Globalization, Long Memory, and Real Interest Rate Convergence: A Historical Perspective

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Abstract: Globalization, a complex phenomenon, reflects the interaction of many technological, cultural, economic, social, and environmental trends. This paper investigates a narrow aspect of three waves of globalizations that occurred in the last 150 years, which refers to the stochastic properties of real interest rates and real interest rate differentials using fractional integration methods. The empirical results provide evidence that in all three globalization waves rejects the hypothesis that a unit root exists in the real interest rate series and supports the hypothesis of real interest rates converge across countries. We fail to find evidence, however, that the results are uniformly consistent across the three waves, suggesting that each globalization involves its own distinct stochastic dynamics.

Keywords: Globalization, fractional integration, real interest rate parity

JEL Classification: C22, E43, G15, N20

1. Introduction

The last 150 years of economic history witnessed severe economic and financial crises such as the Long Depression (1873-1896), the German hyperinflation (1919-1923), the Great Depression (1929-1939), and, more recently, the Great Recession (2007-2009). These episodes stand out as events that transformed the world capital markets and left interest arbitrage differentials higher and more volatile than ever before (Obstfeld and Taylor, 2003).

The last 150 years also witnessed three waves of globalization of trade and finance (Piketty, 2014; Palley, 2018). Globalization, a complex phenomenon, reflects the interaction of many technological, cultural, economic, social, and environmental trends. Given this complexity, any attempt to give a satisfactory definition of globalization is doomed to fail. Rather, we identify the process of globalization as one where the economies and the financial markets become increasingly integrated into a global economic system (Rodrik, 1998; Obstfeld and Taylor, 2003; Bordo, Taylor, and Williamson, 2003).

The first wave of globalization, called the first "golden age" of globalization (Zinkina et al., 2019), took place between 1870 and 1914 (Piketty, 2014; Palley, 2018), coming to an end with World War I. During this period, capital moved freely between countries and trade accelerated significantly (O'Rourke et al., 1994). The gold standard dominated this period, and a truly global market for capital emerged, to which the spread of the gold standard greatly contributed (Zinkina et al., 2019). The volume of global exports increased by nearly two orders of magnitude during 1800–1913 and a major part of this increase occurred during the "golden age" of globalization (Zinkina et al., 2019). In some respects, financial integration was more pronounced than it is today. International migration was certainly greater than it is today with roughly over 40 million people leaving Europe to seek their fortunes in the New World (Easterlin, 1961; Baines, 1994; Hatton et al., 1994). In 1870, world trade as a share of GDP was 17.7 percent, rising to 29.1 percent in 1913t (Ortiz-Ospina and Roser, 2017). Important drivers behind this wave of globalization were the new technologies of the era—steam engine, internal combustion engine, telegraph, electricity—that could bridge long geographical distances and the fact that many countries began to embrace liberal trade policy after years of protectionism. Great Britain led the world's economy with the British Empire as the epicenter of colonialism. The basis for the European free trade system was the 1860 free-trade pact between Great Britain and France. Many other European countries subsequently aligned themselves with this free-trade system (Collier and Dollar, 2002).[1]

Following the outbreak of World War I, the world economy went from a globalized to an almost autarkic world order in the space of a few decades. Global trade collapsed and trended downward throughout the interwar period. The second wave of globalization began in 1944 and ended in 1971 (Piketty, 2014; Palley, 2018). In 1946, world trade as a share of GDP was 15.1 percent. In 1972, it stood at 25.2 percent (Ortiz-Ospina and Roser, 2017). International regulations and organizations to support economic integration at the global level were created after World War II. During this period, the World Bank (IBRD) and the International Monetary Fund (IMF) were created to facilitate

[1] In Chapter II of the *Economic Consequences of Peace*, Keynes memorably reflected on that "happy age" of international commerce and freedom of travel that was destroyed by the cataclysm of the First World War. "The inhabitant of London could order by telephone, sipping his morning tea in bed, the various products of the whole earth, in such quantity as he might see fit, and reasonably expect their early delivery upon his doorstep; he could at the same moment and by the same means adventure his wealth in the natural resources and new enterprises of any quarter of the world, and share, without exertion or even trouble, in their prospective fruits and advantages; or he could decide to couple the security of his fortunes with the good faith of the townspeople of any substantial municipality in any continent that fancy or information might recommend. He could secure forthwith, if he wished it, cheap and comfortable means of transit to any country or climate without passport or other formality, could dispatch his servant to the neighboring office of a bank for such supply of the precious metals as might seem convenient, and could then proceed abroad to foreign quarters, without knowledge of their religion, language, or customs, bearing coined wealth upon his person, and would consider himself greatly aggrieved and much surprised at the least interference. But, most important of all, he regarded this state of affairs as normal, certain, and permanent, except in the direction of further improvement, and any deviation from it as aberrant, scandalous, and avoidable." (pp 8-9).

the smooth operation of the international exchange of goods, services, and assets. In addition, the General Agreement on Tariffs and Trade (GATT) began operation in 1948. GATT set the framework for several important steps towards increased global free trade, particularly via successive reductions in industrial tariffs. Cooperation among countries was based on the Bretton Woods Agreement of 1944. The United States became the leading economy in the world and the dollar became the monetary basis, or key currency, of the financial system.

