

# ”Structural” cycles in world economic growth: long waves dating chronology

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## Abstract

Long waves chronology is generally established by distinguishing different phases in the growth process through the identification of relatively higher and lower average growth rates. In this paper, using World GDP growth rates data over the period 1871-2015, we develop a more precise and rigorous method for dating chronology of long waves in the world production dynamics which is based on the phase difference between a representation in growth rates and in levels. Since the inflection points in the growth rate series correspond to extremal points in the levels we use the ”structural” growth rate cycle, i.e. long-run fluctuations in economic growth, to establish a long waves chronology. The number of high- and low-growth phases of the world economy and their approximate time of occurrence yields a striking concordance with the dating chronologies elaborated by long wave scholars using the growth-phase approach. In terms of the current long wave debate our findings suggest that the upswing phase of the current 5<sup>th</sup> long wave is still ongoing and support the interpretation that the recent financial/economic crisis marks a flattening in the current upswing phase of the world economy.

*Keywords:* Long Waves; Wavelets; World economy; Phase difference; ”Structural” growth rate cycles; Growth-phase approach.

*JEL:* B52, C14, E32, N10, O30

# 1 Introduction

The global economic crisis and the subsequent long-lasting downturn in global economic activity have generated renewed interest in the long wave theory, a long tradition approach primarily interested in the long-term development of capitalist economies.<sup>1</sup> Since the industrial revolution in the late 18<sup>th</sup> century five long waves of economic development have been identified in the long-wave literature, where each wave being characterized by a specific technological revolution - early mechanization and textile innovations, steam power and railways, electrical and heavy engineering, mass production and automotive industry, information and telecommunications - and associated to fundamental structural changes in the economy, society and institutions (Freeman and Louçã, 2001, Perez, 2002).

Notwithstanding the general consensus in terms of the number and driving forces of technology revolutions (and paradigm shifts) in actually observed long waves, there is substantial disagreement about basic issues such as their (exact) historical periodization and the countries involved (see Bosserelle, 2012, 2013, for a detailed review of long wave chronologies). As an example, whilst there is substantial agreement about the timing of the first three Kondratieff waves, both the start and end of the 4<sup>th</sup> are largely disputed (Gore, 2010). Similarly, considerable discussion exists among long wave researchers about the ongoing long wave phase: some scholars suggest that the recent financial crisis and global recession marked the beginning of the downturn the 5<sup>th</sup> long wave (Gore, 2010), others believe that the 2008 crisis marked the end of the prolonged downturn of the 4<sup>th</sup> long wave (Mason, 2015). Someone else believe that we are still in the second half of the upswing phase of the 5<sup>th</sup> wave (Devezas, 2010). Given the high degree of uncertainty in assessing where we are now in the long-term global development cycle a methodology providing accurate and timely recognition of long waves cycle chronology would be of great help.

The purpose of the present study is to propose a straightforward method for the objective and timely periodization of long wave historical patterns of economic activity. The proposed methodology establishes a dating chronology based on the phase difference between different cyclical representations, in particular between a representation in growth rates and in levels (see

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<sup>1</sup>If Kondratieff can be considered as the originator of long wave analysis detecting long waves of approximately fifty years length and Schumpeter ....., Freeman and Perez (1998) are the present most influential contributors in the neo-schumpeterian tradition. Recently, the marxist economist Paul Mason's has brought long wave thinking into a much wider audience than the typical specialist academic audience with his popular book on Post-capitalism.

Mintz, 1969, Anas and Ferrara, 2004). Indeed, since the inflection points in the growth rate series correspond to extremal points in the levels we use the "structural" growth rate cycle, that is the long wave pattern of worldwide economic growth,<sup>2</sup> to establish a long waves chronology. In particular, we first isolate the "structural" growth rate cycle through the application of wavelet multiresolution decomposition analysis to world GDP growth rates over the period 1871-2015 by exploiting the ability of the wavelet transform to deal with two main features of long term patterns of growth: the presence of sharp and sudden changes in the historical macroeconomic time series due to war and crisis episodes, and the presence of smooth structural changes in the long wave component of the growth rate of world output because of the overlapping nature of technological innovations (Kohler, 2012, Swilling, 2013) Next, we identify the turning points as those periods where the long wave component of the world GDP growth rate, i.e. the "structural" growth rate cycle, crosses the zero-line from above (peak) or below (trough). Interestingly, our methodology, by isolating the long-term growth pattern of the world output, allows us to detect alternating periods of high and low economic growth similarly to what is done by the phase-growth approach. But differently from the phase-growth approach, the ongoing long wave phase can be detected in real time and not after the end of the next phase.

Anticipating our results we can say that the long wave pattern of economic growth identified by wavelet analysis is strikingly consistent with that recently identified by Korotayev and Tsirel (2010) using spectral analysis. New historical evidence on the long-term pattern of economic growth is provided for the interwar period, as during the long downswing of the 3<sup>rd</sup> wave there is clear evidence of a minor upswing occurring in the 1920s in coincidence with the "roaring twenties", a period of unprecedented growth in several developed countries, and especially in the US. We can also assess the robustness of our findings by checking whether the established chronology provides a consistent dating of long wave cycles through a comparison with the historical chronologies provided in the long-wave literature. As to established long waves chronology we find that our dating, in terms of the number of high- and low-growth phases of the world economy and their approximate time of occurrence, yields a striking concordance, especially at peaks, with the dating chronologies provided in the long-wave literature, and in particular with Maddison's phases of growth chronology. Finally, as to the discussion about which long wave phase the world economy is currently going on, our findings indicate that, contrarily to Perez (2009) and Reati and Toporowski

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<sup>2</sup>Berry (1991) proposes that K-waves (short for Kondratiev waves) are not growth cycles but structural cycles. Similarly in Devezas and Corradine (2001).

(2009) beliefs, we have not entered the deployment period of the ICT-based techno-economic paradigm yet, since the upswing phase of the current 5<sup>th</sup> long wave is still ongoing.

The paper is organized as follows: in section 2 we discuss the methodological issues related to long waves identification and phase growth detection. Section 3 identifies the dynamics of global economic development using wavelet multiresolution decomposition analysis and establishes the associated long waves chronology. Section 4 examines whether the established chronology is consistent with the dating schemes presented in the literature on Kondratiev waves and section 5 concludes the paper.

## 2 Long waves: methodological issues

The link between technological innovation and long cycles of economic development, firstly theorized by Schumpeter (1939) in his theory of economic development, is common to the most widely accepted theoretical frameworks within long wave researchers. Kondratieff's (1935) type long wave patterns and Schumpeter's (1939) clusters of innovation are the constituting elements of the techno-economic paradigm (TEP) shift framework developed by Freeman and Perez (1988), where great surges of development induce socio-economic transformation effects across all economic activities and provide the key driving force of each long cycle of economic development (Freeman, 2009, and Perez, 2010).<sup>3</sup> The diffusion of each great surge of development, characterized by an installation period and a deployment period (see Perez, 2002, 2011), is described by the typical S-shaped pattern also within the Multi-level Perspective (MLP) theory on socio-technical transitions (Kemp, 1994, Geels, 2005; Grin et al, 2010), the other most influential existing theoretical framework for the explanation of major long-term socio-technical shifts.<sup>4</sup> An attempt to establish a synthesis between different existing frameworks by combining TEP and MLP approaches in a new conceptual framework, called Deep Transitions, has been recently proposed by Schot and Kanger (2015) and Schot, (2016) with the aim of providing a more comprehensive explanation of the great surges of development and transformation pathways that characterized the evolution of socio-technical systems over the past two

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<sup>3</sup>The term techno-economic paradigm instead of "technological paradigm" (Dosi, 1982) reflects the idea that such changes do not merely involve engineering trajectories for specific product or process technologies.

<sup>4</sup>The most important novel feature of the MLP is that a transition of a socio-technical system stems from the interaction of events in its basic components, that is (innovation) niches, socio-technical regimes and landscape (Grin et al., 2010).

centuries.

What these theories suggest is that technological revolutions are the, not exclusive, key drivers of economic development and that each paradigm shift requires a fundamental adaptation of the socio-institutional framework. The introduction of a new techno-economic paradigm represents a process of transformation of the economy that gives rise to long waves of economic growth and determines a change in the structure of the economy. The process of economic development is characterized by major technological breakthroughs which are closely interconnected with structural changes and economic growth. In terms of the effects of major technology shifts on economic growth these considerations suggest that the long-run dynamic pattern of the economy may be subject to sharp and sudden changes.<sup>5</sup> However, the pattern of economic and technological development is likely to be better represented by smooth rather than instantaneous changes or breaks. The traditional practice of presenting long waves dynamics as consecutive cycles has been recently questioned by Gore (2010) and Kohler (2012). They argue that successive technological revolutions, instead of running consecutively, tend to overlap with the deployment phase of a previous cycle and the installation of the new cycle, thus acting as co-drivers of growth-oriented processes. The effect is that the long-wave rhythm of production generated by these overlapping technological revolutions can determine a smooth transition process where the effects of overlapping regime changes on economic growth can be gradual and result in a smooth transition process, rather than taking the form of a sudden or instantaneous structural change.

Although the main emphasis in standard break-testing methodologies has been on examining the implications of structural breaks that take the form of abrupt jumps in the mean or in the slope of the process, there are also several examples of alternative approaches considering a class of models where the change is gradual or happens continuously, such as the innovation outlier models (see Vogelsang and Perron, 1998).<sup>6</sup> Recently, Becker et al. (2006) and Enders and Lee (2009), using a variant of Gallants (1981) Flexible Fourier Form, have developed a unit-root test that allows for an unknown number of structural breaks with unknown functional forms and where a

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<sup>5</sup>The transition to a new techno-economic regime is a period of structural change in which the process of transformation in the economy cannot proceed smoothly, not only because it implies massive transformation and much destruction of existing plant, but mainly because the prevailing pattern of social behavior and the existing institutional structure were shaped around the requirements and possibilities created by the previous paradigm (Perez, 200?).

