing the Heisenberg uncertainty (Grinsted *et al.* 2004, Aguiar-Conraria and Soares 2011b, Olayeni 2016).

We then apply the CWT to define the WPS, which is also known as the wavelet periodogram. This gives us a measure of the variance distribution of the time series as a function of time and period/frequency in a 2D graph. The WPS is given by the following:

$$(WPS)_x(\tau, s) = |W_x(\tau, s)|^2 \quad (4)$$

where W_x is the wavelet transform of $x(t)$ in Equation (2). Accordingly, from wavelet transforms W_x and W_y of $x(t)$ and $y(t)$, respectively, one obtains the cross-wavelet transform $W_{xy} = W_x W_y^*$.

This cross-wavelet transform is used to obtain the cross-wavelet power (CWP), which is defined as $(CWP)_{xy} = |W_{xy}|$, and is interpreted as the local covariance between two time series at each time and frequency (Aguiar-Conraria and Soares 2011b). From the CWP, it is then possible to compute the cross-wavelet coherency R_{xy} , which is equivalent to the coefficient of correlation in a time-domain analysis. Cross-wavelet coherency depicts the regions where the two time series move together in time and in frequency. It is defined as follows:

$$R_{xy} = \frac{|S(W_{xy})|}{\left[S(|W_x|^2) S(|W_y|^2) \right]^{\frac{1}{2}}} \quad (5)$$

where $0 \leq R_{xy}(\tau, s) \leq 1$ and S is the smoothing operator in both time and

scale. Without smoothing, the coherency would be one at all scales and times (Aguiar-Conraria and Soares 2011b).

However, wavelet coherency does not tell us which series leads or lags the other, and this information is necessary when analyzing business cycles. The wavelet phase difference allows us to analyze synchronization and the delays of cycles between series across frequencies and time scales (Aguiar-Conraria and Soares 2011b). It is an angle that is computed as follows:

$$\phi_{xy} = \tan^{-1} \frac{\Im(W_{xy})}{\Re(W_{xy})} \tag{6}$$

where \Im and \Re are the imaginary and real parts, respectively, with $\phi_{xy} \in [-\pi, \pi]$.

Following Aguiar-Conraria and Soares (2011b), the interpretation of the phase difference is straightforward: when $\phi_{xy} \in (-\frac{\pi}{2}, \frac{\pi}{2})$, the time series $x(t)$ and $y(t)$ are in phase (positive correlation); when $\phi_{xy} \in \{[-\pi, -\frac{\pi}{2}) \cup (\frac{\pi}{2}, \pi]\}$, the two series move antiphase (negative correlation). When $\phi_{xy} \in \{(0, \frac{\pi}{2}) \cup (-\frac{\pi}{2}, -\pi)\}$, $x(t)$ leads $y(t)$; when $\phi_{xy} \in \{(-\frac{\pi}{2}, 0) \cup (\frac{\pi}{2}, \pi)\}$, $y(t)$ leads $x(t)$.⁶

For a deeper understanding of business cycle synchronization and to uncover core-periphery patterns, we clustered the wavelet spectra on the basis of the measures of dissimilarities and distance matrices. Following Rouyer *et al.* (2008) and Aguiar-Conraria and Soares (2011a), the distance between spectra W_x and W_y is computed as follows:

$$dist(W_x, W_y) = \frac{\sum_{k=1}^K w_k [d(I_x^k, I_y^k) + d(u_x^k, u_y^k)]}{\sum_{k=1}^K w_k} \tag{7}$$

where u_x^k and u_y^k are the singular vectors, I_x^k and I_y^k are the leading patterns, and w_k is the weight that is equal to the amount of the covariance explained by each axis. If the business cycles of each pair of countries are similar, we expect the distance to be close to zero.

⁶For a simplified and intuitive interpretation of the phase differences, see Figure 4 in Aguiar-Conraria and Soares (2011b p. 17).