From a political perspective, this era is dominated by the Cold War. The Bretton Woods system meant that nations fixed their currency exchange rate relative to the U.S. dollar, which, in turn, fixed the dollar's parity to gold. In an important aspect, the post-World War II international economy was less open than the period prior to World War I. Before World War I, the international flow of capital had been free. The Bretton Woods system, in contrast, was based on governmental control of the international flow of capital. Important drivers of the second wave were the new technologies of the era (jet planes, television, communication satellites, container shipping) (Collier and Dollar, 2002).

The third wave of globalization began in 1989 and continues to the present day (Piketty, 2014; Palley, 2018). Total trade stood at 59.37 percent of global GDP in 2018 as compared to 27.30 percent in 1970 while total exports stood at 30.06 percent of global GDP as compared to 13.64 percent in 1970 (World Bank, https://data.worldbank.org/indicator). Foreign direct investment increased twice as fast as trade. Microprocessors, personal computers, the Internet, and mobile phones are the technological drivers of the third wave. The United States lost its leading role in the world economy, which has become multi-polar, triangularized by the United States, the European Union, and China (Collier and Dollar, 2002).

Against this backdrop, we investigate a narrow aspect of the three episodes of globalization, Specifically, we investigate the stochastic properties of real interest rates and real interest rate differentials during these three waves of globalization. We answer two questions. First, what are the stochastic properties of real interest rates[2] in these three periods? In particular, are real interest rates persistent? Second, are these globalization waves characterized by convergence of real interest rates and are there any significant differences between their dynamic adjustments?

The theoretical importance of both questions in macroeconomic models has generated a great deal of empirical research. The real interest rate is a key variable in the consumption-based asset-pricing models (Lucas, 1978; Hansen and Singleton, 1983), central bank policy models (Taylor, 1993), and the transmission of monetary policy (Neely and Rapach, 2008). The convergence of real interest rates is a key assumption of monetary approach to exchange rate determination (Mussa, 1976; Frankel, 1979) and one of the most relied upon indicators of financial globalization (Levich, 2013) and of the degree of economic integration across countries (Phylaktis, 1999; Obstfeld and Taylor, 2003). The question of convergence concerns the validity of real interest rate parity (RIRP), a macroeconomic condition that combines two cornerstones in international finance, uncovered interest rate parity (UIRP) and expected purchasing power parity (PPP). Moreover, RIRP also has profound implications for the viability of an independent national monetary policy (Mark, 1985; Chortareas et al., 2018).

[2] The real interest rate was first formalized by Fisher (1930). Fisher expressed the real interest rate as the difference between the nominal interest rate and the inflation rate. According to the Fisher hypothesis, the nominal interest rate moves one-for-one with the expected inflation rate. Such a relationship implies that monetary policy has no effect on the real interest rate, which, in turn, suggests that the real interest rate follows a stationary process. On the other hand, the Mundell-Tobin proposition (Mundell, 1963; Tobin, 1965) suggests that the nominal interest rate moves less than one-for-one with the inflation rate because households, in response to increasing inflation, hold less money balances and more of other assets, which reduces the real interest rate. In addition, the so-called limited participation models (Christiano et al., 1997) imply that monetary shocks reduce real interest rates, which suggests that shocks to real interest rates may exhibit persistence (Güney et al., 2015).

The enormous body of research tries to identify the statistical properties of the real interest rate and test for convergence of real interest rates across countries. With few exceptions (i.e., Lai, 1997; Tsay, 2000; Sun and Phillips, 2004; Smallwood and Norrbin, 2008), most of the work, in both cases, has taken advantage of the unit-root methodology. For the unit-root approach to testing of real interest rate, see, among other, Rose (1988), King et al. (1991), Garcia and Perron (1996), Rapach and Weber (2004), Karanasos et al. (2006), and Neely and Rapach (2008). For the unit root approach to testing of real interest rate differentials, see, to cite a few, Wu and Chen (1998), Awad and Goodwin (1998), Wu and Fountas (2000), Nakagawa (2002), Holmes and Maghrebi (2004), Ferreira and León-Ledesma (2007), Arghyrou et al. (2009), Cuestas and Harrison (2010), Güney and Hasanov (2014), Çorakcı et al. (2017), and Bahmani-Oskooee et al. (2019).