<sup>6</sup>Other examples are smooth transition models (Terasvirta, 1994) and Markov regime-switching models.

small number of low frequency components from a Fourier approximation are used to capture the essential characteristics of an unknown functional forms in presence of smooth gradual breaks, They show that a Fourier approximation using the lowest frequency component does reasonably well for the types of breaks often encountered in economic analysis and is especially suitable to mimicking smooth breaks. However, although extremely useful as an alternative representation of the original time series, the Fourier transform has some serious drawbacks. A serious shortcoming of the Fourier analysis is its implicit assumption that no major structural economic changes occurs. Indeed, as all its projections are globals, a single disturbance is likely to affect all frequencies for the entire length of the series, and thus the signal is assumed to be homogeneous over time.

As shown in Gallegati et al. (2017) and Gallegati and Delli Gatti (2017) a suitable statistical apparatus for the problem of extracting long term components from historical time series is provided by wavelet analysis.<sup>7</sup> Wavelets are a relatively new statistical method for the analysis of economic variables that can easily overcome most of the methodological difficulties faced by previous methods when identifying long waves.<sup>8</sup>

The advantages of wavelets are manifold. First of all, the wavelet transform uses a set of orthogonal basis functions which are local, not global. Thus, wavelet analysis, by dealing with local aspects of a signal, provides us with a method having the ability to handle a variety of nonstationary and complex signals, such as historical datasets. Indeed, non-stationarity is an intrinsic feature of datasets used in long waves studies since long-term data tend to display very different patterns over time, like short-lived transient components typical of war and crisis episodes, and to exhibit structural changes in the trend function, as they generally include policy changes, technique innovations and global crisis periods.<sup>9</sup> Second, its frequency resolution is not

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<sup>7</sup>Wavelets, their generation and their potential usefulness are discussed in intuitive terms in Ramsey (2010, 2014). A more technical exposition with many examples of the use of wavelets in a variety of fields is provided by Percival and Walden (2000), while an excellent introduction to wavelet analysis along with many interesting economic and financial examples is given in Gencay *et al.* (2002) and Crowley (2007). The essential characteristics of wavelet analysis are presented in the Appendix.

<sup>8</sup>Similar properties are also displayed by those pass-band filters that are performed in the time domain, but whose desired properties are still formulated in the frequency domain (e.g. Baxter and King, 1999, and Christiano and Fitzgerald, 2003). However, all these filters assume a special kind of data generation process. The long wave component between 32 and 64 years extracted with the Christiano-Fitzgerald band-pass filter yields similar pattern, but different dating chronology.

<sup>9</sup>For example, wholesale price series between late 18th and early 20th century the level of prices tends to display a very large amount of variation over time around a trendless

uniform over the entire frequency range, but differs at different frequency bands (Ramsey, 2000). The multiresolution nature of the wavelet decomposition analysis attains an optimal trade-off between time and frequency resolution levels by means of a basis function that is dyadically dilated or compressed (through a scale or dilation factor) and shifted (through a translation or location parameter) along the signal. Indeed, using short windows at high frequencies and long windows at low frequencies, and thus letting both time and frequency resolutions to vary in time-frequency plane, the wavelet transform provides good frequency resolution (and poor time resolution) at low frequencies, and good time resolution (and poor frequency resolution) at high frequencies. Finally, contrarily to popular band-pass filters like Baxter-King (1999) and Christiano-Fitzgerald (2003) whose approximate bandpass decompositions are optimal under specific time series representation of the process only, wavelet decomposition can be applied without making any assumption about the data-generation process of the series.

### 3 Long waves chronology: the "structural" growth rate cycle

The question of what constitutes a valid indicator for the long-wave phenomenon is crucial to the empirical research on long waves. Initially price data have provided the strongest supporting evidence for the long wave hypothesis, the main reason being that price series have been for a long time the only economic data available and consistently measured.<sup>10</sup> However, thereafter, since the trending behavior of the price level after WWII have lead to difficulties in detecting long cycle movements in prices, price variables have been progressively replaced by production variables in long waves studies (e.g. Lewis, 1978, Kuczynski, 1978, Van Duijn, 1983, Tylecote, 1991, Chase-Dunn and Grimes, 1995, and, more recently, and Korotayev and Tsirel, 2010).

In what follows we investigate the long wave pattern in world production dynamics using World GDP annual growth rates data between 1871 and 2015

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or slightly declining trend, but after WWII prices start increasing as a consequence of a change in the process of price determination (van Duijn, 1979, and van Ewijk, 1982), the effect being the emergence of a strong positive trend (Gallegati et al., 2017).

<sup>10</sup>Indeed, annual data on prices index go back to late 18<sup>th</sup> century, they allow researchers to use the longest possible time span as well as a number of observations higher than any corresponding international dataset on GDP whose data are only available from 1870 onwards only. By contrast, output variables have been reconstructed by economic historians relatively recently and mostly back to mid-19<sup>th</sup> century.

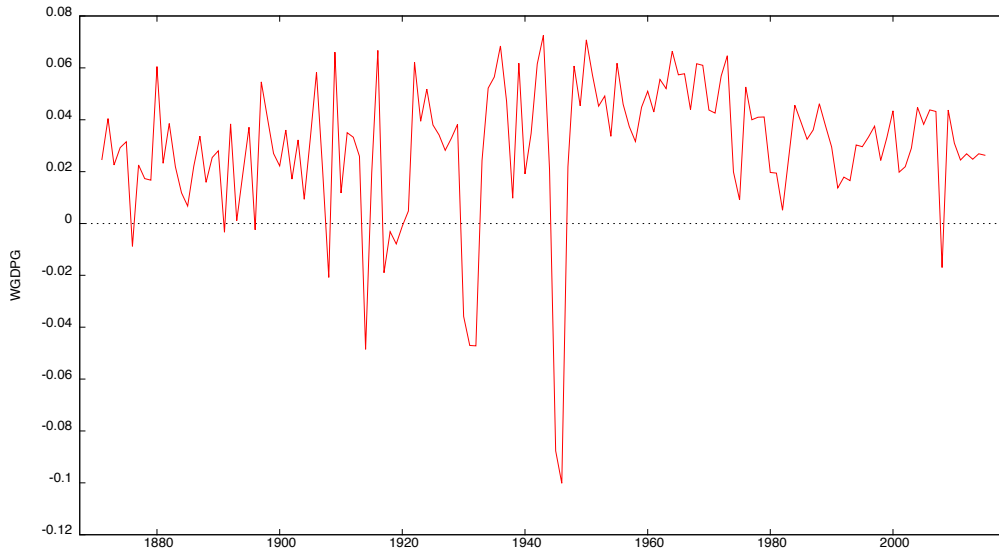


Figure 1: World GDP Annual Growth Rates (%), 1871-2015 (source: Maddison, 2010, and World Bank, 2016)

(see Figure 3),<sup>11</sup> but differently from previous long wave studies we extract the long wave component using wavelet multiresolution decomposition analysis. Specifically, we apply the MODWT rather than the DWT because the latter has several drawbacks: the dyadic length requirement (*i.e.* a sample size divisible by  $2^J$ ), wavelet and scaling coefficients are not shift invariant, and, finally, the MODWT produces the same number of wavelet and scaling coefficients at each decomposition level as it does not use downsampling by two. In order to perform wavelet decomposition analysis of a time series, a number of decisions must be made: which family of wavelet filters to use, what type of wavelet transform to apply, and how boundary conditions at the end of the series are to be handled. There are several families of wavelet filters available, such as Haar (discrete), symmlets and coiflets (symmetric), daublets (asymmetric), etc, differing by the characteristics of the transfer function of the filter and by filter lengths. Daubechies (1992) has developed a family of compactly supported wavelet filters of various lengths, the least asymmetric family of wavelet filters (LA), which is particularly useful for wavelet analysis of time series because it allows the most accurate alignment in time between wavelet coefficients at various scales and the original time series. Therefore, we use the Daubechies least asymmetric (LA) wavelet fil-

<sup>11</sup>Data sources are Maddison (2009) and World Bank (2016).



ter of length  $L = 8$  based on eight non-zero coefficients (Daubechies, 1992). Finally, since wavelet coefficients are affected by boundary conditions at the beginning of the details and smooth vectors, especially at the highest scale levels (e.g. Percival and Walden, 2000), in order to lessen the impact of boundary conditions (at least at the end of the sample), we use the reflection boundary conditions so that the original signal is reflected about its end point to produce a series of length  $2N$  which has the same mean and variance as the original signal.<sup>12</sup>

The application of the MODWT with a number of levels (scales)  $J = 5$  to annual time series produces five wavelet details vectors  $D_1, D_2, D_3, D_4$  and  $D_5$  capturing oscillations with a period of 2-4, 4-8, 8-16, 16-32 and 32-64 years, respectively.<sup>13</sup> Based on the long wave researchers' definition of long wave cycles, i.e. cycles with an average length of about 50 years, and according to the frequency domain interpretation provided in Table 2 in the Appendix, we identify the  $D_5$  component as the wavelet detail component most closely corresponding to Kondratieff-type long wave cycles given that its frequency range is between 32 and 64 years and its average cycle length is around 48 years.

The  $WGDP_{D_5}$  component shown in the top panel of Figure 3 identifies the long-term cyclical component of the world output growth rate. In particular, since no assumption has been made on the underlying nature of the signal and a criterion similar to a locally adaptive bandwidth has been adopted, the wavelet detail component  $D_5$  represents a nonparametric estimation of the long-term pattern of economic growth. According to the pioneering definition of Berry (1991), this long wave pattern may be defined as the "structural" growth rate cycle.<sup>14</sup> Such long wave pattern is highly irregular and exhibits a high degree of variability in terms of the amplitudes and durations of the various waves. This is not surprising for a phenomenon generated by waves of innovative activities whose process of diffusion across the economy depends on the development of a corresponding set of new organizational models.

For comparison purposes in the bottom panel of Figure 3 we present the findings recently reported by Korotayev and Tsirel's (2010, p. 24, Fig. 7) using spectral analysis and loess technique for the long wave pattern in world

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<sup>12</sup>The reflecting boundary conditions therefore condition the estimation of the time scale decomposition on a sort of extrapolation.

<sup>13</sup>See the Appendix for details about the frequency domain interpretation of each signal component in term of periods.

<sup>14</sup>The definition of long waves as "structural" cycles (Berry, 1991, and Corradine and Devezas, 2001), defined as long wave patterns related to the structural analysis of the process of economic development and, in particular, to structural changes, makes more convincing using long time series of aggregate time series of overall economic activity.

