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The Asymmetric path of Economic Long Waves

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ABSTRACT

The purpose of this paper is to analyze the pattern and behavior of Economic Long Waves over time, using the long-wave chronologies of two driving economies, the USA and the UK. The statistical evidence seems in general to support the hypothesis that Long Waves are not symmetric and their regularity is based on longer periods of upwave than downwave (contraction-skewed), which implies a negative asymmetric path of these waves over time.

1. Introduction

The debate on the theory of Long Waves (acronym: LWs) or Kondratieff waves (in short, K-waves)[1] has been ongoing since the first substantial empirical evidence was presented in the 1930s [2–11].[2] From his examination of long-run time series, especially price levels, Kondratieff [16] argues (p. 105): “There is, indeed, reason to assume the existence of long waves of an average length of about 50 years in the capitalistic economy, a fact which still further complicates the problem of economic dynamics”.

Ayres [5], p. 8, claims that:

> Various authors have suggested different long-wave chronologies, depending on the particular countries and time series they were looking at . . . . Bieshaar and Kleinknecht … carried out econometric tests comparing six of the chronologies, including Mandel's, in terms of average growth rates during [upwave] … and subsequent [downwave] … periods for a large number of time series . . . . They concluded that statistical evidence of the existence of waves since 1890 is quite strong and robust.

In general, there are different long-wave chronologies and certain timings of long waves are often better for some countries, but not for the world as a whole: in fact, heterogeneity among countries, due to different socio-economic structures and reaction

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[1] See Modelski [1], p. 75 and 76.

[2] In particular, see Mitchell [12], pp. 15 ff and pp. 49–52; Mortara [2], pp. vii–xxxv; Wagemann [13], pp. 73–80 and pp. 190–195; as for the causes of economic fluctuations see Wagemann [13], pp. 169–174 and Bresciani Turroni [14], pp. 332–363, Modelski [1], pp. 77–80, Papenhausen [15], pp. 790–793; for interesting historical, technological and energy sources discussions about economic cycles see also: Schumpeter [3], pp. 21–182 and papers by Volland [4]; Ayres [5,6]; Berry et al. [7]; Dator [8]; Linstone [9]; de Groot and Franses [10,11] and their references.

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capacity of their sub-systems, affects the patterns and timing of economic cycles, which do not have a synchronized rhythm across countries. The theory of economic cycles argues that Long Waves (LWs) have four phases: prosperity, recession, depression and recovery. These phases form the upwave and downwave periods of LWs, which play a vital role in supporting political economy in the long run. According to Ayres [5], p. 7: "there should be a correlation between rising prices and economic growth (prosperity) and conversely . . . . basic economic theory suggests that sustained prosperity is likely to result in bottlenecks and scarcities that tend to drive prices up. By the same token, stagnation and recession tend to result in underutilization of capital and excess of supply of many commodities, hence (where the markets are unfettered) declining prices. The stylized scheme set forth by Van Gelderen focuses on 'turning points' between inflationary periods [upwaves] … and deflationary periods [downwaves]".

Whereas, Berry et al. [7] claim (p. 114, "original emphasis"):

> "Upwave" growth cycles run for 25 to 30 years, starting in recessions and ending in stagflation crises. They are associated with diffusion of newly-dominant techno-economic paradigms to market saturation . . . . "downwave" growth cycles, also 25 to 30 years long, are associated with technology successions, when peaked-out paradigms are challenged by ascendant sets of techno-economic alternatives, after the shocks of stagflation crises.

It is also important to note that business cycles are nested within the K-waves. The National Bureau of Economic Research [17] has been measuring US Business Cycle Expansions and Contractions since 1854. The analyses of these data (see Table 1A in Appendix A) as well as the economic theory, beginning with the pioneering work by Mitchell and Keynes,[3] show that the contractions are briefer than the expansions. Lenti [20], p. 1159, shows this asymmetric behavior for Italian business cycles (Table 2A in Appendix A), whereas Razzak [18], pp. 235 ff, provides international evidence of business cycle asymmetries.[4] Sichel [22], pp. 225 and 226, distinguishes between two types of asymmetry represented by "steep and deep cycle", Hansen and Prescott [23], p. 850, *inter alia*, study how a binding capacity constraint affects the proprieties of business cycles, which are asymmetric in their model.[5] Cover and Pecorino [26] (p. 452, 454, *passim*) present evidence that business-cycle expansions have been longer and contractions shorter since the end of World War II.[6] The literature is vast and not fully cited here, but a good list of references is found in Verbrugge [28].

Although several works have provided many valuable insights into the theory of economic cycles, there are issues that have not yet been accurately explored by economists and long-wave theorists, such as the analysis of the temporal duration of phases of Long Waves. In particular, although the economic theory has showed empirical evidence about the behavior of business cycles, it has not addressed the questions explicitly addressed here, concerning Long Waves:

> How do Long Waves behave over time?
> Is the period of upwave equal to the period of downwave?

In order to investigate these main economic issues, the purpose of this paper is to analyze the relationship between the temporal duration of upwave and downwave of Long Waves, using the main chronologies suggested by long-wave theorists for the US and UK economies. In particular, the aim is to determine the behavior and shape of these waves over time.