We examine the stochastic properties of real interest rates and the hypothesis of convergence of real interest rates during the three waves of globalization using fractional integration techniques, which allow for a higher degree of flexibility in the dynamic specification of a stochastic process. Fractional integration provides a more general way to describe long-range dependence than the unit-root I(1)/I(0) representation and provides an alternative perspective to examine the unit-root hypothesis. From unit-root tests, one must conclude that either shocks to real interest rates are permanent or transitory (i.e., real interest rates are either I(1) or I(0)) and that all deviations from RIRP are permanent or all deviations quickly dissipate over time (i.e., the real interest rate differentials are either I(1) or I(0)). The fractional integration approach, however, offers an alternative paradigm, which has both theoretical and empirical support. In addition, the classical methods have very low power if the alternatives are in fact fractional (Diebold and Rudebusch, 1991; Hassler and Wolters, 1994; Lee and Schmidt, 1996; and, more recently, Ben Nasr et al., 2014.).

We estimate the fractional parameter using the approach developed by Robinson (1994), a Lagrange multiplier (LM) test that uses the Whittle function in the frequency domain (Dahlhaus, 1989). This exhaustive method allows the test of any real value of the fractional parameter *d*, including cases such as anti-persistence $(d < 0)$, short memory $(d = 0)$, stationary long memory $(0 < d < 0.5)$, nonstationary long memory $(0.5 \leq d < 1)$, unit roots $(d = 1)$, or explosive $(d > 1)$ behavior. Thus, mean reversion of real interest rates is possible even if the real interest rate is not I(0). Moreover, reversion to parity and convergence of real interest rates is possible even if the differential is also not I(0).

This method has several advantages with respect to other methods. For example, it remains valid in nonstationary contexts. That is, it does not require differentiation if the series is nonstationary as is the case with most standard unit-root or fractionally-integrated processes (Gil-Alana et al., 2017). Moreover, the limiting distribution of the test is standard normal and independent of the inclusion of deterministic terms and of the way of modelling the I(0) error term (see Gil-Alaña and Robinson, 1997). The analysis is univariate and eschews the problem of structural breaks.

A vast literature focuses on structural breaks and cross-sectional dependence in testing the stochastic properties of real interest rates and real interest rate differentials. As emphasized by Dreger (2010), however, focusing on historical episodes, the structural break argument is less relevant. Panel estimation delivers a relatively large sample size, but no individual information is extracted. Monetary models of exchange rates are built on the assumption that the RIRP holds on a bilateral basis. The historical perspective embedded in the paper offers the benefit in that it provides a natural set of benchmarks for our understanding of today's world (Obstfeld and Taylor, 2003). We use data on real interest rates for six European countries (France, Germany, the Netherlands, Italy, Spain, and the United Kingdom), Japan, and the United States compiled by Schmelzing (2020) and downloaded from the Bank of England website.

Dreger (2010) and Obstfeld and Taylor (2003) test the validity of the RIRP during distinct monetary regimes. In both cases, however, the approach remains embedded in the unit-root methodology. Dreger (2010) investigates whether the nominal exchange rate regime affects RIRP. The analysis uses 15 annual real interest rates and covers a long time span, 1870–2006. Four subperiods are distinguished and linked to fixed and flexible exchange rate regimes: the gold standard, the interwar float, the Bretton Woods system, and the current managed float. Panel unit-root techniques (Im et al.2003; Bai and Ng, 2004: Pesaran, 2007) are applied to increase the power of the tests, where cross-sectional correlation is embedded via common factor structures. The results suggest that RIRP holds as a long run condition irrespectively of the nominal exchange rate regime. Adjustment towards RIRP, however, is affected by both the institutional framework and the historical episode. Half-lives of shocks tend to be lower under fixed exchange rates and in the first part of the sample. Although barriers to trade and capital controls have been removed, they did not lead to lower half-lives during the managed float.

Similarly, Obstfeld and Taylor (2003) investigate RIRP, focusing on the four different subperiods that correspond to the four different monetary regimes: the gold standard (1890–1914), the interwar period (1921–38), Bretton Woods system (1950–73), and the float (1974–2000). Two unit-root tests are applied to the data for the period as a whole, as well as in the various sub-periods. The first test is the traditional augmented Dickey-Fuller (ADF) unit-root test (Dickey and Fuller, 1979), and the second is the DF-GLS test, one of a family of enhanced point-optimal and asymptotically efficient unit-root tests proposed by Elliott, Rothenberg, and Stock (1996). The hypothesis of a unit root is rejected in almost all cases at the 1-percent level in all periods except for the recent float, based on the more powerful DF-GLS test, which rejects the null of unit root more frequently than the standard ADF test. With respect to the recent float, the evidence against a unit root is stronger over the second sub-period (1986–2000) than over the first (1974–1986).