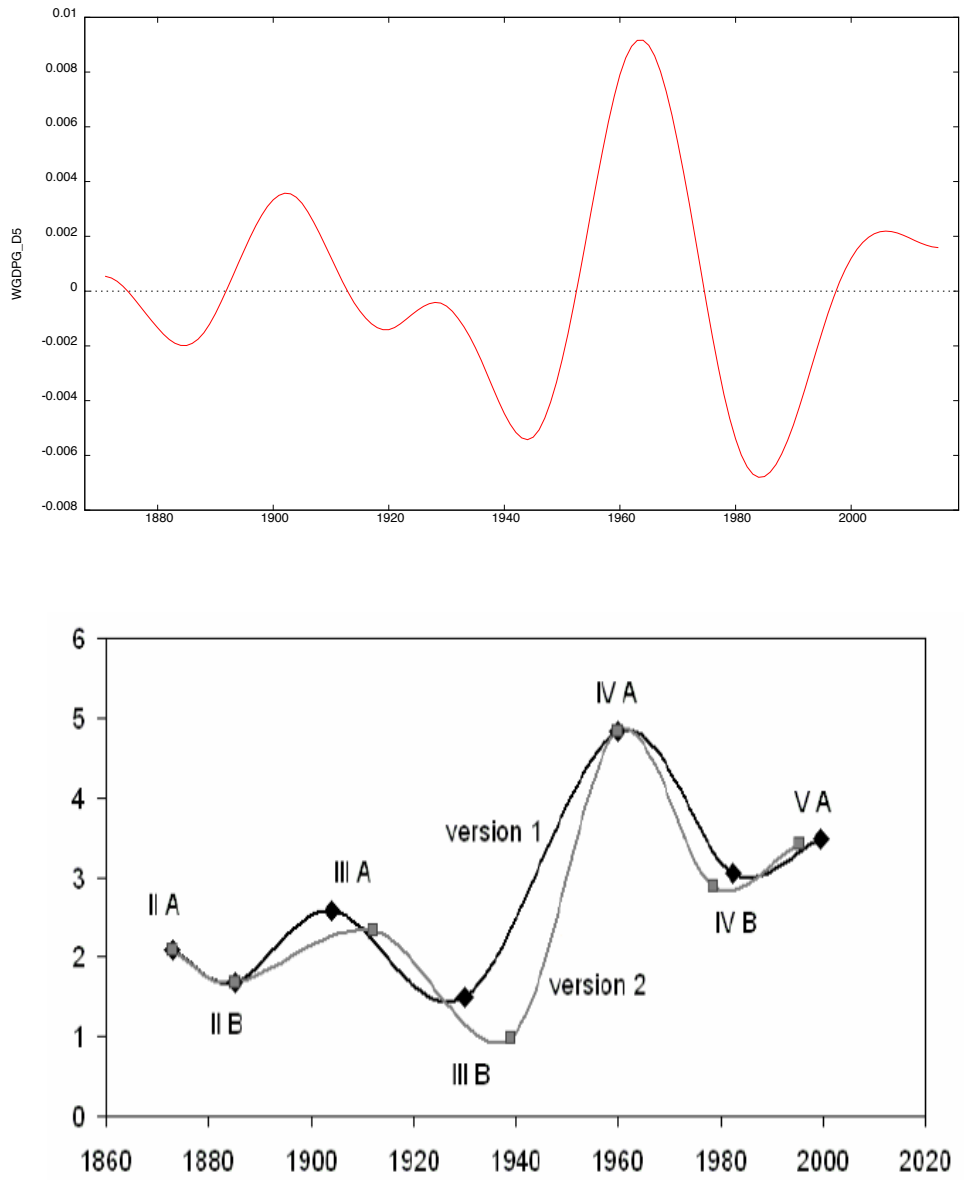


Figure 2: The long wave pattern of World GDP growth rate:  $WGDP_{D_5}$  (top panel) and Korotayev and Tsirel's (2010) estimate (bottom panel)

GDP growth rate. Notwithstanding the different phase amplitude of the overall long wave pattern, due to the different treatment of the trend component that is not eliminated in Korotayev and Tsirel's (2010) procedure, the patterns are remarkably similar. The only notable exception to such a striking resemblance refers to the interwar period where the long downswing phase of the 3<sup>rd</sup> wave is interrupted by the "golden 1920s" boom.<sup>15</sup> This is a period in which statistical methods have always encountered difficulties due to the treatment of war years and its influence on the identification of long waves (see Kleinknecht, 1992, Metz, 1992, and Goldstein, 1999). This is also evident in Korotayev and Tsirel (2010) where the interwar period complicates the detection of the turning points of the 3<sup>rd</sup> long wave. Interestingly, the evidence presented in this section and based on the interaction between WWI and the following strong output growth during the "golden Twenties" provides a straightforward solution for the detection of the turning points of the 3<sup>rd</sup> long wave.

The sequence of upswings and downswings in world GDP growth rates shown in the top panel of Figure 3,  $WGDP_{D_5}$ , delineates the historical long wave pattern of economic growth during the last two centuries. As evidenced by Anas and Ferrara (2004) and Anas et al. (2007) in the  $\alpha AB\beta CD$  approach there is a systematic phase difference between a representation in growth rates and in levels, with periods when the growth rate cycle crosses the zero-line being well aligned with the turning points of the series in levels (see Figure 3).<sup>16</sup> In particular, when the "structural" growth rate cycle crosses the zero-line from above (below) a peak (trough) in the underlying series in levels is detected.

The systematic timing alignment between the "structural" growth rate

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<sup>15</sup>Goldstein (1999, p.90) signals "as a source of potential difficulty for estimating long cycles the interaction between the impact of WWI and the rapid expansion of the 1920s". Over the 1920s the US experienced an unprecedented period of sustained industrial and economic growth based on the implementation of standardized mass-production in industry and large-scale diffusion and use of new products like the automobile, household appliances, and other mass-produced products (the US average annual growth rate of real GNP over the 1920-29 period equal to 4.6 percent). Moreover, over the same period the relative international economic strength of the US economy increased considerably, both in terms of world industrial output and the share of the world market, at the expense of the European countries whose manufacturing industries, transport system and agricultural land had been greatly damaged during WWI. On the European side, notwithstanding the countries directly involved in warfare experienced a reconstruction boom it took much longer to recover and grow, and, as a result, the European countries did not enter a period of economic growth until mid-1920s.

<sup>16</sup>The timing relationships among growth rate, growth and classical cycles, which is at the basis of the  $\alpha AB\beta CD$  approach proposed by Anas and Ferrara (2004) is generally used for monitoring purposes within the business cycle clock framework (Anas et al. 2008),

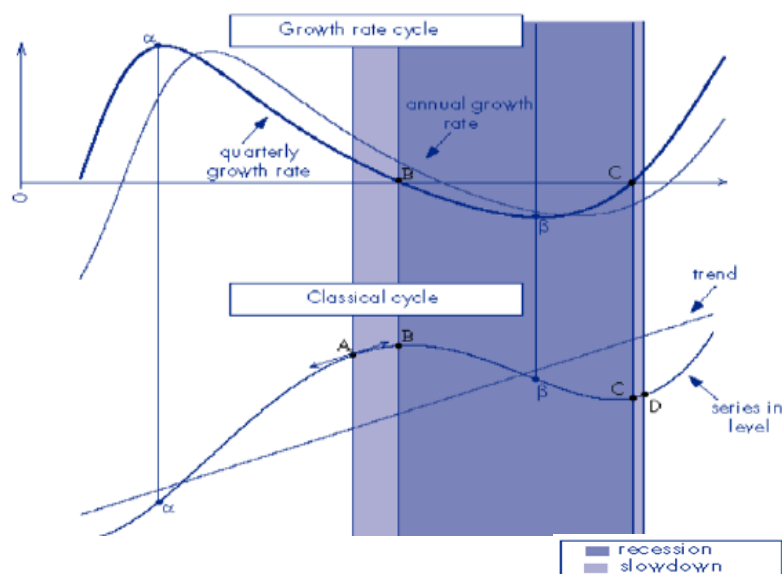


Figure 3: Growth rate cycle and level cycle: timing relationship (source: Anas et al. 2008)

cycle crossing at the zero-line and the turning points of the underlying series allows to establish a long waves chronology based on the long waves pattern shown in Figure 3. According to our analysis the exact long wave periodization would be: 1875 (peak) - 1891-2 (trough) - 1912-3 (peak) - 1951-2 (trough) - 1974-5 (peak) - 2000 (trough). Four long waves are identified, each related to the occurrence of a technological revolutions, after the first long wave associated to the "First Industrial Revolution".<sup>17</sup> In particular:

- the downswing phase of the second wave (railway and steel industries) from 1870s until early 1890s, a period in which the world economies experience a great depression (see Gordon, 1978);
- the third wave (chemical and electrical industries) combines a long wave upswing between early 1890s and the pre-WWI period, and the following long decline beginning before WWI and ending immediately after WWII (from 1913 to 1951), interrupted in the "golden 1920s" by a temporary upswing ending with the Great Depression;

<sup>17</sup>The 1<sup>st</sup> wave and the upswing of the 2<sup>nd</sup> wave cover the first half of the 19<sup>th</sup> century, and thus they are not included in our sample.

- the fourth wave (petrochemicals and automobiles industries) combines the post-war growth upswing phase period between 1951 and mid-1970s, and the downswing phase from mid-1970s until the end of the 20th century. The first is characterized by the reconstruction effect of the 1950s along with the "economic miracle" in the European countries, the latter by class struggles and structural adjustments;
- the upswing phase of the 5<sup>th</sup> wave (information technology), beginning at the start of the new century<sup>18</sup> and driven by the boom experienced by many developing countries (Gore, 2010), which is still ongoing and is currently under scrutiny in order to understand what the recent financial crisis and the Great economic recession represent in terms of the 5<sup>th</sup> Kondratieff cycle.

In terms of the debate about the current long wave our findings support the interpretation that the recent global financial crisis does not mark the beginning of the downturn of the 5<sup>th</sup> long wave. The definitive peak of the 5<sup>th</sup> long wave and the subsequent downswing have not happened yet, although they seem to be imminent. In that respect, and in terms of the Perez-Freeman innovation paradigm framework,<sup>19</sup> the upsurge of investments in renewable energies, energy efficiency and clean technologies that is currently under way suggests that we could be entering into the development period of a techno-economic paradigm shift where technologies and innovations in resource efficiency are likely to be drivers of the next sixth long wave of innovation and technology by triggering long-term productivity increases for the global economy.