2. Hypothesis of asymmetric path of economic long waves

Using the System Dynamic National Model, Sterman [29] presents an integrated theory of the economic long wave. He discusses several tenets concerning the long-wave behavior.[7] The first process that may affect the behavior of LWs is the "capital self-ordering" (Sterman [31], p. 18). In particular, Sterman [29] states:

> To illustrate the role of self-ordering in the long wave, consider the economy in equilibrium. If the demand for consumer goods and services increases, the consumer goods industry must expand its capacity and so places orders for new factories, equipment, vehicles etc. To supply the higher volume of orders, the capital-producing sector must also expand its capital stock and hence places orders for more buildings, machines, rolling stock, trucks, etc., causing the total demand for capital to rise still further in a self-reinforcing spiral of increasing orders, a greater need for expansion, and still more orders (pp. 114–115) . . . . a wide range of self reinforcing processes significantly amplify the demand, increasing the amplitude and lengthening the period of fluctuations (p. 111).

[3] These economists have been quoted by Razzak [18], p. 230 and 231; cf. also Chalkley and Lee [19], p. 623 and 624.

[4] Cf. also Basu and Taylor [21], pp. 48-62; in general, the period of US business cycles can be divided into 68.6% expansions and 30.9% contractions (Table 1A in Appendix A). These results and the main studies described in this section confirm that the pattern of business cycles is characterized by temporal compression of contractions and temporal dilatation of expansions over time (asymmetry).

[5] See also Kydland and Prescott [24], who analyze the hours per workers and change in number of workers in the business cycle theory. In addition, Hodrick and Prescott [25] "propose a procedure for representing a time series as the sum of a smoothly varying trend component and a cyclical component" (p. 1), the so-called Hodrick–Prescott filter to estimate the trend.

[6] See Romer [27], pp. 24-33, for more evidence on changes in economic fluctuations over time.

[7] Cf. also Graham and Senge [30], pp. 283–290 and pp. 308–310.

In other words, according to Sterman [29]:

> One basic cause of overexpansion is the tendency for production systems to amplify changes in demand (p. 111) . . . . the customer demand is amplified by stock adjustments caused by delays in receiving goods (p. 112) . . . . other sources of amplification include growth expectations and the spread of optimism (p. 113) [cf. also Mitchell [32], p. 5 and Sterman [31], p. 47] . . . . the amplification of demand by stock adjustments … is responsible for several oscillatory modes of behaviour including … the Kuznets or intermediate cycle of roughly 15–25 years (p. 114) . . . . Simple modes show that the amplification of demand by inventory and backlog adjustments leads, in isolation, to highly damped oscillations in capital investment with periods of about 20 years (*ibidem*).

A second process that may affect the economic dynamics of LWs is the following:

> Expectations of future growth lead to additional investment, further swelling demand . . . . Once a capital expansion gets under way, the self-ordering loops amplify and sustain it until production catches up to orders, excess capacity is built up, and orders begin to fall (Sterman [29], p. 118)

The national model includes a broad range of additional amplifying feedbacks described by Sterman [29]:

> other positive feedback loops operate through the labour markets to add additional amplification (pp. 119 ff) … The strength of the reinforcing mechanism involving inflation and real interest rates depends on a lag between change in inflation and the response of nominal interest rates (p. 125).

Sterman [31] also states that: "The additional mechanisms involve … debt, consumer demand, international trade, innovation, and even political value" (p. 22).[8]

Graham and Senge [30] argue that (p. 308):

> The upturn of a long wave, which lasts about 30 years, is characterized by self-reinforcing pressures to acquire more physical capital to meet rising demand for capital, increase capital intensity of production, and take advantage of high returns on investment.

This theoretical framework is the background to state the following utterance. Let us assume that:

- $\alpha=$ *upwave* growth of the long wave (upswing period) is the time gap from long-wave beginning to boom (peak), measured in years;
- $\beta=$ *downwave* is the period (in years) from boom to long-wave end (trough);
- The Wavelength of LWs (or K-waves) is divided into upwave α and downwave growth β.

Under these assumptions and according to the endogenous, dynamic theory of the economic long wave [29–31,33], the following is stated:

Hypothesis. The upwave phase α of Kondratieff waves is a longer period than the downwave phase β: $\alpha>\beta$ (negative asymmetry of LWs).

The purpose of the present study is to see whether statistical evidence supports the hypothesis that long waves have periods of upwave longer than downwave over time. The chronologies of the 1st–2nd–3rd–4th Long Waves, based on two driving economies, the USA and the UK, will be considered.

3. Empirical analysis

In this section, statistical evidence about the upturn and downturn length of long waves (or K-waves) is analyzed, in order to test the previous hypothesis and to determine the behavior and shape of these waves. The results can provide main implications for the political economy of growth in the long run.

The empirical strategy is based on a simple approach to determine the lapse of time and phases of K-waves. In particular, the data used are the historical chronologies of long waves of prices measured by esteemed scholars, such as Kondratieff [16] (p. 106, see Chart I), Van Gelderen,[9] Mandel,[10] Van Duijn [34] (p. 563), Kuznets [35] (p. 109), Berry and Kim [36] (p. 5). The next step is to calculate, *by the arithmetic mean*,[11] the average upwave period, downwave period, boom timing, and average wavelength (rhythm) of Long Waves in the US and the UK, two countries driving worldwide economic growth. In addition, the variance of the years of long-wave chronologies is measured by standard deviation (σ). This indicator of variability σ is supposed to be a reliable measure of the error of K-waves timing over time.