The structure of the paper is as follows. Section 2 presents the relevant theory. Section 3 outlines the statistical model incorporating deterministic components and long-range dependence. Section 4 considers the test results. Section 4 concludes the paper.

2. Relevant theory

The (*ex ante*) RIRP hypothesis emerges by assuming the validity of uncovered interest parity (UIP), ex ante relative purchasing power parity (PPP), and the Fisher conditions. UIP proposes that the nominal interest rate differential equals the expected rate of depreciation of the exchange rate. That is,

$$i_t - i_t^* = E_t(s_{t+1} - s_t) \tag{1}$$

where i_t and i_t^* denote the domestic and foreign nominal interest rates and s_t denotes the logarithm of the nominal exchange rate expressed as units of domestic currency per unit of foreign currency at time *t*. E_t is the expectation operator conditioned on information available at time *t*. A superscript * refers to foreign variables.

The *ex ante* relative PPP links the expected rate of depreciation of the exchange rate to the expected inflation rate differential:

$$E_t(s_{t+1} - s_t) = E_t(\pi_{t+1} - \pi_{t+1}^*) \tag{2}$$

where $\pi_{t+1} = p_{t+1} - p_t$ represents the domestic inflation rate at time *t*+1 and p_t equals the logarithm of the domestic price level at time *t*. The two parity conditions imply:

$$i_t - E_t\pi_{t+1} = i_t^* - E_t\pi_{t+1}^* \tag{3}$$

If the Fisher equation is valid for both the domestic and foreign country, then equation (3) implies the equality of the *ex ante* real interest rate across countries

$$E_t r_{t+1} = E_t r^*_{t+1} \tag{4}$$

where r_{t+1} denotes the domestic real interest rate at time *t*+1. Equation (4) gives the *ex ante* real interest rate parity (*ex ante* RIRP) condition, or, stated differently, the hypothesis that the *ex ante* real interest rates equalize across countries. Under the assumption of rational expectations, the difference between the *ex post* real interest rates (i.e., the real interest rate differential), equals a random error term related to the inflation forecast error. That is,

$$RIRD_{t+1} = r_{t+1} + r^*_{t+1} = \varsigma_{t+1} \tag{5}$$

where $\varsigma_{t+1} = \varepsilon_{t+1} - \varepsilon^*_{t+1}$ represents the inflation differential forecasting error which is serially uncorrelated with zero mean and $RIRD_{t+1}$ denotes the real interest rate differential at time *t*+1. Equation (5) provides the basis for the empirical analysis. We test the validity of RIRP in the long run by examining whether real interest rate differentials are mean reverting.

3. Methodology

Fractional integration analysis involves annual data on long-term real interest rate for eight countries over the three globalization periods from 1870 to 1914, 1944 to 1971, and 1989 to 2018. The countries are Spain, France, Germany, Holland (The Netherlands), Italy, Japan, the United Kingdom, and the United States.

We define the real interest rate r_t as the difference between the nominal interest rate, i_t, and the rate of inflation, π_t. That is, $r_t = i_t - \pi_t$. Then the real interest differential $rdiff_t^{US}$ is defined as the difference between the real interest rate of a given country and the real interest rate of the United States, $r_t^{US} = i_t^{US} - \pi_t^{US}$, taken as the reference country, $rdiff_t^{US} = r_t - r_t^{US}$.

The Lagrange Multiplier (LM) procedure uses the Whittle function in the frequency domain and tests the null hypothesis $H_0 : d = d_0$ for any real value of d_0 in a model given by:

$$y_t = \beta_0 + \beta_1 t + x_t, \quad t = 1,...,T \qquad (6)$$

where y_t is the observed series, β_0 and β_1 are the coefficients corresponding, respectively, to the intercept and linear time trend, and x_t is an I(d) process defined as:

$$(1-L)^d x_t = u_t, \quad t = 1,...,T \qquad (7)$$

where u_t is an I(0) process (defined as a covariance stationary process with spectral density function that is positive and finite at all frequencies). This includes for u_t, the white noise case and the ARMA process of the form:

$$\Phi_p(L)u_t = \Theta_q(L)\varepsilon_t \qquad (8)$$

where all the roots of the AR polynomial $\Phi_p(L)$ and the MA polynomial $\Theta_q(L)$ are outside the unit circle, L is the lag operator ($Lx_t = x_{t-1}$). Using equations (7) and (8) together, we can identify x_t as an autoregressive fractionally-integrated moving-average process, ARFIMA (*p, d, q*). The operator $(1-L)^d$ is the fractional filter defined by means of the gamma function $\Gamma(\cdot)$ as follows:

$$(1-L)^d = \sum_{k=0}^{\infty} \frac{\Gamma(k-d)L^k}{\Gamma(-d)\Gamma(k+1)}, \qquad (9)$$

where the parameter d can assume any real value. Robinson (1994) shows that under certain very mild regularity conditions, the LM-based statistic $\hat{r}$ converges in distribution to $N(0,1)$.