IV. Data and Empirical Results

We use data extracted from the World Development Indicators (WDI) of the World Bank. Following existing literature, we measured real economic activity by real GDP. The extracted dataset consists of annual real GDP growth rates for five EAC countries: Burundi, Kenya, Rwanda, Tanzania, and Uganda (i.e., excluding South Sudan, for which sufficient data is unavailable). The series of available data span the period of 1961~2015 for Burundi, Kenya, and Rwanda; 1983~2015 for Uganda; and 1989~2015 for Tanzania. For this study, only the resulting common period is used, namely, 1989~2015.

It is always useful to start with a time-domain descriptive analysis. Table 1 reports the descriptive statistics of growth rates for the five EAC countries. For the common period, Burundi had the lowest mean growth rate at 1.2%, whereas Uganda had the highest at 6.6%, followed by Rwanda and Tanzania. Judging by the coefficient of variation (the ratio of the standard deviation to the mean), Uganda and Tanzania were by far the most stable economies, followed by Kenya. Burundi had the most unstable economic growth, which was mainly due to periods of civil war. Overall, the descriptive information in Table 1 shows that conflicts had a negative shock on the growth of East African economies, particularly Burundi, Rwanda, and—to a lesser extent—Kenya, because they experienced negative growth rates during conflict periods.

Table 1. Descriptive statistics for economic growth rates

(1989~2015)

| Country | Mean | Std. Dev. | CV | Min | Max |
|----------|------|-----------|--------|--------|-------|
| Burundi | 1.23 | 4.17 | 338.88 | -8.00 | 5.38 |
| Kenya | 3.65 | 2.39 | 65.32 | -0.80 | 8.40 |
| Rwanda | 5.31 | 13.37 | 251.67 | -50.25 | 35.22 |
| Tanzania | 5.26 | 2.21 | 42.04 | 0.58 | 8.46 |
| Uganda | 6.64 | 2.20 | 33.07 | 3.14 | 11.52 |

Figure 1 plots the real economic growth rates in EAC countries. The worst period was 1993~2000 because it was characterized by negative economic

growth in Burundi. The Burundian economy showed a period of sustained recovery during 2006~2014, but this was interrupted because of the political unrest that followed, and the Burundian economy decreased by 4% in 2015. Similarly, the economy of Rwanda experienced negative growth during 1990~1994, which was a period characterized by civil war. The worst year was 1994, during which the Rwandan genocide took place and the economy plummeted by 50%. The economic recovery of Rwanda started in 1995, with the economy growing at 35%. These two years (1994 and 1995) stand out in Figure 1 as outliers that result in excessive variations (Table 1). However, the economy of Rwanda has been growing steadily since 1995. In addition to the economies of Rwanda and Burundi, which have been affected by conflicts, the 2007~2008 Kenyan postelection crisis severely affected its economy, but there was a quick recovery in 2009. Overall, Figure 1 indicates that there have been relatively fewer variations after 1998; the gap has narrowed, and the economies seem to converge.

Figure 1. Time series plot of real economic growth

(EAC Countries, 1989~2015)