[8] Cf. also Sterman [29], pp. 126–128.
[9] Quoted by Ayres [5], pp.7 ff.
[10] Quoted by Ayres [5], p. 8.
[11] Arithmetic mean is a robust indicator of central tendency of data.

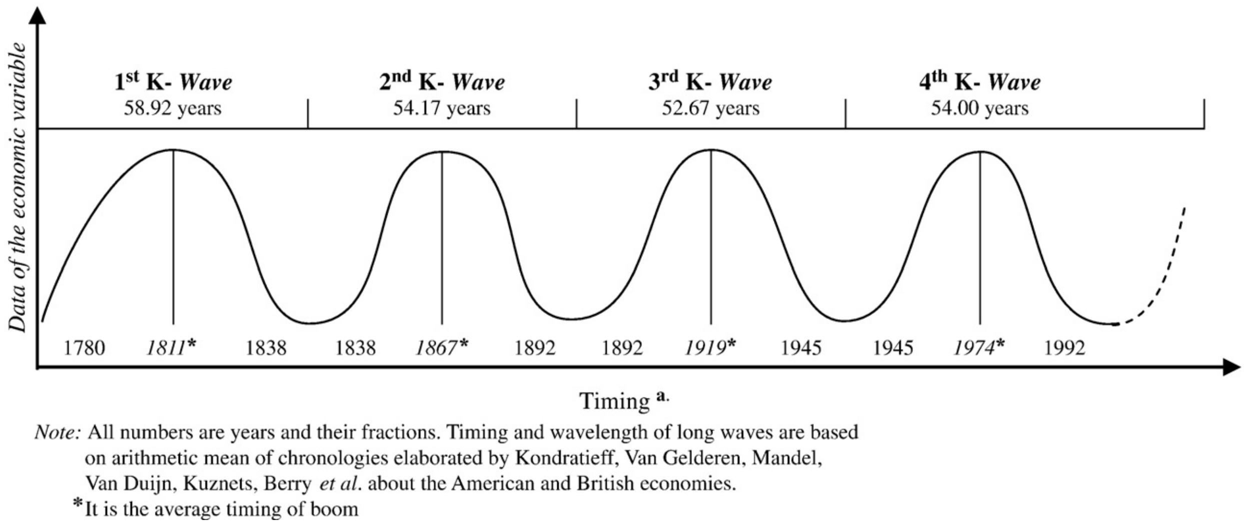

Fig. 1. Temporal pattern of long waves based on US and UK chronologies.

Fig. 1 describes the path of long waves, since the end of the Eighteenth century, considering the average timing.

The relevant Table 1, section C, shows the average period of long waves, based on US and UK data, which is roughly 54.94 years with σ (standard deviation) equal to 2.73 years. To support this result, Marchetti [37], reference to the Fig. 4, claims: "By fitting total energy and electric energy growth curves with logistics and plotting the residuals as percent deviations from fitting curve, B. Stuart of Nutevco … [showed that] the sinusoidal oscillation of the deviations has a period of 54 years". Berry et al. [7], p. 114, state that: "expansion and diffusion of techno-economic systems drives the 54-year long waves of prices" (i.e. "54-year Kondratiev waves", p. 111).[12] Therefore, *ceteris paribus*, it is supposed that the average period of LWs, equal to 54.94 years ($\sigma=2.73$), based on US and UK economies, can be considered as a good proxy of the wavelength (in years) of K-waves.

The wavelength of the US and the UK economies can be divided into an upwave and a downwave period, like it is assumed in the previous section. In particular, the facts are that:

- *The US economy* displays an average upwave period, based on price index, equal to: 29.50 years for the 1st K-wave; 28.75 years for the 2nd K-wave; 27.50 years for the 3rd K-wave and 29.00 years for the 4th K-wave. The arithmetic mean of these values is 28.69 years, the standard deviation σ is 0.85 years, which indicates the dispersion around the central tendency. Conversely, the average downwave period of the US economy is: 28.50 years for the 1st K-wave; 25.00 for the 2nd K-wave; 26.25 for the 3rd K-wave and 25.00 for the 4th K-wave. The arithmetic mean of these values is 26.19 years, the standard deviation σ is 1.65 years (Table 1, section A). In short, for the US economy the average upwave is $\alpha=28.69$ years, greater than the average downwave phase (β = 26.19 years).
- *Mutatis mutandis, the UK economy* displays an average upwave duration that is: 34.00 years for the 1st K-wave; 29.50 years for the 2nd K-wave; 25.50 years for the 3rd K-wave, missing values for the 4th K-wave. The arithmetic mean of these values is 29.67 years ($\sigma=4.25$ years). The average downwave period in the UK economy is: 24.50 years for the 1st K-Wave; 25.50 for the 2nd K-wave; 25.00 for the 3rd K-wave. The arithmetic mean of these values is 25.00 years, σ is 0.50 year (see Table 1, section B). In brief, the arithmetic mean, over time, of the UK upwave period is $\alpha=29.67$ years, longer than the downwave period ($\beta=25$ years).
- *US and UK data*. Empirical evidence based on US and UK data over four K-waves (see Table 1, section C) shows that the upwave growth "α" phase of a K-wave has an average period equal to 29.15 years ($\sigma=$ St. Dev. = 2.01), whereas the average downwave period is $\beta=25.79$ years ($\sigma=$ St. Dev. = 0.98).