We estimate equations (6) and (7) for a) real interest rates and b) real interest rate differentials. For each model, we also consider the three standard cases of a) no intercept or deterministic trend $(\beta_0 = 0, \beta_1 = 0)$, b) only an intercept $(\beta_0$ unknown and $\beta_1 = 1)$, and c) both an intercept and linear time trend (both β_0 and β_1 unknown).

Regardless of the case considered, the model in equations (6) and (7) implies that y_t is a stationary process only if $d < 0.5$. Otherwise, if $d \geq 0.5$, it is not covariance-stationary and is highly persistent. In the latter case, y_t can either be mean-reverting $(d < 1)$) or not $(d \geq 1)$. The estimation of *d* enables one to distinguish between unit-root and near-unit-root processes.

4. Test results

Tables 1 - 3 present the estimates of the fractional parameter *d* and related deterministic components. We highlight in bold the significant models according to the deterministic terms. In parenthesis, we report the 95 percent confidence bands of non-rejection values of *d* using Robinson's (1994) parametric approach.

Each table includes two panels. Panel A displays the estimates of persistence of the real interest rates, while panel B displays the estimates of *d* for the real interest rate differentials with respect to the U.S. real interest rate. Finally, Tables 1, 2, and 3 present the findings for the first, second, and third waves of globalization, respectively,

Table 1 presents the estimates related to the first wave of globalization from 1870-1914. From Panel A, we observe that no cases prove adequate for the specification with $\beta_0 = 0$ and $\beta_1 = 0$. The cases of Spain, France, Germany, Italy, and the United States require a linear time trend and intercept, while Holland, Japan, and the United Kingdom require only the intercept. Evidence of mean reversion of the real interest rates (i.e., d is significantly below 1) emerges in all cases. Persistence or long memory (i.e., $0 < d < 1$) appears in the cases of Spain, Holland, and the United Kingdom; short memory (i.e., $d = 0$) appears in the cases of Germany, Italy, Japan, and the United States. France displays anti-persistence ($d < 0$). [3]

From Panel B, we note that the model requires a time trend and intercept in three cases of interest rate differentials—France-US, Italy-US, and UK-US. The specification with an intercept only occurs in the Spain-US case. Germany-US, Holland-US, and Japan-US require no regressors. All real interest rate differentials exhibit evidence of mean reversion, which supports the convergence hypothesis. Long memory appears only in the case of Spain-US, which indicates that convergence in this case required more time. In the remaining cases, we cannot reject the I(0), stationary, hypothesis. Thus, these results suggest that convergence of real interest rates occurs in the first globalization wave. In the long memory cases, however, shocks take a much longer time to disappear completely than in the short memory case. Table 2 presents the estimates related to the second globalization wave from 1944 to 1971. From Panel A, we observe that only for Spain does the specification with $\beta_0 = 0 \; and \; \beta_1 = 0$ prove adequate. The model requires the linear time trend and intercept in the cases of Germany, Holland, Japan, the United Kingdom, and the United States. France and Italy only require the intercept. Evidence of

[3] Anti-persistence does not appear as frequent phenomenon in economics. Long-memory properties mostly focus on persistence. Anti-persistence, however, does appear in a few papers. Caporale, et al. (2020) find evidence of anti-persistence in European stock markets. Dimitrova et al. (2019) find several episodes of significant anti-persistence in the BTC-USD and S&P500 stock market indexes. Anti-persistent behavior exhibits prolonged damped oscillations. Persistent and anti-persistent processes are two well-known examples of time-series models with hyperbolic decay. In the time domain, persistent processes show a positive long-range dependence between the observations, while anti-persistent often reverse direction and exhibit strong negative autocorrelations. In terms of the spectral density, persistence shows a singularity of the spectrum at the origin, while anti-persistent time series exhibit zero spectral density at the origin (Dittmann and Granger, 2002). Persistent processes trend locally while anti-persistent processes avoid trends, switching signs more frequently than a random process (i.e., it is more volatile than the random walk).

mean reversion of the real interest rates (i.e., d < 1), appears in all cases except Spain and France. Persistence and long memory (*0<d*) appears in the cases of France and the United States. Short memory (i.e., $d = 0$) appears in all the remaining cases. We find no evidence of anti-persistence (d < 0).