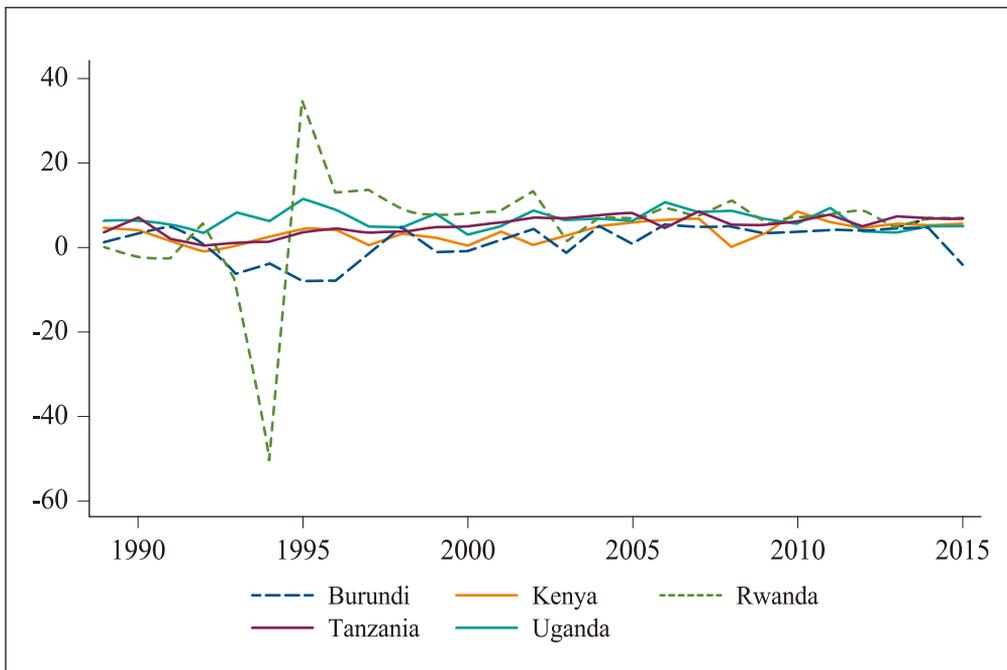
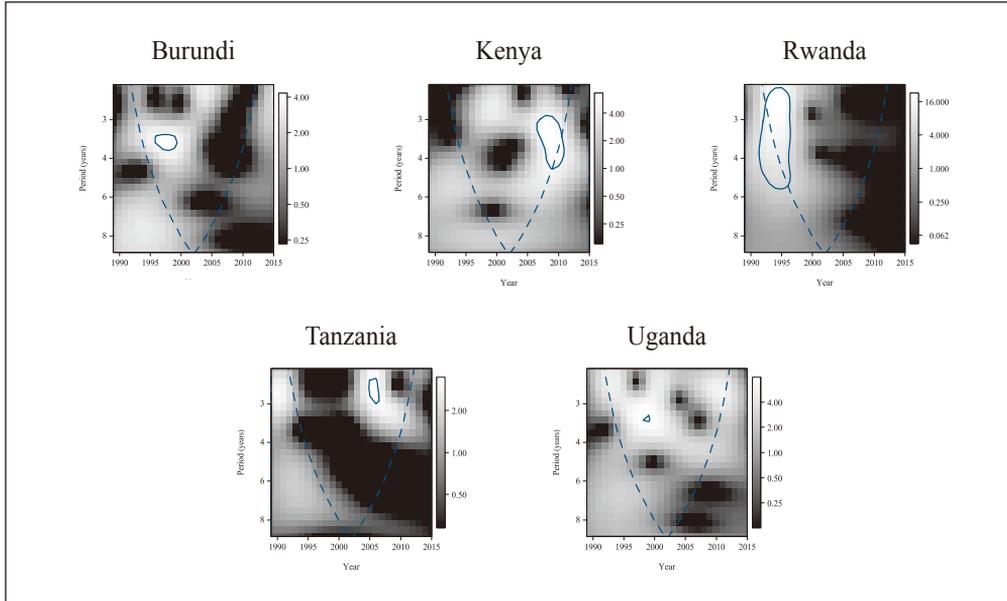


Figure 2 presents the WPSs of real economic growth of each of the five EAC countries. A WPS shows the local variance of the time series and helps localize the periods that contributed more to the overall variance in the series both in time and frequency. In terms of economic growth, high variability (white shade in the figure) can arise owing to policy changes or other major events that affect economic activity, such as instability. Looking at Burundi, there was high power at around 1993~2002 at cycles of three to four years. The thick black contour that designates the 5% significance level (and encompasses an area with significance below that level) fell in 1996~2000 at a cycle of three and one-half to around four years. During this period, Burundi experienced civil war, and as suggested by the time-domain descriptive analysis, this war took a toll on the economic activities of the country. The same pattern is observed in the Kenyan postelection violence in 2007, and in the turbulent period in Rwanda during the 1990s (until 1996). In the latter case, this is reflected by the high wavelet spectra at higher and medium frequencies of up to a six-year cycle. For Uganda, the variance looks more or less equally distributed across time but with relatively high power for cycles of up to four years. Tanzania experienced less volatile economic growth, except after 2005 when the power increased, and there is significance in the region corresponding to cycles of two to three years.