Hence the empirical evidence, in general, supports: $\alpha>\beta$. □

3.1. Robustness

Table 2 shows the result of the paired-samples *t*-test,[13] which confirms that the paired difference of upwave and downwave period (considering data on US and UK economies jointly) is significant at 5%. Hence, according to this test we can accept the

[12] Cf. also Sterman [29], p. 109 and Sterman [31], p. 46.

[13] The paired-samples *t*-test procedure compares the means of two variables. It computes the differences between values of the two variables for each case and tests whether the average differs from 0. The assumptions are that the observations for each pair should be made under the same conditions. The mean differences should be normally distributed. Variances of each variable can be equal or unequal [38].

Table 1
Temporal patterns for the 1st–2nd–3rd–4th long waves of prices based on average timing.

Arithmetic mean of US chronologies based on price index [a]									
Waves	Upwaves: α			Downwaves: β			Duration of cycles	Upwave [b] %	Downwave [b] %
Section A	A = begin	B = end	Length B–A = C	A' = begin	B' = end	Length B'–A' = D	$C+D$		
1-K	1778.00	1807.50	29.50	1808.00	1836.50	28.50	58.00	50.86	49.14
2-K	1836.75	1865.50	28.75	1865.50	1890.50	25.00	53.75	53.49	46.51
3-K	1890.75	1918.25	27.50	1918.25	1944.50	26.25	53.75	51.16	48.84
4-K	1944.50	1973.50	29.00	1967.00	1992.00	25.00	54.00	53.70	46.30
Arithmetic mean			28.69 [c]			26.19 [c]	54.88 [c]	52.28 [c]	47.72 [c]
St. deviation = σ			*(0.85)*			*(1.65)*	*(2.09)*	–	–
Arithmetic mean of UK chronologies based on price index [a]									
Waves	Upwaves: α			Downwaves: β			Duration of cycles	Upwave %	Downwave %
Section B	A = begin	B = end	Length B–A = C	A' = begin	B' = end	Length B'–A' = D	$C+D$		
1-K	1781.00	1815.00	34.00	1815.00	1839.50	24.50	58.50	58.12	41.88
2-K	1839.50	1869.00	29.50	1869.00	1894.50	25.50	55.00	53.64	46.36
3-K	1894.50	1920.00	25.50	1920.00	1945.00	25.00	50.50	50.50	49.50
4-K	–	–	–	–	–	–	–	–	–
Arithmetic mean			29.67 [c]			25.00 [c]	54.67 [c]	54.27 [c]	45.73 [c]
St. deviation = σ			*(4.25)*			*(0.50)*	*(4.01)*	–	–
Arithmetic mean of US and UK chronologies based on price index [a]									
Waves	Upwaves: α			Downwaves: β			Duration of cycles	Upwave %	Downwave %
Section C	A = begin	B = end	Length B–A = C	A' = begin	B' = end	Length B'–A' = D	$C+D$		
1-K	1779.50	1811.25	31.75	1810.33	1837.50	27.17	58.92	53.89	46.11
2-K	1837.67	1866.67	29.00	1866.67	1891.83	25.17	54.17	53.54	46.46
3-K	1892.00	1918.83	26.83	1918.83	1944.50	25.83	52.67	50.94	49.04
4-K [e]	1944.50	1973.50	29.00	1967.0 [d]	1992.00	25.00	54.00	53.70	46.30
Arithmetic mean			29.15 [c]			25.79 [c]	54.94 [c]	53.06 [c]	46.94 [c]
St. deviation = σ			*(2.01)*			*(0.98)*	*(2.73)*	–	–
Std. error mean			*1.01*			*0.49*			

Note: data are years and their fractions.
[a] These years are average timing based on chronologies of long waves worked out by Kondratieff, Van Gelderen, Mandel, Van Duijn, Kuznets, Berry et al.
[b] This value is given by: $\left(\frac{wavelength}{length\ of\ upwave\ or\ downwave}\right) \times 100$.
[c] Arithmetic mean, below standard deviation (σ) in round brackets.
[d] 4th K wave calculated only on US data, since UK data are missing.
[e] This value is not an arithmetic mean.

hypothesis that the upwave phase α in a Kondratieff wave is a longer period than the downwave phase β, owing to an actual difference in the average periods of upswings and downswings, based on the structure and dynamics of economic systems in the long run. This paired-samples T-test confirms for a long wave that (Table 2):

$$Upwave\,length > downwave\,length: \alpha > \beta. \square$$

Remark. If we consider the data about the US and the UK separately, the critical behavior of LWs, based on longer upwave phases (hypothesis stated), is confirmed over time (cf. Table 1, sections A and B).

Assuming that

– The analysis of the US economy shows an average upwave length of 28.69 years (σ = 0.85) longer than the average downwave length, which is equal to 26.19 years (σ = 1.65);

Table 2
Temporal paired samples test on chronologies from US and UK economies.