From Panel B, we note that the model requires a time trend and intercept in only two cases, Holland-US and Japan-US. The specification with an intercept only occurs in three cases, France-US, Germany-US, and Italy-US. Spain-US and UK-US require no regressors. Real interest rate differentials exhibit evidence of mean reversion in all cases, which supports the convergence hypothesis. France-US, however, displays a very high degree of persistence. Long memory occurs only in the case of France-US, while we cannot reject the short memory hypothesis in the cases of Spain-US, Italy-US, Japan-US, and UK-US. Anti-persistence occurs for Germany-US and Holland-US, indicating a non-monotonic pattern of convergence. Thus, these results suggest that convergence of real interest rates also occurs in the second globalization wave.

Table 3 displays the estimates related to the third globalization wave from 1989 to 2018. From Panel A, we observe that the model requires the linear trend and intercept specification in all cases. Evidence of mean reversion of the real interest rates $(d < 1)$ is present in all cases. Persistence and long memory appear in the cases of Spain and Italy, while short memory ($d = 0$) is present in all the remaining cases. We find no evidence of anti-persistence ($d < 0$).

From Panel B, the model requires a time trend and intercept in three cases—France-US, Germany-US, and Holland-US. The specification with an intercept only occurs in two cases—Italy-US and Japan-US. Spain-US and UK-US require no regressors. All seven cases exhibit evidence of mean reversion, which supports the convergence hypothesis. The short-memory hypothesis, however, occurs only in three cases, France-US , Germany-US, and Japan-US. Long memory, on the other hand, occurs in four cases—Spain-US, Holland-US, Italy-US, and UK-US.. This suggests that during the third globalization wave, convergence of real interest rates exists. The number of cases, however, of long memory exceeds that of the previous two globalizations, which indicates that on average the convergence process takes longer to reach equilibrium. On the other hand, we find no evidence of anti-persistence.

During the first wave of globalization Great Britain started to dominate the world, both geographically, through the establishment of the British Empire, technologically, through the innovations of the industrial revolution, and financially, through the hegemonic role of the pound sterling during the gold standard (Spahn, 2001). For these reasons we conduct an additional analysis of the first wave and consider the case where the UK is the reference country, i.e., $rdiff_t^{UK} = r_t - r_t^{UK}$ The results do not show significant differences and are presented in Table 4. In all cases, we cannot reject the hypothesis of mean reversion of the real interest rate differentials. As for the deterministic components, no deterministic terms are required in the case of Japan, whereas an intercept is required for Italy, Germany and France, and a time trend for the remaining cases of Holland, Spain and the US. Finally, the estimates of the fractional parameter d are negative in all except one case, Spain. However, the null hypothesis of anti-persistence cannot be accepted, and short memory behavior cannot be rejected in any single case.

The general findings suggest two important conclusions. First, we reject the null hypothesis of a unit root in real interest rates, implying mean reversion of real interest rates. Second, we also reject the null hypothesis of unit root in the real interest rate differentials, implying convergence of real interest rates. An interesting difference also exists in these findings. The stochastic behavior of both real interest rates and real interest rate differentials is not uniformly consistent across the three globalization waves. Rather, the fractional parameter exhibits switching behavior, crossing over from short memory to persistence and from short memory and persistence to anti-persistence, and *vice versa* This emphasizes the main point of applying fractional integration methods. They discern different aspects of mean reversion.

First, consider the real interest rate estimates. The preponderance of the outcomes indicates short-memory, 16 out of 24 times. Waves 2 and 3 include six short-memory outcomes. The exceptions are France and the United States that record long-memory outcomes in wave 2 and Spain and Italy that record long-memory outcomes in wave 3. Wave 1 includes the most diversity with France recording an anti-persistence outcome and Spain, Holland, and the United Kingdom recording long memory outcomes.

Second, consider the real interest rate differentials. Once again, the preponderance of the outcomes indicates short memory, 13 out of 21 times. Wave 1 shows the most consistency with all countries recording short-memory outcomes except for Spain, which records a long-memory outcome. The results from the UK-based differentials, however, are even stronger in favor of the RIRP, as they indicate short-memory outcomes in all cases, including Spain. Wave 3 includes four countries with long-memory outcomes—Spain-US, Holland-US, Italy-US, and UK-US. The other real interest rate differentials record short memory outcomes. Finally, in wave 2, France-US records a long-memory outcome and Germany-US and Holland-US record anti-persistence outcomes. The other four real interest rate differentials record short-memory outcomes.