This analysis of the WPSs shows that conflicts were the main factor that negatively affected economic growth in some EAC countries. The long-time absence of countrywide conflicts in Tanzania, Uganda, and—to a lesser extent—Kenya explains stable economic activities in these countries.

Figure 2. WPSs of real economic growth

(1989~2015)



(Note) The power ranges from black (low variability) to white (high variability). The thick black contour indicates significance at the 5% level and encompasses an area with significance below that level. The cone of influence (COI) where the edge effects might distort the picture is shown as a discontinued thick black line, which is estimated by Monte Carlo simulations with 10,000 replicates using phase-randomized surrogate series. These plotted spectra are bias-corrected following Liu *et al.* (2007) and Veleda *et al.* (2012).⁷ The horizontal axis indicates the year. The vertical axis indicates the frequency in terms of periods: long and short periods correspond to low and high frequencies, respectively.

To investigate the comovement and lag/lead relationships among EAC economies, Figure 3 depicts the pairwise wavelet coherency of business cycles for the five countries, with its subfigures sorted on the basis of economy size: the wavelet coherencies of the largest economy (Kenya) versus the second-, third-, fourth-, and fifth-largest economies are listed first, the wavelet coherencies of the second-largest economy (Tanzania) versus economically smaller economies are given subsequently, and so on. The shading ranges from black (low coherency) to white (high coherency). The thick black contour indicates significance at the 5% level and encompasses an

⁷These authors rectify the bias in the WPS version of Torrence and Compo (1998). The bias results in the reduction of power at low periods. This correction is available in biwavelet package version 0.14. Computations were performed using R version 3.1.3.

area with significance below that level.

The arrows in Figure 3 indicate the phase difference between the economic growth series of two countries. The arrows pointed to the right and up indicate that the cycles are in phase with the cycle of the first-listed country leading that of the second listed country (imagine two sine curves of the same frequency with the peak of the first sine curve occurring slightly before that of the second; the sine curves are then in phase with the first leading the second). The arrows pointed to the right and down indicate that the cycles are in phase with the cycle of the second listed country leading that of the first; if the arrow points directly to the right, the cycles are completely in phase without either country's cycle leading the other. The arrows pointed to the left and up indicate that the cycles are antiphase with the second listed country's cycle leading that of the first (imagine two sine curves of the same frequency with the trough of the second sine curve occurring slightly before the peak of the second; the sine curves are then antiphase with the second leading the first). The arrows pointed to the left and down indicate that the cycles are antiphase with the cycle of the first-listed country leading that of the second; if the arrow points directly to the left, the cycles are completely antiphase without either country's cycle leading the other.

When significant coherence (below the 5% level) occurred, the business cycle of the Kenyan economy was in phase with those of Tanzania and Uganda, with Kenya leading both after 2000. It is important to mention that these three economies (Kenya, Tanzania, and Uganda) account for 92% of the total GDP of EAC. The GDPs of Kenya, Tanzania, and Uganda in 2017 were 74.9 billion US dollars, 52.1 billion US dollars and 25.9 billion US dollars according to WDI data, respectively, whereas the GDPs of Rwanda and Burundi were only 9.1 billion US dollars and 3.5 billion US dollars, respectively.