## 4 Historical chronologies of long waves: a comparison

The methodology proposed in this paper allows to detect periods of relatively high and low growth by isolating the long-term growth rate cycle component of world output. In that respect, the years when the long-term pattern of economic growth crosses the zero-line provides a long wave chronology consistent

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<sup>18</sup>The end of the fourth wave divides scholars' opinions. For example, if according to Mason (2015) there is no evidence of a wave upswing beginning around 1990, Tyfield (2016) shows not only a clear global upswing through 1990s, but also a further upswing from 2000.

<sup>19</sup>According to the paradigm of technological innovation there are two periods within an innovation paradigm with the diffusion of innovation preceded by a technological development period occurring during the downswing phase of a long wave.

with the phase-period growth rates approach. According to growth-phase approach production growth rates are the characteristic that distinguishes the alternating phases of the long wave. Hence, the dates corresponding to the beginnings and ends of different phases are selected so that in each phase the growth rate is significantly higher or lower than that of the adjacent phase.<sup>20</sup> The advantage of the methodology proposed in this paper with respect to the phase-growth approach is twofold. First, the periodization of the growth process does not depend on the arbitrary subdivision of the time scale. Second, it has the ability to lessen its recognition lag, that is the relatively long interval between the occurrence and recognition of turning points and growth phases. As a result the extraction of the long wave component can provide a timely signal about the current growth phase whilst the phase-growth approach, similarly to step cycles (Mintz, 1969), needs the average rates in each of three successive cycle phases to provide a chronology.

In order to evaluate whether the chronology established with our methodology provides a consistent dating of long wave cycles we compare it with the historical past chronologies provided in the long-wave literature, mostly based on the phase-growth approach. Therefore, along with the long wave chronology derived from the  $D_5$  component of annual world GDP growth rates Table 1 offers a survey of dating schemes elaborated by several long wave scholars, i.e. Kuczynski (1978, 1982), Freeman and Louçã (2001), Korotayev and Tsirel (2010), Maddison (1991, 2003), Perez (2007) and, more recently, Tyfield (2016).<sup>21</sup> In particular, we take into account the phase periods turning points reported in Kuczynski's (1978), where dates of turning points are calculated using the average annual growth rates of capitalist world industry for the period 1850-1977, with phase-period growth rates being used to measure long wave expansion and stagnation phases. Freeman and Louçã's (2001) and Perez (2007) dating base schemes are based on the Freeman/Perez techno-economic paradigm shift framework described in section 2, actually the most widely accepted theoretical framework within long wave researchers (Freeman and Perez, 1988, and Perez, 2002). Furthermore, we consider three additional dating schemes that are carried up to the present. The first dating chronology is that obtained by Korotayev and Tsirel (2010) using the same dataset as ours. The second chronology is based on Maddison's (1991, 2003) phases of capitalist development, where different phases of growth are identified by major changes in growth momentum. Turning points are identi-

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<sup>20</sup>The long wave chronologies based on the phase-growth approach share the view that the growth rate changes in steps during successive time periods being characterized by, respectively, relatively high and low rates of the world GDP growth. The two phases are generally called Phase A and Phase B in the long waves literature.

<sup>21</sup>A complete list of existing long wave chronologies may be found in Bosserelle (2012).

fied by inductive analysis and iterative inspection of empirically measured<sup>22</sup> and "systems characteristics" such as the policy-institutional framework and policy attitudes. The last dating chronology, Tyfield (2016), is based on the combination of Kondratiev waves with the dynamics of the political-cultural level and the geopolitical processes of hegemony of the A-B (Arrighi-Braudel) cycles.

The comparison with alternative long waves dating schemes is reported in Table 1 and in Figure 4, where the  $D_5$  component of the annual world GDP growth rate is displayed along with grey shaded areas based on the other long wave chronologies reported in Table 1.<sup>23</sup> Both the number of growth phases and the approximate time of occurrence of high-rate and low-rate phases are correctly identified by the  $D_5$  component of annual world GDP growth rates. Indeed, despite minor differences in dating several turning points, the zero-line crossing of the long-term growth rate cycle yields approximately the same turning dates of the growth-phase chronology reported in the literature on long waves: one-half (the timing of peaks) coincide exactly, one-half (the timing of troughs) roughly. The main differences emerge at the end of the 3<sup>rd</sup> and 4<sup>th</sup> waves, where our chronology tends to postpone the beginning of the upswing phase by about a decade with respect to the dating provided by all alternative dating schemes.<sup>24</sup> The only exception is Maddison's chronology whose alignment of the phase growth changes is perfect from 1913 onwards.<sup>25</sup> Interestingly, our chronology also exhibits a high degree of dating conformity with that presented by the research division of the global banking group Standard Chartered with reference to periods of "historically high global growth, lasting a generation or more" characterized by a nation that becomes a dominant economic driver for the world economy (Standard Chartered 2010). Two "supercycles", roughly corresponding to periods of long waves upswings, are detected for the past, 1870-1913 and 1946-1973, with the global economy growing on average by 2.7% and 5%, respectively, and one for the current period, 2000-2030, where Asian countries are expected to drive future growth at global level.

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<sup>22</sup>Maddison employs several macroeconomic indicators, that is the rate of growth of the volume of output, the output per head and exports, the cyclical variations in output and exports, unemployment, and the rate of change in consumer prices.

<sup>23</sup>The chronology is mostly based on Kuczynski (1982), Freeman and Louçã (2001) and Korotayev and Tsirel (2010) dating schemes.

<sup>24</sup>That the end of the 4<sup>th</sup> wave did not expired in the 1990s is also argued by Mason (2015), although in his view the downturn of the 4<sup>th</sup> wave prolonged until 2008 .

<sup>25</sup>Before WWI Maddison's dating fails to detect a phase change in early 1890s probably because his methodology aims at identifying major changes in growth momentum.

Table 1: Historical phases A (upswings) and B (downswings) in world production dynamics based on the growth-phases approach

Phases	Kuczynski (1978)	Freeman and Louçã (2001)	Korotayev and Tsirel (2010)	Maddison (2003)	Perez (2007)	Tyfield (2016)	$D_5(WGDP)$
A2	-	1848	-	-	1848	1840	-
B2	1872	1873	1876	1870	1875	1875	1875
A3	1893	1895	1895	-1913	1893-5	1890	1892
B3	1917	1918	1914	1913	1908	1925	1913
A4	1940	1940	1947	1950	1929-43	1940	1952
B4	1968	1973	1974	1974	1971	1975	1975
A5	-	-	1992	2001	2001	1990	2000

Sources: Kuczynski (1978), Freeman and Louçã (2001), Maddison (1991, 2003) and Korotayev and Tsirel (2010), Tyfield et al. (2015).



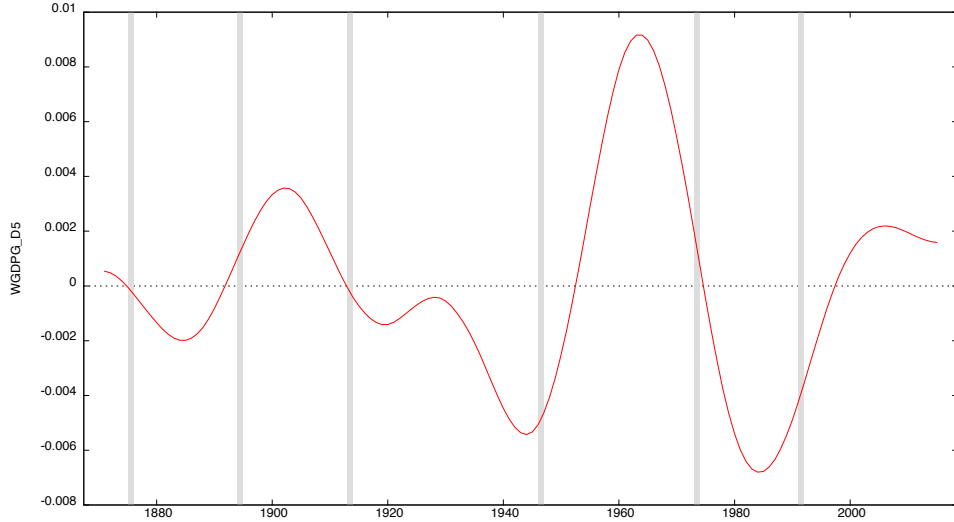


Figure 4: The  $D_5$  component of annual world GDP growth rates,  $WGDP_{D_5}$ , with grey shaded areas represents dating based on growth phases chronologies currently available in the literature.

## 5 Conclusion

In this paper we apply wavelet multiresolution decomposition analysis to annual world GDP growth rates over the period 1871-2015 with the aim of identifying and detecting long-term economic growth waves. Based on the phase difference between a representation in growth rates and in levels we establish a chronology of long wave cycles in the global economy starting from the identification of the "structural" growth rate cycle, defined as the long-term pattern of economic growth. What we find is a considerable degree of conformity in terms of the number of growth phases and their approximate time of occurrence with existing long waves dating schemes, especially with Maddison's chronology. Interestingly, our approach, by extracting a long-term growth rate cycle, can provide a dating chronology similar to those based on phase-growth approach, but its periodization is not arbitrarily and its dating of the growth-phase chronology is much more timely. In terms of the current debate about where we are within the 5<sup>th</sup> long wave, our findings support the interpretation that the recent global financial crisis marks a flattening in the current upswing phase of the world economy, with the global economy approximating the end of a period of a relatively high growth associated to the early phase of decline of the current dominant paradigm. Anyway, the definitive peak of the 5<sup>th</sup> long wave and the subsequent downswing have not

happened yet (but are likely to be imminent).