5. Concluding comments.

This paper provides first-time evidence on the stochastic behavior of real interest rates and real interest rate differentials during three waves of globalization, 1870-1914, 1944-1971, and 1989-2018. We apply fractional integration methods, a preferable approach to the standard ARMA framework based on the classical dichotomy I(0)/I(1), since it allows the integration parameter to assume fractional values and, thus, capture a much wider range of stochastic dynamics. Our main conclusion is rather simple. We reject the null hypothesis of a unit root in real interest rates $(d < 1)$, and, in real interest differentials, which confirms the validity of the real interest rate parity in times of globalization. Beyond that, however, each globalization wave exhibits its own distinct dynamics with the stochastic behavior of both real interest rates and interest rate differentials switching, within the mean reversion framework, from short memory to long memory and *vice versa*, as well as from persistence to anti-persistence, and *vice versa*.

Table 1. Estimates of *d* during the first globalization wave (1870-1914) US-based differentials

Country	No regressors	With intercept	With a time trend
Panel A: Real Interest Rates			
SPAIN	0.57 (0.41, 0.78)	0.44 (0.29, 0.69)	**0.31 (0.07, 0.67)**
FRANCE	0.21 (0.06, 0.51)	0.04 (-0.09, 0.22)	**-0.53 (-0.74, -0.26)**
GERMANY	-0.24 (-0.35, 0.09)	-0.24 (-0.43, 0.06)	**-0.40 (-0.62, 0.02)**
HOLLAND	0.35 (0.15, 0.62)	**0.26 (0.10, 0.53)**	0.13 (-0.11, 0.51)
ITALY	0.04 (-0.15, 0.37)	0.03 (-0.14, 0.29)	**-0.09 (-0.30, 0.24)**
JAPAN	-0.09 (-0.33, 0.47)	**-0.09 (-0.40, 0.46)**	-0.09 (-0.41, 0.47)
UK	-0.27 (-0.03, 0.59)	**0.18 (0.00, 0.51)**	0.11 (-0.19, 0.50)
US	0.23 (0.01, 0.47)	0.15 (0.00, 0.34)	**-0.18 (-0.45, 0.19)**
Panel B: Real Interest Rate Differentials			
SPAIN – US	0.27 (0.07, 0.56)	**0.22 (0.04, 0.53)**	0.14 (-0.11, 0.53)
FRANCE – US	-0.01 (-0.16, 0.25)	-0.01 (-0.16, 0.23)	**-0.22 (-0.43, 0.13)**
GERMANY – US	**0.04 (-0.18, 0.41)**	0.04 (-0.15, 0.32)	-0.03 (-0.22, 0.29)
HOLLAND – US	**0.01 (-0.18, 0.26)**	0.01 (-0.18, 0.29)	0.00 (-0.20, 0.29)
ITALY – US	0.00 (-0.14, 0.26)	0.00 (-0.18, 0.28)	**-0.04 (-0.23, 0.26)**
JAPAN – US	**-0.08 (-0.31, 0.37)**	-0.08 (-0.34, 0.37)	-0.14 (-0.42, 0.36)
UK – US	0.00 (-0.16, 0.22)	0.00 (-0.15, 0.20)	**-0.16 (-0.34, 0.09)**

Note: In bold, the most adequate specification in relation to the deterministic terms. In parenthesis the 95 percent confidence band of non-rejection values of *d* using Robinson's (1994) parametric approach.

Table 2. Estimates of *d* during the second globalization wave (1944-1971) US-based differentials

Country	No regressors	With intercept	With a time trend
Panel A: Real Interest Rates			
SPAIN	**0.29 (-0.37, 1.03)**	0.26 (-0.28, 1.05)	0.14 (-0.41, 1.05)
FRANCE	1.04 (0.61, 1.72)	**0.79 (0.46, 1.74)**	0.74 (0.36, 1.92)
GERMANY	0.01 (-0.13, 0.23)	0.01 (-0.18, 0.27)	**-0.21 (-0.42, 0.11)**
HOLLAND	0.30 (0.06, 0.50)	0.26 (0.06, 0.51)	**0.11 (-0.12, 0.44)**
ITALY	0.06 (-0.22, 0.45)	**0.06 (-0.19, 0.47)**	1.14 (-0.05, 1.29)
JAPAN	0.29 (0.11, 0.57)	0.27 (0.10, 0.51)	**0.18 (-0.02, 0.47)**
UK	0.51 (0.28, 1.21)	0.52 (0.30, 1.24)	**0.19 (-0.38, 1.32)**
USA	0.30 (0.07, 0.73)	0.29 (0.08, 0.69)	**0.09 (0.21, 0.64)**
Panel B: Real Interest Rate Differentials			
SPAIN – US	**0.06 (-0.16, 0.49)**	0.06 (-0.20, 0.49)	0.02 (-0.34, 0.50)
FRANCE – US	0.98 (0.59, 1.54)	**0.72 (0.44, 1.56)**	0.66 (0.35, 1.62)
GERMANY – US	-0.46 (-0.56, -0.28)	**-1.01 (-1.14, -0.63)**	-0.98 (-1.19, -0.64)
HOLLAND – US	-0.70 (-0.81, -0.02)	-0.62 (-0.88, -0.02)	**-0.67 (-0.96, -0.01)**
ITALY – US	0.05 (-0.23, 0.46)	**0.04 (-0.21, 0.52)**	1.12 (-0.07, 1.47)
JAPAN – US	0.13 (-0.08, 0.48)	0.12 (-0.07, 0.42)	**0.04 (-0.19, 0.38)**
UK – US	**-0.03 (-0.31, 0.43)**	-0.03 (-0.30, 0.43)	-0.02 (-0.29, 0.45)