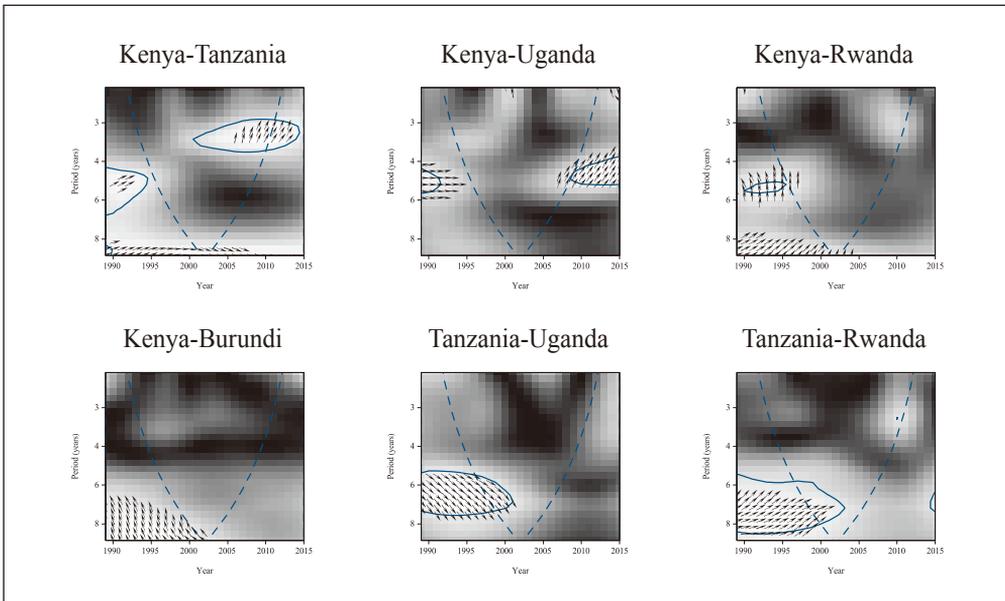
The Kenyan economy also led the Rwandan economy in phase at cycles of eight years until 2005 (albeit outside the area of significant wavelet coherence). Similarly, the business cycles of Kenya and Tanzania were in phase at long cycles of eight to nine years outside the area of significant wavelet coherence; this comovement shifted to short cycles of three to four years (with significant wavelet coherence) after 2005, which is the year that corresponds to the establishment of the EAC customs union. Kenya and Uganda were in phase at medium cycles of four to six years in the late 1980s

and early 1990s, and this comovement reemerged in 2005 after a long break since 1995.

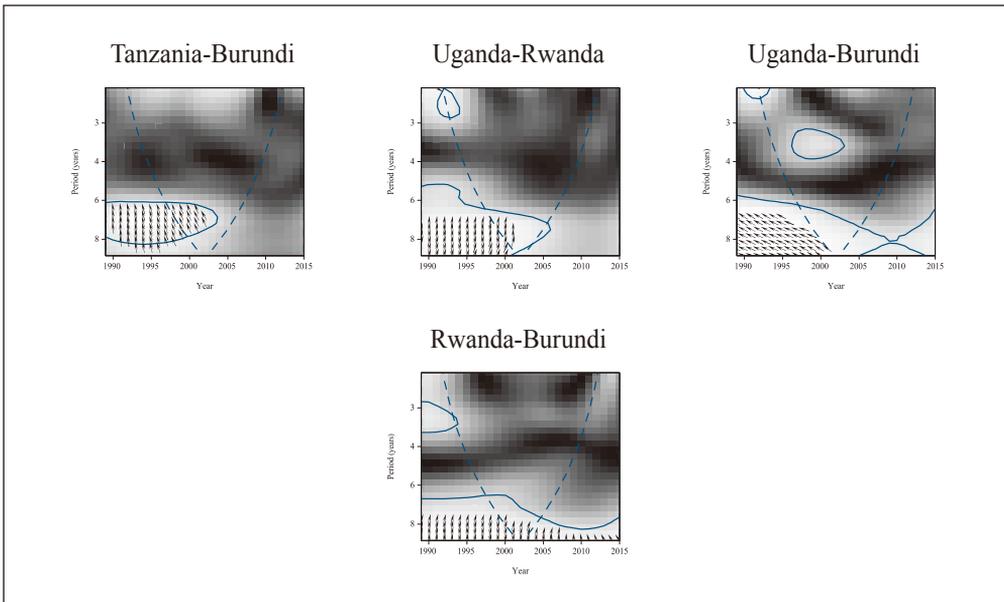
In Burundi, the business cycle was leading the business cycles of Kenya, Tanzania, and Uganda antiphase prior to 2001 at a very low frequency (long cycles of around seven to eight years, but not in an area of significant wavelet coherence with Kenya). The business cycle of Rwanda led that of Burundi in phase for the whole period at long cycles of 8 to 10 years until 2008, and the Burundi business cycle led the antiphase of Rwanda in these long cycles. These findings show how the business cycle of Burundi was detached from the rest of the EAC, except from Rwanda. Moreover, the fact that the business cycles of Burundi and Rwanda were in phase at long cycles for the whole period prior to 2008 implies that the two economies are historically more or less affected by common shocks, but this situation may be changing given the post-2008 information.