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## 6.1 varie

*Schumpeter's (1939) was the first to provide a theory of economic development that explain the long-term dynamics of capitalist economy in terms of technological revolution, the so-called "creative destruction" process, and to ..... the link between innovation and economic activity. The emphasis on economic growth ..... within the neo-schumpeterian approach which*

*explains long lasting cycles by waves of innovations generated by general-purpose technologies (Bresnahan and Trajtenberg, 1995) which determine techno-economic paradigm shifts in the sense of Perez (1985), Freeman and Perez (1988) and Freeman and Louçã (2001) and imply the emergence of long waves of economic growth in world production dynamics.*

and that the new developments associated with renewable energy and clean technology (to bio-technologies) are preparing the next 6<sup>th</sup> wave of economic development (Allianz, 2010). A timely recognition (chronology) of long wave phase chronology highlights the methodology for on-going analysis of business conditions objective and timely<sup>26</sup> The contribution of this approach for the exact periodization of long lasting (wave) cycles is twofold : it overcomes the main limitation of the phase-growth approach and is suitable for real time detection on the .

Within an innovation paradigm (i.e. logistic waves of techno-economic paradigm shifts) (between old and new drivers of economic growth)

in this paper we apply wavelet multiresolution decomposition analysis to extract the long wave component of the growth rate of world output.

(roughly marks half-way through the upswing phase of the 5<sup>th</sup> long wave) As concluded by Pearson and Foxon, (2012) the start of the next potentially more sustainable global development cycle driven by the green-tech and low-carbon innovations and associated to the so-called 6th technological revolution has not emerged yet (still to come). progressive emergence of a new (energy) cluster

using traditional statistical methods or simulation techniques has proved to be a complex undertaking that is still a topic of controversy A shortcoming of traditional statistical and econometric methods in the analysis of very long time series is that, notwithstanding long wave scholars postulates such structural changes, as the drivers of such changes as long as wave research postulates such structural changes and tries to explain the drivers of such changes an empirical method that is based on such an assumption seems to be inadequate to the research topic Given the difficulties of statistical treatment of long waves long wave researchers have devoted a considerable part of their research on refining econometric techniques. a different approach to structural changes has emerged in the literature which ..... that the effects of major structural changes, as those related to technology shift processes, should be modeled as smooth and gradual processes rather than as sharp and sudden changes occurring instantaneously.<sup>27</sup>

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<sup>26</sup>Although dating is an ex post exercise, and therefore accuracy may be more important than timeliness, real-time detection is nevertheless important.

<sup>27</sup>For example, Leybourne, Newbold and Vougas (1998) and Kapetanios, Shin and Snell (2003) develop unit-root test where the deterministic component of the series is a logistic



By using similar methodologies based on phase-period growth rates several scholars of the capitalist crisis approach found that production consistently grows more rapidly on long wave upswings (e.g. Mandel 1975, Kleinknecht 1981, Gordon 1978, Kuczynski 1982).

is above or below the zero line, that is years where world GDP growth rate is above or below the long-term growth rate. periods of relatively high vs low growth are identified with can be used to identify the dating of turning points so as to

(and is also remarkably similar to alternative filtering methods like the Christiano-Fitzgerald, 2003, band-pass filter) their historical (exact) periodization remains controversial as the dating chronologies reported in the literature are somewhat contrasting (by long wave researchers are generally approximate and sometimes contrasting).

*..... the question whether the global economic crisis of 2009 marks the beginning of the end of the 5<sup>th</sup> Kondratieff cycle<sup>28</sup> or the start of the 6<sup>th</sup> Kondratieff wave is highly debated (central to the long wave debate).*

to establish a reference dating chronology for long waves cycles at world (global) level (as regards the world economy). dating long waves cycles entails ascertaining economy-wide turning points

Since the timing of rises and falls in growth rates differs from the timing of the underlying series, peaks and troughs in growth rates cannot serve to delimit long wave phases in the usual sense. in the occurrence of turning points among different representations of cyclical fluctuations, where growth rates peaks precede level peaks and growth rate cycle troughs leading level cycle troughs.

The methodology applied in the paper consists in first obtaining a non-parametric estimate of the long wave pattern in the world economy by applying wavelet multiresolution decomposition analysis to world GDP growth rates To do it we first obtain a non-parametric estimate of the long-term growth rate cycle component of world output over the period 1871-2012 (source: Maddison international dataset, 1995, 2001, 2003, 2009) by using wavelet multiresolution decomposition analysis.

The aim of this paper is to provide a methodology for identifying upswings and downswings phases of long waves in capitalist development and dating the growth phases chronology. We use world GDP growth rates to identify and to characterize structural cycles (Berry, 1991, Devezas and Corradine, ), that is long wave patterns of economic growth related to the structural anal-

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and an exponential smooth transition process, respectively.

<sup>28</sup>Each wave is characterized by long periods of prosperity which have generally ended in major crisis (Allianz Global Investors, 2010).

ysis of the process of economic development and, in particular, to structural changes.

The timing of the peaks and troughs (turning points) of the Kondratieff cycle are then detected by periods at which the long wave component of world GDP growth rate crosses the zero-line (takes a zero value)

As technological revolutions (paradigm shift) represent major structural changes ....., we define the irregular long term oscillatory pattern in the world system as a "structural cycle" (Berry, 1991, Schon, ).<sup>29</sup>

The main advantages of the proposed methodology are that wavelets are particularly useful for dealing with raw series that contain sharp and sudden changes, as it is the case of historical dataset with war and crisis episodes, such as those included in historical datasets, and whose long term components extracted from The main contribution is that the turning points identification of the growth phase chronology, is based on the business cycle analysis interpretation of the growth rate or acceleration cycle of the long-term variations at the level of the world economy. Moreover, our methodology, by isolating the long-term growth rate cycle component of world output, allows a comparison with the chronology based on the phase-growth approach.

After identifying the long wave component in world GDP growth rate, which conforms well to that identified by Korotayev and Tsirel (2010) using spectral analysis and loess method and to the historical narrative proposed by long wave scholars,

conclude our methodology can easily provide a reliable and timely tool for analyzing the dynamics of long wave patterns in historical time series by easily overcoming most of the methodological difficulties faced by previous statistical methodologies.

by exploiting the timing relationship between growth rate cycles and step cycles.

which consider structural breaks as sharp and sudden changes occurring instantaneously with new technologies replacing the old ones, do not determine sudden or jump in the structural change Together these phases form a structural cycle of about four decades. In this view, innovations have evolved in an interplay with economic growth and structural change major economic and structural cycles like these precisely and so these dates are approximate.

The effects of such technology shift processes on the long-run growth pattern These changes occur smoothly rather than instantaneously,

or jump in the estimates indicates a structural break, i.e.the relationship has changed its character. Smooth changes are usually indicative of

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<sup>29</sup>Berry (1991) proposes that K-waves (short for Kondratieff waves) are not growth cycles but are structural cycles.

misspecification A smooth transition between two different regimes is sometimes more useful than just assuming the discrete transition between them, their attractiveness as compared to conventional switching models Smooth transition models

”A relationship that is considered to imply a particular growth regime, must therefore change in a specific way in order to be associated with a regime shift. In a descriptive framework one may be able to observe such shifts if growth rates, taken as representative descriptions of the growth phenomenon under consideration, move across certain boundaries which partition the space in association with clearly defined rules. Such rules could relate to specific values or ranges of growth rates or combinations thereof”

that generates a new K-wave each characterized by a low-growth and high-growth regime. cycles in growth rates and cycles in levels structural cycles ,i.e. a form of basically irregular oscillatory patterns across growth path recent techniques for the econometric modelling of structural change

These long wave patterns may be defined as structural cycles<sup>30</sup> given that the pattern of economic growth is

The long-term cyclical component of the world output growth rate, defined as structural cycle (Schon, ).

Since each wave is characterized by long periods of prosperity which have generally ended in major crisis (Allianz Global Investors, 2010) the global recession of 2009 has been raising a number of interesting questions for investors and policy- makers: Does the recent financial crisis marks the end of the post-WWII long-term development cycle (and simultaneously the beginning of a new phase of prosperity)? Has the information and telecommunications technology revolution entered into its deployment phase (Information Age)? Will ”green-tech” innovations emerge as the key-driver of the technological revolution for the next global development cycle?

However, in order to detect the exact timing of the fundamental technological and structural transformations of the economy is still highly controversial as well as the choice of the appropriate methodology for identification and extraction of long waves. Indeed, long waves researchers have provided contrasting results with respect to the periodization of such long term fluctuations in production series and real variables like industrial output, GDP, etc. (Bosserele, 2012).

The proposed methodology is applied to the annual rate of growth of world GDP over the period 1870-2012

long cycles of development within capitalist economies, lasting around 50-60 years in total

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<sup>30</sup>The definition of structural cycles

Long-wave periodization is generally detected by investigating the existence of systematic differences in the average growth rates between upswings and downswings phases of long waves, and then testing whether such difference is statistically significant (Mandel, 1978, 1995). However, the periodization detected with this methodology is not unique, since this statistically significant systematic difference can be obtained with similar different periodization.

given its ability to interpret longer run historical economic patterns in terms of

that allows to long wave periodization to identify the turning points of long waves at the world economy level to identify turning points of long waves growth rates such that the difference in growth rates between upswings and downswings phases of long waves is statistically significant.

Given the link between technological cycles and economic growth

Although there is no evidence supporting the notion that growth phases are driven exclusively by technological revolutions (Gore, 2010)

is reported separating high-growth and low-growth phases of world economy

provide evidence on the long-term patterns of economic growth

While the explanation (determinants) of these long term fluctuations in economic growth remains central in the agenda of ....., much less attention has been devoted to the detection of such long cycles in the economic development.

Much less attention has been devoted to the question of detecting such long waves

The aim of this paper is to investigate whether long waves are a general phenomena by looking at cycles in economic activity for the global economy.

long-term socio-technical systems change The Deep Transition framework (Schot and Kanger, 2015) will address these two gaps by attempting , Towards a conceptual framework of Deep Transitions.

separate Kondratiev-type long waves.

with the deployment phase of a previous cycle and the installation of the new cycle acting as co-drivers of growth-oriented processes

(see Freeman and Louçã, 2001, Perez, 2002).