Based on data from US and UK economies		Paired differences					t	df	Sig. (2-tailed)
		Mean	Std. deviation	Std. error mean	95% confidence interval of the difference				
					Lower	Upper			
Pair 1	Upwave period–downwave period	3.35	1.60	0.80	0.81	5.90	4.19	3.00	0.02

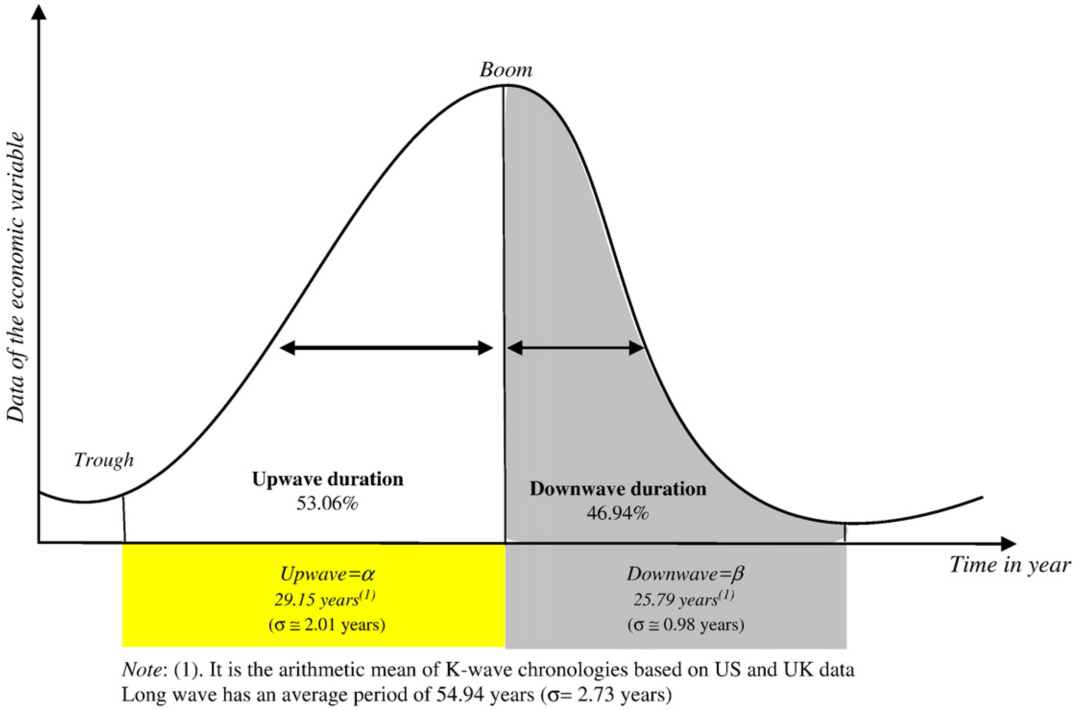

Fig. 2. Typical negative asymmetry of a Kondratieff wave.

– Also the UK economy has an average upwave period longer than the average downwave period (*i.e.* 29.67 years *vs.* 25 years); this behavior of LWs in the UK economic system is similar to that displayed by the US economy;
– Joint US and UK data further confirm, by a paired-samples *t*-test, these findings: that the upwave of LWs is actually longer than the downwave phase;
– These countries (the US and the UK) are drivers for worldwide economic growth and several leading countries display a behavior in their economic cycles similar to that of the US and UK economies;

Then the statistical evidence, in general, supports the hypothesis stated:

the upwave phase "α" of Kondratieff waves is a longer period than the downwave phase "β".

The vital implication of this fundamental finding is that:

Long Waves are not symmetric and they have a negative asymmetric path over time.

A geometrical graph of a LW, bounded in a lapse of time, is represented in Fig. 2. This distribution is similar to a normal curve $y = \frac{N}{\sigma\sqrt{2\pi}}\int_{-\infty}^{+\infty} e^{\frac{-(x-\mu)}{2\sigma^2}}$ with a light negative asymmetric path around the economic boom.

In general, the LWs have an average upwave temporal duration equal to 53.06% of the wavelength, whereas the average downwave temporal duration is 46.94% (see Fig. 2 and Table 1, section C). This result confirms that LWs have a negative asymmetric path generated by skewed downswings or downswings compressed over time.

4. Concluding remarks

Statistical evidence from the previous sections supports the hypothesis that *Long waves have longer periods of upwave than downwave.*

More specifically, this regularity in the behavior of LWs causes, de *facto*, these waves to have asymmetric paths. In order to support this vital hypothesis for the theory of Long Waves, using the System Dynamic National Model, Sterman [29] presents an integrated theory of the economic long wave, where he describes the following rough result: "The long wave tends to be asymmetrical, with a gradual expansion over about 20 years followed by a relatively swift decline and depression period of 15–20 years" (p. 115). The statistical evidence of this study reinforces and refines the *non*-symmetric behavior and shape of LWs over time, showing the actual length of upswings and downswings, as well as their proportion over the long-wave length.

As far as the following economic questions are concerned:

> Why do Long Waves (LWs) have an asymmetric path over time?
> Why do LWs have a longer period of upwave (~53% of wavelength) than downwave (~47%)?

the negative asymmetric path of LWs is rooted in the "self-ordering of capital" ([29], pp. 114–116), which through a wide range of "self-reinforcing processes" ([29], pp. 116 ff. and cf. [31], p. 20 and 21, *passim*) amplifies the demand by "positive feedback loops" ([29], p. 119 and cf. [31], p. 21) with firms, labor and financial markets (real interest rate dynamics).

In fact, these reinforcing mechanisms amplify the demand of capital created by firms, boosting amplitude and lengthening the upwave[14]; after the boom, the "self-ordering loops reverse" ([29], p. 118). In addition, LWs are also driven by economic and technological forces such as innovations — see Mensch [39]; cf. also Devezas et al. [40] and de Groot and Franses [11]. Devezas et al. [40] analyzing the 4th Kondratieff wave, observe a succession of events (p. 923, reference to the Fig. 2): "the inventions appearing during the up-wave and during the first recession period, innovations clustering all along the down-wave and further recession period, and finally the widespread diffusion occurring at the trough and transition period into the fifth K-wave".[15] Therefore, the process of technological innovation, which is accumulated in the economic downturn and then is spread over time amplifying its effects, may generate a disproportionate (allometric) upwave growth of LWs.