Figure 3. Wavelet coherency of real economic growth

(1989~2015)



(continued)

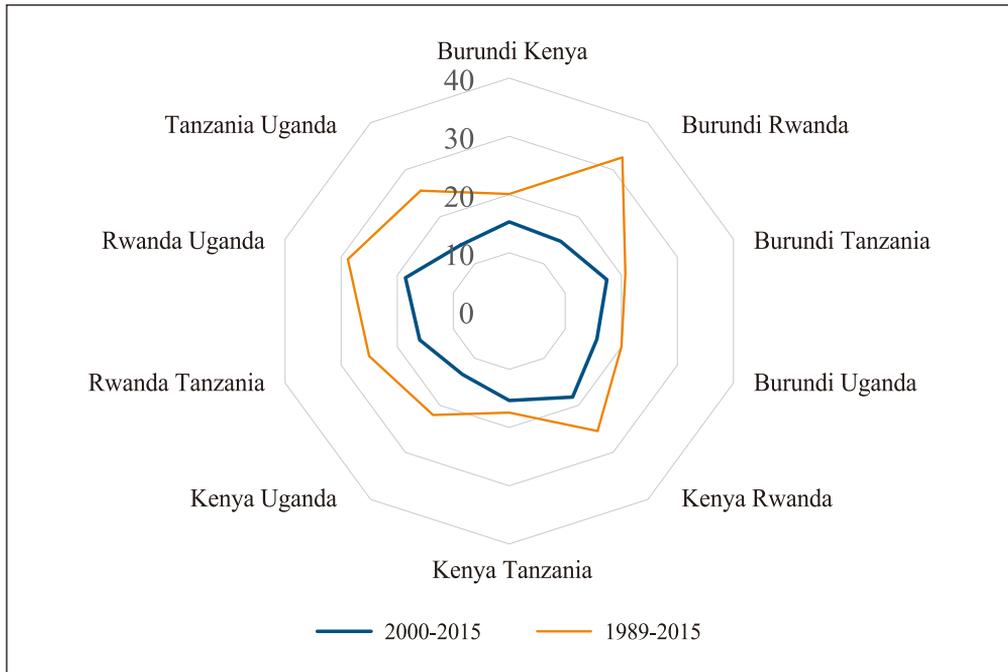


(Note) The power ranges from black (low coherency) to white (high coherency). The thick black contour indicates significance at the 5% and encompasses an area with significance below that level. The COI where edge effects might distort the picture is shown as a discontinued thick black line, which is estimated by Monte Carlo simulations with 10,000 replicates by using phase-randomized surrogate series. These plotted spectra are bias-corrected following Liu *et al.* (2007) and Veleza *et al.* (2012). The arrows indicate the phase difference between the economic growth series of two countries. The arrows pointed to the right and up (left and down) indicate that the series are in phase (antiphase) with the first series leading. The arrows pointed to the right and down (left and up) indicate that the series are in phase (antiphase) with the second series leading. The arrows pointing directly right (left) indicate that the series are completely in -phase (antiphase) with neither series leading the other.