Within the neo-Schumpeterian perspective Gore (2010) elaborates a long-wave approach to the global crisis

technological cycles to economic growth the notion that growth phases are driven exclusively by technological revolutions (Gore, 2010) this effort. Although Gore admits there is no evidence to support the notion that growth phases are driven exclusively by technological revolutions (Gore, 2010), he has enriched the overall picture by correlating the price cycles derived from

Berrys work (Berry, 1991) with the socio-technical cycles derived from Perez's work. Read together these are very rough approximations of actual growth cycles without in any way suggesting that the actual complex drivers of economic growth at any moment in time are reducible to these long-wave dynamics. His key insight seems to confirm Khler's argument that S-curves do not run consecutively (as represented by both the MLP and, to some extent, by Perez), but instead they tend to overlap with the deployment phase of a previous cycle and the installation of the new cycle acting as co-drivers of growth-oriented processes (Khler, 2012). If we accept the synthesis proposed by Gore, then conceptually we need to look for the dual drivers (which includes the deployment phase of the 5th and of necessity the installation of the 6th technological revolution) of the springsummer period of the next global development cycle

From the perspective of long waves of historical development the global crisis of 2009

(Gore, 2010, Perez, 2009)

In this paper we ... the evolution of the global economy from about 1850 onwards

the current global economic crisis simultaneously marks the end of the post-WWII long-term development cycle, the mid-point of the information age and potentially the start of a new era of sustainable development

Prof Mark Swilling from the School of Public Leadership at Stellenbosch University ([www.sopmp.sun.ac.za](http://www.sopmp.sun.ac.za)) and Academic Director of the Sustainability Institute ([www.sustainabilityinstitute.net](http://www.sustainabilityinstitute.net)), engaged with the argument of whether current scholars who draw on the apparent success of Kontratieff long-wave theory to make sense of the economic crisis, can be implemented as useful strategy for anticipating sustainable futures. Swilling pointed out that although there has been some convincing evidence for the usefulness of the long-wave theory, the obvious danger in implementing it blindly over all scales and time frames, is that they are prone to produce a kind of determinism that links technological innovations to socio-political development.

This paper argues that the global recession of 2009 marks the ending of a global development cycle which began in the early 1950s. The long-wave rhythm of production and prices in the global development cycle is generated by the life cycle of investment and innovation during a technological revolution, related changes in supply and demand for natural resources, and inertia and transformation in the socio-institutional framework within which development takes place. From this perspective, the global recession is interpreted as a blocked structural transition. Whilst failings in the financial system triggered the global financial crisis, that crisis and the recession are more deeply rooted in contradictions in the global development trajectory.

A paradigm shift in development theory and practice is a crucial element of the socio-institutional transformation now necessary to re-boot the global development cycle. (Abstract, Gore 2010)

the multi-level perspective (Grin et al. 2010), neo-Schumpeterian perspectives (Gore 2010; Khler 2012) and a political ecology perspective on transitions (Lawhon and Murphy 2011)

3. 6th cycle: the author has - correctly in my view - suggested a 6th cycle in the making - s/he needs to point out that this is NOT what Perez has argued, i.e. significantly wavelet theory has allowed this author to confirm a sixth wave which is not the mainstream perspective as represented by Perez - this should be made explicit, and also why wavelet approach allows for this - maybe Perez's hostility towards a sixth wave is due to her dependence on spectral methods?

4. The author should engage with the long wave approach proposed in Paul Mason's book *Postcapitalism* - I would suggest that this popular book has brought long wave thinking into a much wider audience than the specialist academic audience and is, possibly, therefore even more influential than Perez. This book is not cited which is a pity. More importantly, I would propose include Mason's periodization - which is a critique of Perez's - into Table 2. This would significantly improve the scope and impact of the article.

5. I strongly disagree with raising new arguments in the conclusion. Two new arguments are introduced into the conclusion that I strongly agree with, but should therefore be in the body of the article, possibly a short new section before the conclusion. The two arguments are more speculative, but very important, namely where we are in the 5th cycle post-2007, and the possibility of the 6th cycle (which links to my point 3 above).

The main contribution of this paper is to propose a unifying method for detecting phase periods in Kondratieff waves.

We use the relationship between different representation of cyclical movements, that is growth rate or accelerator cycle and level cycle, to establish a dating scheme (chronology) for Kondratieff waves.

Given the link between technology changes and long waves regime or growth phase change takes the form of smooth structural changes. This link is reinforced by the Long wave growth (rate) cycles represent structural cycles as they represent phase of capitalist development. Turning points represents smooth structural breaks S-shaped innovation-growth cycles

There is room for argument as to which years are terminal for demarcation purposes, particularly as the use of annual data means that the periodicity has to be rather precise

The methodology for long waves pattern recognition in economic time

series has been longly debated in the literature on long waves. The methods initially used for identifying long waves in economic variables aimed at isolating major fluctuations in the deviations of a variable around its trend through a combination of detrending procedures and smoothing techniques (e.g. Kondratieff, 1926).<sup>31</sup> More recently, the similarity between long waves detection and growth cycles extraction has favored the application of spectral methods to long wave analysis (e.g. Kuczynski, 1978, Van Ewijk 1982, Bieshaar and Kleinknecht, 1984, Metz, 1992, 2011, Diebolt and Doliger, 2006, 2008, Korotayev and Tsirel, 2010). Although the spectral-theory approach is in principle appropriate for long wave detection, the application of spectral analysis has several drawbacks, the most important being that the observed series need to be stationary in order to be analyzed with the tools of spectral analysis, a requirements that is particularly troublesome in the current context as the dataset used in long waves analysis includes two hundred years of data including several war episodes.

structural breaks in a series are assumed to occur instantaneously and manifest themselves contemporaneously. However, a number of authors have recognized that

overlapping rather than consecutive long wave cycles. each successive Kondratiev wave is identified with the deployment of a specific, all-pervasive, technological revolution The dominant view in this body of research is to search for consecutive cycles, that is neat curves that flow consecutively. are likely to be gradual rather than technology shifts have strong impact on economic growth

”The (historical) role of such pervasive technologies has been the subject of the Schumpeterian literature on economic growth and structural change. In this literature, which is by no means undisputed (e.g., Smith, 2001 is quite critical), one finds a framework that explains the subsequent rise and fall of pervasive technological systems, and their interaction with the economy. What the theory suggests is that structural change, economic growth and major technological breakthroughs are closely interconnected, and can only be analyzed jointly. a sequence of five long waves, each one driven by a technological revolution that is related to a bunch of basic innovations. the occurrence of one or a number of interrelated basic (or radical) innovations. These basic innovations provide the opportunity for increasing growth rates, i.e., for the upswing of a new long wave to set in.” Verspagen

Thus, the relationship between these waves of technical change and long

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<sup>31</sup>These methods have been criticized for adopting ad-hoc solutions for trend estimation and moving average length, especially because statistical artifacts and significant errors in long waves detection can be created by, respectively, detrending methodologies and faulty trend estimates.

cycles in economic growth Each wave is then characterized by a particular match of technological and of social and institutional innovations "structural change as an uneven phenomenon punctuated by technological revolutions that give rise to long-term movements of real and monetary variables, i.e. long waves" Reati All in all, each long cycle (wave) of economic development is driven by clusters of technological innovations that introduce new techno-economic systems and give rise to long waves of economic growth characterized by socio-institutional changes. once the potential of the old is exhausted techno-economic paradigm is replaced by the new paradigm coming close to exhaustion The centrality of innovation and technological change to processes of economic growth process of transformation that relates to technological change processes of restructuring driven by techno-economic, social and institutional change (Perez, 1983), the effects of major technology shifts on economic growth are likely to be gradual rather than technology shifts have strong impact on economic growth the crucial relationship is that between economic growth and structural change, in the sense that economic growth is a necessary condition for structural change There have been distinct and important phases of development the process of capitalist development Major system shocks change the momentum of capitalist development at certain points major changes in growth momentum there have nevertheless been significant changes in the momentum of capitalist development. paradigm they represent phases of capitalist development

Khlers argument that S-curves do not run consecutively (as represented by both the MLP and, to some extent, by Perez), but instead they tend to overlap with the deployment phase of a previous cycle and the installation of the new cycle acting as co-drivers of growth-oriented processes (Khler, 2012).

consecutive or overlapping cycles: in an article by Kohler the traditional practice of presenting long waves as consecutive rather than overlapping is questioned. I suspect the author tends to replicate the dominant trend in this body of research which is to search for neat curves that flow consecutively. But I suspect that the data generated by the wavelet approach mind lend itself to the representations suggested by Kohler and Swilling.

Two main related questions are crucial in the long wave debate

"structural breaks in a series are assumed to occur instantaneously and manifest themselves contemporaneously. However, a number of authors have recognized that the effects of structural change on the level or slope of a series can be gradual. For example, Leybourne, Newbold and Vougas (1998) develop a unit-root test such that the deterministic component of the series is a logistic smooth transition process. Similarly, Kapetanios, Shin and Snell (2003) allow the deterministic component to be an exponential smooth transition process. Although the Fourier approximation is designed to work when



breaks are gradual .... An important (dis)advantage of a Fourier approximation is that it is a global, rather than a local, approximation. a Fourier approximation using a single frequency component ... is especially suitable to mimicking smooth breaks. ... it seems reasonable to use the low frequency components to mimic structural change.”

structural breaks should be modeled as smooth and gradual processes rather than as sharp and sudden changes occurring instantaneously The recently developed unit root and stationarity tests model any structural break(s) of unknown form as a smooth process via a Fourier approximation using a variant of Gallants (1981) Fourier flexible form. The motivation is that the Fourier series is able to capture the essential characteristics of the series, like nonlinear trends determined by one or more structural breaks, by using only a small number of low frequency components.

Although extremely useful as an alternative representation of the original time series, the Fourier transform has some serious drawbacks. First of all, in Fourier analysis a single disturbance affects all frequencies for the entire length of the series as all projections are globals, and thus the signal is assumed to be homogeneous over time. Thus, if the signal is a nonperiodic one, the summation of the periodic functions, sine and cosine, does not accurately represent the signal. Such a feature restricts the usefulness of the Fourier transform to the analysis of stationary processes, whereas most economic and financial time series display frequency behavior that changes over time, i.e. they are nonstationary (Ramsey and Zhang, 1995). A useful approach to the problem of handling with non-stationary signals is provided by wavelet analysis because its frequency resolution is not uniform over the entire frequency range, but differ for different frequency bands (Ramsey, 2000). The wavelet transform uses a basis function that is dilated or compressed (through a scale or dilation factor) and shifted (through a translation or location parameter) along the signal so as to provide a time-frequency representation where all the information is associated with specific time horizons and locations in time. Hence, a wavelet is similar to a sine and cosine function in that it also oscillates around zero, but differs because, as wavelets are constructed over finite intervals of time, they are well-localized both in the time and the frequency domain (see Percival and Walden, 2000, and Gencay et al. 2001). In contrast to Fourier analysis, wavelets are compactly supported as are all projections of a signal onto the wavelet space are essentially local, rather than global, and thus need not be homogeneous over time. Indeed, much of the usefulness of wavelet analysis has to do with its flexibility in handling a variety of nonstationary signals. Wavelets, in opposition to time and frequency domain analyses, consider nonstationarity an intrinsic property of the data rather than a problem to be solved by pre-processing

the data (Schleicher, 2002).