It is also important to remark that long waves are affected by the path of capitalistic systems, which interacts with geo-political systems. The *non*-symmetric behavior of LWs, based on an upwave longer than the downwave, is multicausal and a further possible determinant might be that periods of peace (and socio-economic stability) are longer than war times across driving countries, with fruitful effects on economic growth patterns, which underpin K-wave dynamics. In addition, the diffusion of democratization across countries has increased global wealth and wellbeing and, as a consequence, it might also have extended the upwave trend of LWs (cf. Modelski and Perry III [42], p. 366–369; Coccia [43], pp. 255 ff).

The uniformity of Long Wave behavior, typified by upwave amplification and downwave compression, is suitable to describe the main characteristics of these waves over time. This general *non*-symmetric behavior of LWs, across several countries, is due to the fact that the modern global economy is a socio-economic organism based on symbiotic relationships among its sub-sets (countries), forming an interrelated system governed by similar socio-economic laws (cf. Wagemann [13], Cap. IX, pp. 100–101).[16]

This research is based on the US and UK economies, which are still the driving countries (but not the only ones[17]) for worldwide economic growth; the behavior of their economic cycles is an apt signal that shocks and/or booms are approaching in the global economic system, like the latest global financial crisis, described by Goldstein [44] (pp. 263–267), or the negative premonitory signals of current huge public debts (e.g. in 2009, the US have a ratio public debt/GDP equal to 70%, the UK has a value of 68.5% that has been increasing over time).

The results discussed here focus on a deterministic approach based on long-wave chronologies worked out by scholars. Nevertheless, being turbulent and dynamic, the world is subject to probable stochastic shocks that affect long-wave behavior in the long run.

Although the regularity of LWs based on negative asymmetric behavior has been demonstrated, a margin of uncertainty remains about the exact length of the downwave and upwave period, due to the multidimensional forces that drive capitalistic systems (*e.g.* economic, energy, political, social and technological factors).[18] The vital finding of the present study might be considered an empirical law that shows the asymmetric pattern of LWs. However, this empirical law might modify over time and space, because of several socio-economic-technological factors, instability, and human behavior that is not always rational. In fact, new events added to old ones increase the turbulence of modern socio-economic systems and make the analysis of long-wave behavior a more and more difficult task.[19] These conclusions are not, of course, comprehensive. There is need for further and more detailed research into the *non*-symmetric behavior of long waves as well as into its inner causes in order to support both pro-cyclical political economy of growth during upturn and counter-cyclical investments for counteracting downturn period.

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[14] Cf. Graham and Senge [30], p. 308–309; Sterman [29], pp. 17–22, pp. 45–47 and Appendix A.

[15] See Reati and Toporowski [41], pp. 409-431, for an interesting analysis of the economic policy concerning the Fifth Long Wave.

[16] Despite this similar asymmetric path of LWs, the rhythm of these waves is not synchronized across countries, but it presents some temporal lags.

[17] The current and future global economy will be based on the increasing importance of Asian economies (such as China, India and Japan), as well as of the Brazilian and Russian economies, etc. (most of these countries are called BRIC countries, an acronym that refers to the fast-growing economies of Brazil, Russia, India, and China). These economies can affect the pattern of next K-waves and future researches have to consider the crucial role of these countries.

[18] Of course, the length of upwave and downwave changes depending on the structure of the economic systems and their ability to react to exogenous and endogenous stimuli.

[19] The events that complicate the analysis of long waves are: financial shocks (cf. Goldstein [44], pp. 263–267), terrorism warfare (cf. Linstone [45], p. 115), crisis of primary energy resources (see Volland [4]), changes in geo-economic equilibrium, political instability, technological revolutions, and so on (see Devezas [46]).

Appendix A. Data of business cycles

Table 1A
US business cycles (expansions and contractions).