Considering that our study, to the best of our knowledge, is the first study that looks at the time-frequency comovement among the EAC countries, comparisons with time-domain studies that have been conducted thus far cannot be established in a straightforward manner. However, the wavelet coherency analysis given earlier suggests that after the establishment of EAC in 2005, the Ugandan and Tanzanian economies became more synchronized with Kenya, with the economy of Kenya being the leader. As mentioned earlier, these countries have historically enjoyed the benefits of long cooperation under several regional integration arrangements; this situation explains the comovement. The rest of the EAC (Rwanda and Burundi) has had long-period business cycle synchronization. One tentative explanation for this synchronization is the similarity in the history of conflicts in the

two countries with the possibility of spillovers from one country to another. Although the economy of Rwanda recovered in 1995 and experienced fast growth thereafter, the Burundian civil war continued until 2006. Just recently, instability erupted again in the country, thus resulting in a deceleration in growth. Furthermore, the fact that Rwanda and Burundi joined the EAC seven years later in 2007 may explain the lack of synchronization between the two countries and the rest of EAC. However, even after joining EAC, there is no evidence that the economies of Rwanda and Burundi are catching up.

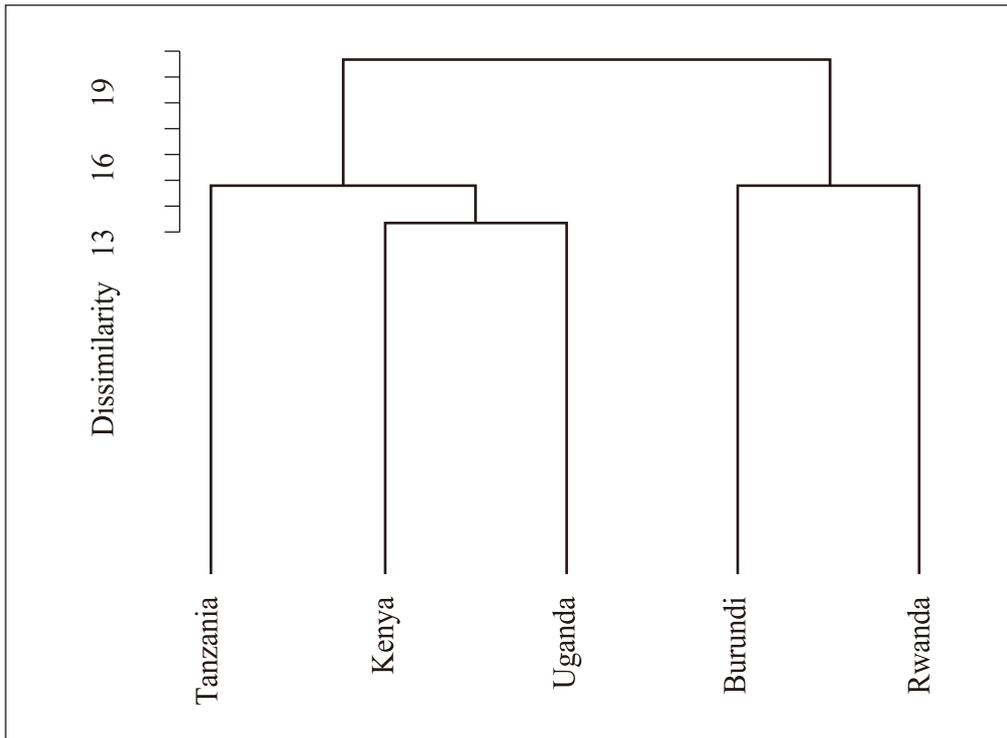
For further analysis, Figure 4 plots the pairwise wavelet spectra distances during 1989~2015 and after the establishment of EAC in 2000. Distances are computed on the basis of Equation (7). Table A1 in the Appendix 1 reports the wavelet spectra matrices. The logic behind these distances is that if two countries have similar business cycles, they also have similar wavelet spectra, thus indicating that the contribution (at each time and frequency) of cycles to the total variance is the same and that the ups and downs of each cycle occur simultaneously (Aguar-Conraria and Soares 2011a). Even though there is evidence that synchronization improved after 2000, there are still significant differences among the business cycles of EAC countries. Considering the period after the establishment of EAC in 2000, the most similar business cycle pairs are Kenya and Uganda (13.4578), Tanzania and Uganda (14.0328), and Burundi and Rwanda (14.8130), and the least similar are Rwanda and Uganda (18.5268), Kenya and Rwanda (18.2599), and Burundi and Tanzania (17.4169).