Although the evidence provided by early 20<sup>th</sup> century long wave authors on the existence of long waves in the dynamics of the economy is based on the observation of long wave patterns in price series, many authors have later questioned this relation arguing that long wave patterns in prices do not correspond with the long-term movements of real variables, e.g. in van Duijn (1983) and Goldstein (1988). In particular, according to van Duijn (1983), institutional and market changes<sup>32</sup> are likely to have weakened the relationship between price and production changes by affecting the mechanism of price formation, as evidenced by the uninterrupted increase of prices after the 1930s. On the theoretical side, the emphasis on economic growth follows, for example, from innovation theories like Schumpeter's (1939) theory of economic development, where long economic cycles are induced by "clusters of innovations" originating from the innovating economy and spreading to followers countries. Hence, long economic cycles are explained by very important innovations, that is general-purpose technologies (Bresnahan and Trajtenberg, 1995) or techno-economic paradigms in the sense of Perez (1985), Freeman and Perez (1988) and Freeman and Louçã (2001), that imply the emergence of long waves of economic growth in world production dynamics.

These alternations of periods of high growth rates with periods of low growth rates have been given the definition of step cycles in the business cycle literature (Mintz, 1969, 1972).<sup>33</sup> "Step cycles" are detected by the average rates of change during subsequent periods against the normal rate in each cycle, where the normal rate is defined as the average rate in a full cycle.<sup>34</sup> To set a turn in step cycles the following conditions must be satisfied: i) it must be valid as the end of one cycle phase and the beginning of the next cycle, and ii) it must provide a correct partitioning between two adjacent turns of the opposite type. Thus, cycle phases in step cycles are defined as periods of varying length characterized by growth rates which are classified as high or low by comparing the average rate for each cycle phase "against two normal rates: the average rate of the cycle beginning with that phase and the average rate of the cycle ending with that phase" (Mintz, 1969, p.69).

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<sup>32</sup>Examples of such changes are the cost-of-living clauses included in wage contracts, the price -setting behavior of oligopolistic industries and the increased weight of industrial as compared to agricultural goods.

<sup>33</sup>Friedman and Schwartz (1963) were the first to detect this phenomenon with reference to monetary series and business cycles for the US.

<sup>34</sup>The full cycle must comprise two parts: in one the average rate of change must be significantly higher than the cycle average, whereas in the other it must be significantly lower.

”Periodization made by Maddison is different from Mandel’s above mentioned periodization. Madison takes the period 1870-1913 as a single wave, and therefore disregards the protracted depression of 1873-1893. Apart from exclusion of the period 1826-1973, Madison’s periodization is conformable with the one set forth in Mandel (1986, p.16). However, in Madison’s periodization the recession starting with 1973 comes to an end in 1992. While it seems necessary to divide the post-1973 period into sub-periods, it should be noted that a sufficient time has not yet passed to establish the actual turning points of such division.”

”Mason surveys the five Kondratieff long waves that the global economy has experienced: from 1790 to 1848, the factory system, steam power and canals generated the upswing, and the end of the cycle came with the depression of the 1820s and political crises in Europe. Railways, the telegraph, and machines making machines, generated the second cycle, which lasted from 1848 to the 1890s, when a long depression occurred. Scientific management was the business model that enabled heavy industry, electrical engineering and mass production to drive the third long wave from the 1890s to 1945, which was ended by the Second World Wars destruction of capital. In the fourth cycle, from 1945 to 2008, transistors, automation, and computers, created a long economic upswing. The oil price shock of 1973 started the decline, which culminated in the financial crisis of 2008. A fifth long cycle then started, driven by information and communication technology, a global marketplace, and information goods: but, as Mason shows, it has stalled. The first four cycles were accompanied by large workforces which were increasingly organised and therefore able to extract sufficient proceeds of production to fuel the cycle. Foolishly, neoliberalism has broken the power of labour, and has therefore prevented the fifth cycle from taking off. A second factor that has contributed to the fifth cycle not taking off and this is one of Masons major themes is the rise of information goods that are essentially free: many of them are designed to be free, and even if they are not, then in practice they become free or almost free. Recorded music is the classic example. With information goods being increasingly important and with increasingly sophisticated 3D printing, we shall soon see products that we never thought could be free or almost free becoming so and in many contexts markets will become increasingly irrelevant. We shall be in an era of postcapitalism. The fifth Kondratieff wave will fizzle out, and there will be no more of them.”

”Paul Mason sees post-capitalism as a consequence of information technology: Postcapitalism is possible because of three impacts of the new technology in the past twenty-five years (xv): 1) the blurring of boundaries between labour and free time, 2) the abundance of information, 3) collaborative digital peer production. The main contradiction today is between the possi-

bility of free, abundant goods and information and a system of monopolies, banks and governments trying to keep things private, scarce and commercial (xix). This analysis overestimates information economy because capitalism is not just digital and informational capitalism, but at the same time financial capitalism, hyper-industrial, fossil fuel capitalism, mobilities capitalism, etc. (Fuchs 2014a, chapter 5). Mason argues for a long wave theory of crisis and capitalism that combines Kondratieffs long wave theory (that assumes that capitalist development has the form of 50-year long cycles consisting of 25 years of economic upswing followed by 25 years of downswing) and Marxs theorem of the tendency of the rate of profit to fall (TRPF). The fifth long waves takeoff has stalled (47) because of neoliberalism and information technology (48). [F]irms use profits to pay dividends rather than to reinvest (71). Factors enabling neoliberalism would have been fiat money, financialisation, the doubling of the workforce, the global imbalances, including the deflationary effect of cheap labour, plus the cheapening of everything else as a result of information technology (106). For Mason, the fourth cycle lasted from the late 1940s until 2008 (72) and was driven by transistors, synthetic materials, mass consumer goods, factory automation, nuclear power and automatic calculation (48). He argues that in contrast to Joseph Schumpeters assumptions, innovations and the adoption of new technologies do not stem from entrepreneurial inventiveness, as Schumpeter argued, but from working class struggles that force capitalism to reinvent itself (75-76). The key technologies of the stalled fifth cycle would be network technology, mobile communications, a truly global marketplace and information goods (48). The combination of Kondratieff and Marx in a Marxist version of long-wave theory as alternative to Schumpeterianism is not new. Paul Mason completely ignores and does not seem to be aware of Ernest Mandels work, especially his book *Late Capitalism* (Mandel 1975; for a discussion, see: Fuchs 2016d, 151-152, 211). Mandel argued that there are long waves in the development of the rate of profit and that the 4th long waves downswing was initiated around 1967. Like Mandel, also Mason assumes that the tendency of the rate of profit to fall drives long waves that last fifty years: The tendency of the rate of profit to fall, interacting constantly with the counter-tendencies, is a much better explanation of what drives the fifty-year cycle than the one Kondratieff gave (p. 77). Mandel wrote in his 1972 PhD dissertation *Late Capitalism*:

The history of capitalism on the international plane thus appears not only as a succession of cyclical movements every 7 or 10 years, but also as a succession of longer periods, of approximately 50 years. [] An economic upswing is possible only with a rising rate of profit, which in its turn creates the conditions for a fresh extension of the market and an accentuation of

the upswing. At a certain point in this development, however, the increased organic composition of capital and the limit to the number of commodities that can be sold to the final consumers must both lower the rate of profit and also induce a relative contraction of the market. These contradictions then spill over into a crisis of over-production. The falling rate of profit leads to a curtailment of investments which turns the downswing into a depression (Mandel 1975, 120, 439).

Mason like Kondratieff, Schumpeter and Mandel assumes that fifty-year cycles are the long-term rhythm of the profit system (77). But Masons own claims contradict this metaphysical assumption that the wave-length is fixed to 50 years: He in other places in the book argues that the fourth wave was 60 years long (72). Given that capitalism is a complex, dynamic, open system (Fuchs 2004, 2008b, 2002), the deterministic assumption that there are long waves that last 50 years is simply not feasible (for a more detailed version of this argument, see: Fuchs 2016d, 150-159). Other than neo-Schumpeterians such as Christopher Freeman and Carolita Perez, Mason rejects the assumption that the information technology paradigm is resulting in a new long wave with sustained growth. The reason why he does so is however not scepticism of deterministic, undialectical and instrumental logic, but another form of determinism: Paul Mason assumes, as we will see, that information technology has to result in the breakdown of capitalism.”

”According to Mason, in the late-1990s, the elements of a fifth long wave came into being. Network technology, mobile communications, a truly global marketplace and information goods should, in long-wave terms, have led to a vigorous economic upswing. However, this boom has failed to materialise, and Mason lays the blame squarely at the feet of neoliberalism.

The reason? The very same information technologies that could have proved the basis for an upturn are, on Masons score, qualitatively different from the technological surges that founded other long-cycles. The advent of sophisticated computer technologies has fundamentally altered the relationship between physical work and information. Using a variety of useful vignettes, such as the revolution effected in jet engine design, Mason demonstrates how information technology has transformed the design, production and lifecycles of commodities. The result is that, [t]he great technological advance of the early twenty-first century consists not of new objects but of old ones made intelligent. The knowledge content of products is becoming more valuable than the physical elements used to produce them.”