Trough (min)	Peak (max)	Duration (in months)				
		Contraction	Expansion	Cycle	Contraction[1] %	Expansion[1] %
December 1854 (IV)	June 1857 (II)	–	30			
December 1858 (IV)	October 1860 (III)	18	22	40	45.0	55.0
June 1861 (III)	April 1865 (I)	8	46	54	14.8	85.2
December 1867 (I)	June 1869 (II)	32	18	50	64.0	36.0
December 1870 (IV)	October 1873 (III)	18	34	52	34.6	65.4
March 1879 (I)	March 1882 (I)	65	36	101	64.4	35.6
May 1885 (II)	March 1887 (II)	38	22	60	63.3	36.7
April 1888 (I)	July 1890 (III)	13	27	40	32.5	67.5
May 1891 (II)	January 1893 (I)	10	20	30	33.3	66.7
June 1894 (II)	December 1895 (IV)	17	18	35	48.6	51.4
June 1897 (II)	June 1899 (III)	18	24	42	42.9	57.1
December 1900 (IV)	September 1902 (IV)	18	21	39	46.2	53.8
August 1904 (III)	May 1907 (II)	23	33	56	41.1	58.9
June 1908 (II)	January 1910 (I)	13	19	32	40.6	59.4
January 1912 (IV)	January 1913 (I)	24	12	36	66.7	33.3
December 1914 (IV)	August 1918 (III)	23	44	67	34.3	65.7
March 1919 (I)	January 1920 (I)	7	10	17	41.2	58.8
July 1921 (III)	May 1923 (II)	18	22	40	45.0	55.0
July 1924 (III)	October 1926 (III)	14	27	41	34.1	65.9
November 1927 (IV)	August 1929 (III)	13	21	34	38.2	61.8
March 1933 (I)	May 1937 (II)	43	50	93	46.2	53.8
June 1938 (II)	February 1945 (I)	13	80	93	14.0	86.0
October 1945 (IV)	November 1948 (IV)	8	37	45	17.8	82.2
October 1949 (IV)	July 1953 (II)	11	45	56	19.6	80.4
May 1954 (II)	August 1957 (III)	10	39	49	20.4	79.6
April 1958 (II)	April 1960 (II)	8	24	32	25.0	75.0
February 1961 (I)	December 1969 (IV)	10	106	116	8.6	91.4
November 1970 (IV)	November 1973 (IV)	11	36	47	23.4	76.6
March 1975 (I)	January 1980 (I)	16	58	74	21.6	78.4
July 1980 (III)	July 1981 (III)	6	12	18	33.3	66.7
November 1982 (IV)	July 1990 (III)	16	92	108	14.8	85.2
March 1991(I)	March 2001 (I)	8	120	128	6.3	93.8
November 2001 (IV)	December 2007 (IV)	8	73	81	9.9	90.1
Average, all cycles: 1854–2001 (32 cycles)	(In months) Arithmetic mean (*Standard Dev.*)	17.44 (*12.29*)	38.73 (*27.18*)	56.44 (*28.53*)	30.9%	68.6%
	Max (months)	65	120	128		
	Min (months)	6	10	17		
1854–1919 (16 cycles)	Arithmetic mean (*Standard Dev.*)	22.53 (*14.14*)	26.63 (*9.72*)	48.93 (*18.05*)		
1919–1945 (6 cycles)	Arithmetic mean (*Standard Dev.*)	18.00 (*12.74*)	35.00 (*25.71*)	53.00 (*32.16*)		
1945–2007 (11 cycles)	Arithmetic mean (*Standard Dev.*)	10.18 (*3.25*)	58.36 (*35.01*)	68.55 (*36.02*)		

Note: 1. Contraction or expansion % is: $\left(\frac{\textit{Cycle period}}{\textit{duration of contraction or expansion}}\right) \times 100$.

Quarterly dates are Roman numbers in parentheses. Standard Dev. is in parentheses to right of arithmetic mean.
Source: NBER [17].

Table 2A
Italian business cycles 1945–1965.

Cycles	Initial min	Max	Final min	Duration (in months)			Expansion %	Contraction %
				Expansion	Contraction	Cycle		
I	May 1945	September 1947	March 1948	28	6	34	82.35	17.65
II	March 1948	July 1949	March 1950	16	8	24	66.67	33.33
III	March 1950	Apr 1951	June 1952	13	14	27	48.15	51.85
IV	June 1952	June 1955	February 1956	36	8	44	81.82	18.18
V	February 1956	September 1957	August 1958	19	11	30	63.33	36.67
VI	August 1958	July 1960	January 1961	23	6	29	79.31	20.69
VII	January 1961	October 1963	January 1965	33	15	48	68.75	31.25
	Average, all cycles: 1945–1965 (in months)			24.00	9.71	33.71	70.05%	29.95%
			(*Standard Dev.*)	(*8.68*)	(*3.68*)	(*8.99*)		
			Max (months)	36	15	48		
			Min (months)	13	6	24		

Source: Lenti [20], p. 1159.