Figure 4. Wavelet spectra distances

To deepen our analysis, we now investigate the core-periphery pattern in the proposed EAMU. A homogeneous subset qualifies as the core of the monetary union if it accounts for a major share of the total output. The next wavelet tool helps us group wavelet spectra on the basis of spectra similarities in time and frequency. Figure 5 plots the cluster trees that are based on the wavelet spectra distance matrix. As illustrated in this figure, among the members of the proposed EAMU, Kenya, Uganda, and Tanzania are linked to each other at smaller distances, thus indicating that their economies face common shocks. Moreover, this group accounts for approximately 90% of the total EAC GDP and qualifies as the core of the monetary union. On the contrary, Rwanda and Burundi form another group, thus indicating that they also share similar business cycles (common shocks) and qualify as the periphery of EAMU. The core is expected to exercise a disproportionate influence on the common monetary policy to the detriment of the peripheral regions (Ferreira-Lopes and Pina 2011). These findings highlight that the core/periphery divide is another threat to the viability of EAMU, in addition to the low degree of synchronization among EAC economies.

Figure 5. Wavelet cluster tree of EAC business cycles

(2000~2015)



(Note) The cluster tree groups wavelet spectra based on time-frequency similarities. The tree is based on the computed distance (wavelet dissimilarity) matrix that sets the covariance threshold at 99% of the total covariance.

V. Summary and Conclusion

OCA theory suggests that various criteria need to be fulfilled for an eventual successful monetary union. We investigated the degree of synchronization of growth cycles among the potential members of EAMU and assessed the prevalence of core-periphery patterns. The novelty of our analysis is that we applied wavelet analysis, which is a powerful computational tool for assessing comovements with information on both time and frequency localizations. Accordingly, we used three wavelet tools: WPS, cross-wavelet coherency, and wavelet spectra clustering.

The WPSs showed volatile periods of growth cycles that were mainly due to conflicts, particularly in Rwanda and Burundi, and to postelection violence in Kenya to a lesser extent. A pairwise analysis of growth cycle comovements via cross-wavelet coherency highlighted important variations both in time and frequency, thus showing that when there is significant wavelet coherency with in phase business cycles, Kenya typically leads all countries in its business cycle (except it was completely in phase with Uganda at four- to six-year periods in the early 1990s), Uganda leads Tanzania, Tanzania leads Rwanda, and Rwanda leads Burundi. The evidence also suggests that the establishment of a customs union in 2005 improved synchronization among the Kenyan, Tanzanian, and Ugandan economies, with the Kenyan economy as the leader.

Furthermore, wavelet clustering based on a measure of dissimilarity via the matrix of distances between the wavelet spectra of the five countries highlighted the prevalence of core-periphery patterns in the EAC. The business cycles of Kenya and Uganda were synchronized with the business cycle of Tanzania. Considering that these three countries accounts for approximately 90% of the total EAC GDP, it qualifies as the core of the EAMU, whereas Rwanda and Burundi form the peripheral cluster. The core-periphery divide implies that the core is expected to play an anchor role in the proposed monetary union.

In summary, the presence of asymmetric shocks that affect the EAC economies and the prevalence of core-periphery patterns among these countries cast doubts on the readiness and eventual viability of the EAMU. However, the three countries that form its core seem to be potential candidates for the proposed EAMU.

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Appendix 1:

Table A1. Distance matrix

| Country | Burundi | Kenya | Rwanda | Tanzania | Uganda |
|-----------------|----------------|--------------|---------------|-----------------|---------------|
| Burundi | | 15.31518 | 14.81301 | 17.4169 | 15.64802 |
| Kenya | 20.10593 | | 18.25999 | 15.35453 | 13.4578 |
| Rwanda | 32.62151 | 25.47166 | | 15.98849 | 18.52685 |
| Tanzania | 20.71753 | 17.45358 | 24.98175 | | 14.03283 |
| Uganda | 20.00013 | 22.04568 | 28.80181 | 25.55958 | |

(Note) The lower part shows wavelet spectra distances during the period 1989~2015. The upper part shows distances after the establishment of EAC (2000~2015).