## 7 Appendix: Spectral and wavelet analysis

Spectral analysis provides a frequency domain representation of a signal (or a function) where the same information as the original function is approximated by the sum of periodical functions with fixed frequencies, i.e. sines and cosines. The signal can then be analyzed for its frequency content because the Fourier coefficients of the transformed function represent the contribution of each sine and cosine function at each frequency.<sup>35</sup>

The simultaneous estimation of several cyclical components may be also pursued using wavelet analysis.<sup>36</sup> Like spectral analysis, wavelet analysis allow to decompose any signal into a set of time scale components, each reflecting the evolution through time of the signal at a particular range of frequencies and to study the dynamics of each component separately, but with a resolution matched to its scale since the wavelet basis function is dilated (or compressed) according to a scale parameter to extract different frequency information.<sup>37</sup>

Both transforms can be viewed as a rotation in function space to a different domain that for Fourier Transform contains basis functions that are sines and cosines, whereas for the wavelet transform, this new domain contains more complex basis functions called wavelets (see Strang, 1993). The basis functions used by the Fourier transform (upper and middle panel) and the wavelet transform (lower panel) are displayed in Figure 5.

Figure 5 shows that wavelets are mathematical functions that transform the data into a mathematically equivalent representation by using a basis function that is similar to a sine and cosine function in that it also oscillates around zero, but differ because, as wavelets are constructed over finite intervals, they are well-localized both in the time and the frequency domain. Since the Fourier transform uses a linear combination of basis functions ranging over  $\pm$  infinity, all projections in Fourier analysis are globals, and thus a single disturbance affects all frequencies for the entire length of the series. Thus, if the signal is a nonperiodic one, the summation of the periodic

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<sup>35</sup>The contribution of each individual frequency (periodical function) to the total variance of the (stationary) time series under consideration can be obtained by estimating the sample spectrum through the application of the Fourier transform.

<sup>36</sup>Although widely used in many areas of applied sciences (i.e. astronomy, acoustics, signal and image processing, geophysics, climatology, etc.), wavelet applications have been only recently used in fields like economics and finance after the papers by Ramsey and his co-authors (see Ramsey and Zhang, 1995, 1996, and Gallegati and Ramsey, 2013, 2014).

<sup>37</sup>Moreover, the transformation to the frequency domain does not preserve the time information so that it is impossible to determine when a particular event took place, a feature that may be important in the analysis of economic relationships. In other words, it has only frequency resolution but not time resolution.

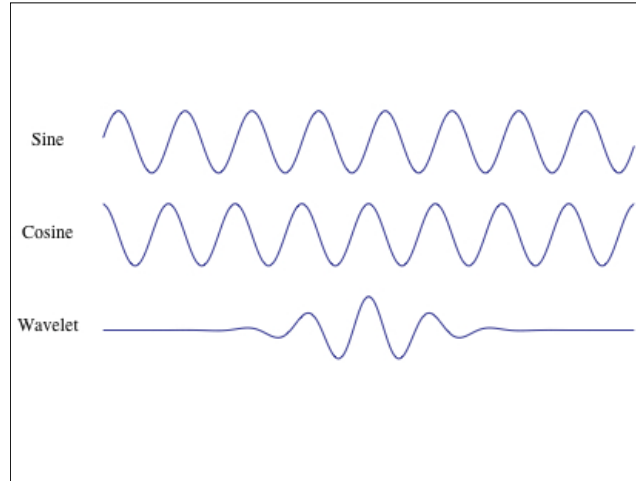


Figure 5: Sines (top), cosines (middle) and wavelet (bottom) basis functions.

functions, sine and cosine, does not accurately represent the signal. Such a feature restricts the usefulness of the Fourier transform to the analysis of stationary processes, whereas most economic and financial time series display frequency behavior that changes over time, i.e. they are nonstationary (Ramsey and Zhang, 1996). Hence, although spectral analysis is in principle an appropriate methodology for long wave analysis because of its ability to simultaneously estimate the contribution of several cyclical components, in practice its application is greatly limited by the requirement that the series be detrended in order to achieve stationarity. But then one is back in the realm of detrending methods along with their problems of arbitrariness in the estimation and elimination of the trend component.<sup>38</sup>

By contrast wavelet analysis may overcome the main problems evidenced by Fourier analysis since wavelets are compactly supported, as are all projections of a signal onto the wavelet space are essentially local, not global, and thus need not be homogeneous over time. Being performed locally, the wavelet transform allows the analysis of series that by their nature, as it is for long historical time series data, are likely to exhibit short-lived transient components like abrupt changes, jumps, and volatility clustering, typical of war episodes or crisis episodes. Unlike spectral analysis and related statistical techniques, wavelet analysis consider nonstationarity an intrinsic property

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<sup>38</sup>Detrending procedures are not neutral with respect to the results relating to the existence of cycles: "the smoothing techniques may create artefacts" (Freeman and Louçã 2001, p. 99).

of the data rather than a problem to be solved by pre-processing the data. Indeed, much of the usefulness of wavelet analysis has to do with its flexibility to handle a variety of complex and nonstationary signals so that the data need neither be detrended nor corrections for war years are needed anymore.<sup>39</sup> Hence, with wavelet analysis we can avoid the practice of studying history by erasing part of the history (Freeman and Louçã, 2001).

Finally, long waves revealed by spectral analysis are based on the assumption of regular fixed periodicities (van Duijn, 1983), but if the signal is a nonperiodic one, the summation of the periodic functions like sines and cosines, does not accurately represent the signal. By contrast wavelet analysis breaks down any time series into the sum of nonperiodic oscillatory components (quasi-periodic functions) whose irregular pattern is likely to resemble cyclical movements better than any approach requiring fixed periodicities. In sum, wavelet analysis, like spectral analysis, is particularly well suited for detecting cycles, but unlike spectral methods has the ability to detect cyclical components that are spaced irregularly in time and can be applied to non-stationary time series.

The wavelet transform maps a function  $f(t)$  from its original representation in the time domain into an alternative representation in the time-scale domain  $w(t, j)$  applying the transformation  $w(t, j) = \psi(\cdot)f(t)$ , where  $t$  is the time index,  $j$  the scale (i.e. a specific frequency band) and  $\psi(\cdot)$  the wavelet filter. There are two basis wavelet filter functions: the father and the mother wavelets,  $\phi$  and  $\psi$ , respectively. The first integrates to 1 and reconstructs the smooth and low frequency parts of a signal, whereas the latter integrates to zero and describes the detailed and high-frequency parts of a signal.

The formal definition of the father wavelet is the function

$$\phi_{J,k} = 2^{-\frac{J}{2}} \phi \left( \frac{t - 2^J k}{2^J} \right) \quad (1)$$

defined as non-zero over a finite time length support that corresponds to given mother wavelet

$$\psi_{J,k} = 2^{-\frac{J}{2}} \psi \left( \frac{t - 2^J k}{2^J} \right) \quad (2)$$

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<sup>39</sup>Corrections for war periods (war data are influenced by pre-war armament booms, war economy and post-war reconstruction booms around WWII and to a lesser extent WWI) are generally applied to original data by interpolating series for the war years (Metz, 1992) or a priori elimination of the impact of the war periods (Korotayev and Tsirel, 2010) on the assumption that such shocks can be seen as disturbances in the normal structure of data.



with  $j = 1, \dots, J$  in a  $J$ -level wavelets decomposition. The mother wavelet, as said above, plays a role similar to sines and cosines in the Fourier decomposition. It serves as a basis function to construct a set of wavelets, where each element in the wavelet set is obtained by compressing or dilating and shifting the mother wavelet, in order to approximate a signal.

For a discrete signal or function  $f_1, f_2, \dots, f_n$ , the wavelet representation of the signal or function  $f(t)$  in  $L^2(R)$  can be given by

$$f(t) = \sum_k s_{J,k} \Phi_{J,k}(t) + \sum_k d_{J,k} \Psi_{J,k}(t) + \dots + \sum_k d_{j,k} \Psi_{j,k}(t) + \dots + \sum_k d_{1,k} \Psi_{1,k}(t) \quad (3)$$

where  $J$  is the number of multiresolution components or scales, and  $k$  ranges from 1 to the number of coefficients in the specified components. The coefficients  $d_{jk}$  and  $s_{Jk}$  of the wavelet series approximations in (3) are the details and smooth wavelet transform coefficients representing, respectively, the projections of the time series onto the basic functions generated by the chosen family of wavelets, that is

$$\begin{aligned} d_{j,k} &= \int \psi_{j,k} f(t) dt \\ s_{J,k} &= \int \phi_{J,k} f(t) dt \end{aligned}$$

for  $j = 1, 2, \dots, J$ . The smooth coefficients  $s_{Jk}$  mainly capture the underlying smooth behavior of the data at the coarsest scale, whereas details coefficients  $d_{1k}, \dots, d_{jk}, \dots, d_{Jk}$ , representing deviations from the smooth behaviour, provide progressively finer scale deviations.<sup>40</sup>

The multiresolution decomposition of the original signal  $f(t)$  is given by the following expression

$$f(t) = S_J + D_J + D_{J-1} + \dots + D_j + \dots + D_1 \quad (4)$$

where  $S_J = \sum_k s_{J,k} \Phi_{J,k}(t)$  and  $D_j = \sum_k d_{j,k} \Psi_{j,k}(t)$  with  $j = 1, \dots, J$ . The sequence of terms  $S_J, D_J, \dots, D_1$  in (4) represent a set of components that provide representations of the signal at the different resolution levels 1 to  $J$ . The term  $S_J$  represents the smooth long-term component of the signal and the detail components  $D_j$  provide the increments at each individual scale, or resolution, level. Each signal component has a frequency domain interpretation. As the wavelet filter belongs to high-pass filter with passband

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<sup>40</sup>Each of the sets of the coefficients  $s_J, d_J, d_{J-1}, \dots, d_1$  is called a crystal in wavelet terminology.

given by the frequency interval  $[1/2^{j+1}, 1/2^j]$  for scales  $1 < j < J$ , inverting the frequency range to produce a period of time we have that wavelet coefficients associated to scale  $j = 2^{j-1}$  are associated to periods  $[2^j, 2^{j+1}]$ . The frequency domain interpretation of each signal component, in term of periods, is presented in Table 2 for a  $J = 5$  level decomposition analysis.

Table 2: Frequency interpretation in periods for a  $J = 5$  level decomposition

Scale level $J$	Detail level $D_j$	Frequency resolution
1	$D_1$	2-4
2	$D_2$	4-8
3	$D_3$	8-16
4	$D_4$	16-32
5	$D_5$	32-64
6	$S_5$	>64