References

[1] G. Modelski, What causes K-waves? Technol. Forecast. Soc. Change 68 (1) (2001) 75–80.
[2] G. Mortara (Ed.), Cicli Economici, vol. VI, UTET, Torino, 1932.
[3] J. Schumpeter, Le teorie dello sviluppo economico, in: G. De Maria (Ed.), Dinamica Economica, vol. V, Utet, Torino, 1932, pp. 21–182.
[4] C.S.A. Volland, A comprehensive theory of long wave cycles, Technol. Forecast. Soc. Change 32 (2) (1987) 123–145.
[5] R.U. Ayres, Technological transformations and long waves. Part I, Technol. Forecast. Soc. Change 37 (1) (1990) 1–37.
[6] R.U. Ayres, Technological transformations and long waves. Part II, Technol. Forecast. Soc. Change 37 (2) (1990) 111–137.
[7] B.J.L. Berry, H. Kim, H.M. Kim, Are long waves driven by techno-economic transformations? Evidence for the U.S. and the U.K. Technol. Forecast. Soc. Change 44 (2) (1993) 111–135.
[8] J. Dator, Return to long waves, Futures 31 (3–4) (1999) 361–372.
[9] H.A. Linstone, From my perspective. From information age to molecular age, Technol. Forecast. Soc. Change 71 (1–2) (2004) 187–196.
[10] B. de Groot, P.H. Franses, Stability through cycles, Technol. Forecast. Soc. Change 75 (3) (2008) 301–311.
[11] B. de Groot, P.H. Franses, Cycles in basic innovations, Technol. Forecast. Soc. Change 76 (8) (2009) 1021–1025.
[12] W.C. Mitchell, Fenomeni e Fattori dei Cicli Economici, in: G. Mortara (Ed.), Cicli Economici, vol. VI, UTET, Torino, 1932, pp. 5–58.
[13] E. Wagemann, Introduzione alla Teoria della Congiuntura Economica, in: G. Mortara (Ed.), Cicli Economici, vol. VI, UTET, Torino, 1932, pp. 61–207.
[14] C. Bresciani Turroni, Le Previsioni Economiche, in: G. Mortara (Ed.), Cicli Economici, vol. VI, UTET, Torino, 1932, pp. 211–364.
[15] C. Papenhausen, Causal mechanisms of long waves, Futures 40 (9) (2008) 788–794.
[16] N.D. Kondratieff, The long waves in economic life, Rev. Econ. Stat. 17 (6) (1935) 105–115.
[17] NBER (2010), National Bureau of Economic Research, http://www.nber.org/, accessed January 4.
[18] W.A. Razzak, Business cycle asymmetries: international evidence, Rev. Econ. Dyn. 4 (1) (2001) 230–243.
[19] M. Chalkey, I.H. Lee, Learning and asymmetric cycles, Rev. Econ. Dyn. 1 (3) (1998) 623–645.
[20] L. Lenti, Statistica Economica, UTET, Torino, 1972.
[21] S. Basu, A.M. Taylor, Business cycles in international historical perspectives, J. Econ. Perspect. 13 (2) (1999) 45–68.
[22] D.E. Sichel, Business cycle asymmetry: a deeper look, Econ. Inq. 31 (2) (1993) 224–236.
[23] G.D. Hansen, E.C. Prescott, Capacity constraints, asymmetries, and the business cycle, Rev. Econ. Dyn. 8 (4) (2005) 850–865.
[24] F.E. Kydland, E.C. Prescott, Hours and employment variation in business cycle theory, Econ. Theory 1 (1) (1991) 63–81.
[25] R.J. Hodrick, E.C. Prescott, Postwar U.S. business cycles: an empirical investigation, J. Money, Credit Bank. 29 (1) (1997) 1–16.
[26] J.P. Cover, P. Pecorino, The length of US business expansions: when did the break in the data occur? J. Macroecon. 27 (3) (2005) 452–471.
[27] C.D. Romer, Changes in business cycles: evidence and explanations, J. Econ. Perspect. 13 (2) (1999) 23–44.
[28] R. Verbrugge, Investigating cyclical asymmetries, Stud. Nonlinear Dyn. Econom. 2 (1) (1997) 15–22.
[29] J.D. Sterman, An integrated theory of the economic long wave, Futures 17 (2) (1985) 104–131.
[30] A.K. Graham, P.M. Senge, A long-wave hypothesis of innovation, Technol. Forecast. Soc. Change 17 (4) (1980) 283–311.
[31] J.D. Sterman, A behavioural model of the economic long wave, J. Econ. Behav. Organ. 6 (1) (1985) 17–53.
[32] W.C. Mitchell, Business Cycles and their Causes, University of California Press, Berkley, 1941, p. 5.
[33] J.W. Forrester, Business structure, economic cycles, and national policy, Futures 8 (3) (1976) 195–214.
[34] J.J. Van Duijn, The long wave in economic life, Economist (125) (1977) 544–576.
[35] S. Kuznets, Economic Change, Norton, New York, 1953, p. 109.
[36] B.J.L. Berry, H. Kim, Leadership generations: a long-wave macrohistory, Technol. Forecast. Soc. Change 46 (1) (1994) 1–9.
[37] C. Marchetti, Kondratiev revisited—after one kondratiev cycle, Presented at the International Conference on Regularities of Scientific-Technical Progress and Long-Term Tendencies of Economic Development, Novosibirsk, Akademgorodok, USSR, March 14–19, 1988.
[38] SPSS, Statistical Package for Social Sciences, SPSS Inc, Headquarters, 233 S. Wacker Drive, Chicago, USA, 2010.
[39] G. Mensch, Stalemate in Technology: Innovations Overcome the Depression, Ballinger Pub. Co, Cambridge, MA, USA, 1979.
[40] T.C. Devezas, H.A. Linstone, H.J.S. Santos, The growth dynamics of the internet and the long wave theory, Technol. Forecast. Soc. Change 72 (8) (2005) 913–935.
[41] A. Reati, J. Toporowski, An economic policy for the fifth long wave, BNL Q. Rev. (231) (2004) 395–437.
[42] G. Modelski, G. Perry III, Democratization in long perspective revisited, Technol. Forecast. Soc. Change 69 (4) (2002) 359–376.
[43] M. Coccia, Democratization is the driving force for technological and economic change, Technol. Forecast. Soc. Change 77 (2) (February 2010) 248–264.
[44] J.P. Goldstein, Heterodox macroeconomics and the current global financial crisis, in: J.P. Goldstein, M.G. Hillard (Eds.), Heterodox Macroeconomics. Keynes, Marx and Globalization, Routledge, London and New York, 2009.
[45] H.A. Linstone, Book Review, Kondratieff Waves, Warfare and World Security, edited by Tessaleno C. Devezas, IOS Press, Amsterdam, 2006, Technological Forecasting and Social Change, 74 (1) (2007) 113–116.
[46] T.C. Devezas (Ed.), Kondratieff Waves, Warfare and World Security, NATO Science Series, ISO Press, Amsterdam, 2006.

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