Note: See Table 1.

Table 3. Estimates of *d* during the third globalization wave (1989-2018) US-based differentials

Country	No regressors	With intercept	With a time trend
Panel A: Real Interest Rate			
SPAIN	0.56 (0.34, 0.84)	0.43 (0.27, 0.64)	**0.43 (0.25, 0.66)**
FRANCE	0.65 (0.44, 0.91)	0.46 (0.34, 0.58)	**-0.11 (-0.32, 0.19)**
GERMANY	0.66 (0.44, 1.02)	0.48 (0.34, 0.67)	**-0.09 (-0.35, 0.30)**
HOLLAND	0.62 (0.38, 0.99)	0.45 (0.28, 0.62)	**0.16 (-0.16, 0.62)**
ITALY	0.63 (0.42, 0.88)	0.45 (0.31, 0.61)	**0.40 (0.24, 0.60)**
JAPAN	0.48 (0.25, 0.79)	0.27 (0.19, 0.60)	**-0.14 (-0.53, 0.43)**
UK	0.66 (0.44, 0.95)	0.58 (0.37, 0.88)	**0.35 (-0.12, 0.86)**
USA	0.57 (0.39, 0.75)	0.42 (0.28, 0.59)	**-0.11 (-0.42, 0.43)**
Panel B: Real Interest Rates Differential			
SPAIN – US	**0.38 (0.18, 0.65)**	0.37 (0.18, 0.63)	0.42 (0.23, 0.66)
FRANCE – US	0.16 (-0.15, 0.50)	0.12 (-0.10, 0.36)	**-0.01 (-0.25, 0.36)**
GERMANY – US	0.13 (-0.12, 0.42)	0.13 (-0.11, 0.41)	**0.00 (-0.12, 0.30)**
HOLLAND – US	0.36 (0.05, 0.78)	0.34 (0.05, 0.75)	**0.47 (0.16, 0.82)**
ITALY – US	0.46 (0.24, 0.80)	**0.42 (0.21, 0.69)**	0.46 (0.26, 0.71)
JAPAN – US	0.19 (-0.22, 0.73)	**0.17 (-0.18, 0.71)**	0.17 (-0.19, 0.70)
UK – US	**0.47 (0.17, 0.94)**	0.50 (0.17, 0.97)	0.46 (-0.01, 0.96)

Note: See Table 1.

Table 4. Estimates of *d* during the first globalization wave (1870-1914) UK-based differentials

Country	No terms	An intercept	A linear time tren
SPAIN – UK	0.42 (0.26, 0.65)	0.33 (0.19, 0.56)	**0.17 (-0.04, 0.50)**
FRANCE – UK	-0.16 (-0.36, 0.18)	**-0.15 (-0.38, 0.16)**	-0.13 (-0.35, 0.17)
GERMANY – UK	-0.31 (-0.64, 0.09)	**-0.27 (-0.49, 0.08)**	-0.25 (-0.47, 0.12)
HOLLAND – UK	0.04 (-0.12, 0.28)	0.04 (-0.11, 0.27)	**-0.07 (-0.26, 0.21)**
ITALY – UK	-0.07 (-0.22, 0.21)	**-0.06 (-0.27, 0.20)**	-0.11 (-0.31, 0.18)
JAPAN – UK	**-0.11 (-0.38, 0.46)**	-0.11 (-0.42, 0.47)	-0.12 (-0.43, 0.47)
UK – UK	-0.00 (-0.16, 0.24)	-0.00 (-0.15, 0.20)	**-0.16 (-0.34, 0.09)**

Note: In bold the selected specification for each series.

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