DOI: 10.24193/OJMNE.2022.40.03

ASSESSING THE RESILIENCE OF UK'S ECONOMY AFTER THE COVID-19 PANDEMIC AND BREXIT

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Absract: *The objective of the paper is to assess the resilience of UK's economy towards two economic shocks: the Covid-19 pandemic that hit the global economy in Q4 2019, in years 2020, 2021 and 2022 and the Brexit following the withdrawal of UK from the European Union on 31 January 2020. To assess the resilience of UK's economy, two sets of forecasts are generated: forecasts using historical data including the pandemic and the Brexit (from Q1 1998 to Q4 2021) and not including the pandemic and the Brexit (from Q1 1998 to Q3 2019). The computation of the difference of their averages is an indicator of the resilience of the economy during the pandemic, the greater the difference the greater the resilience. Eurozone is used as benchmark. By subtracting the average forecasted 2022-2050 Eurozone quarterly GDP growth rate (annualized) obtained with the Q1 1998-Q4 2021 data, +2.93%, by the one obtained with the Q1 1998-Q3 2019 data, +1.59%, the difference is +1.33%, whereas with UK the difference is -2.33% [-0.24% - (-2.09%)]. Thus, Eurozone shows a greater resilience (+1.33%) than the UK (-2.33%) based on 2022-2050 forecasts. In addition, the authors pointed out that the average of the 2022-2050 quarterly (annualized) growth rate forecasts of the Eurozone is expected to be +2.93% with the 1998-2021 data whereas it is expected to be only -2.09% for UK The Eurozone economy shows better prospects than the UK economy.*

Keywords: GDP, spectrala analysis; wavelet analysis; forecasting; UK economy; Eurozone economies.

1. Introduction

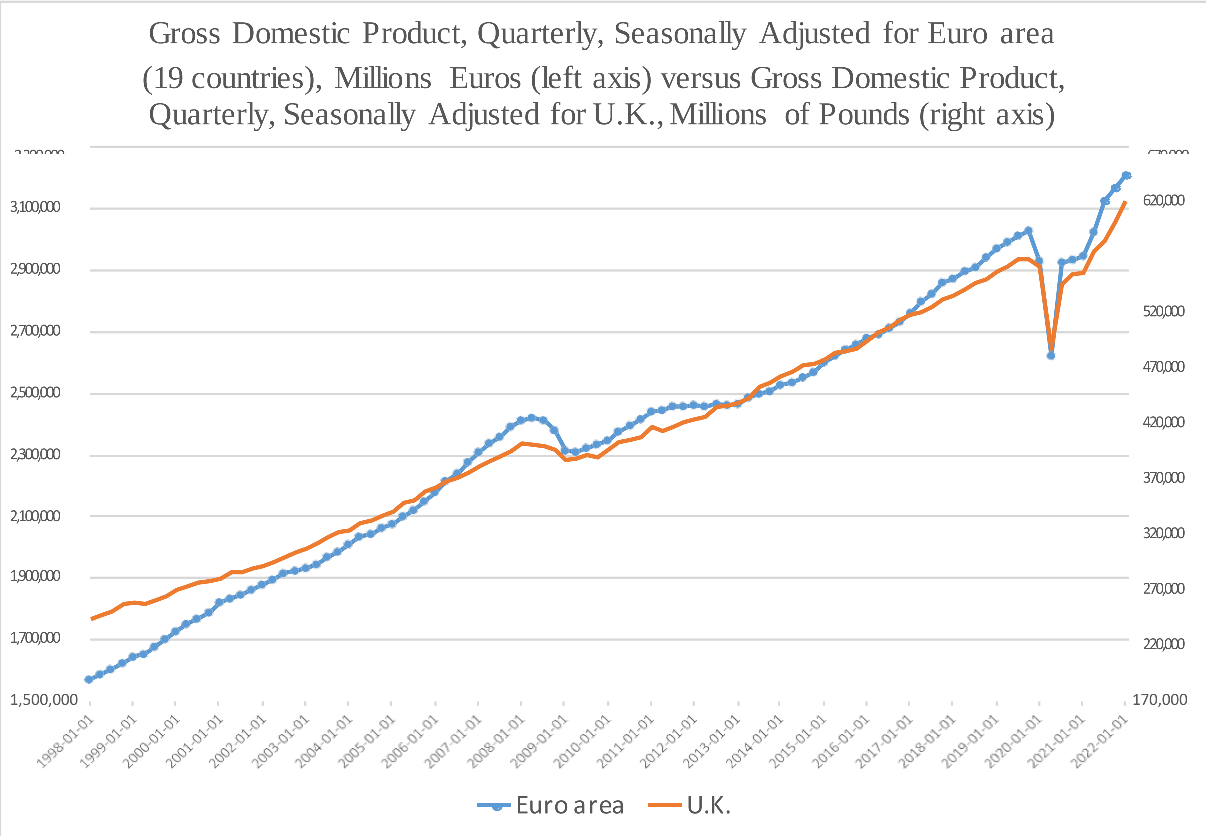
This paper presents UK's 2050 GDP forecasts before (up to 2019) and during the pandemic and the Brexit (up to 2021) by using spectral analysis. The objective of the paper is to assess the resilience of UK's economy towards these two shocks with its 2050 projections. These projections are benchmarked to the 2050 GDP forecasts of the Eurozone (19 countries). The Eurozone is the monetary union of 19 out of 28 European Union member states, all of which have adopted the Euro as their single currency and sole legal tender. The monetary authority of the Eurozone is the Eurosystem. Eurozone members are Austria, Belgium, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain, Greece, Slovenia, Cyprus, Malta, Slovakia, Estonia, Latvia, and Lithuania. The other nine members of the European Union continue to use their own national currencies, although most of them have undertaken to adopt the Euro in the future.

The assumption in this research is that GDPs propagate through time in waveforms. Wavelet analysis capture the dynamics of these waves. Wavelet analysis expands functions in terms of wavelets generated in the form of translations and dilations of a fixed function called the mother wavelet. The resulting wavelets have special scaling properties, localized in time and frequency, permitting a closer connection between the represented function and their coefficients. Greater numerical stability in reconstruction and manipulation is ensured (Lee and Yamamoto, 1994, p. 44). Extending the analysis to the complex-behavior of economic signals, the originality of this paper lies in the application of wavelet analysis to economic variables subject to common dynamics such as GDP time series. Rostan and Rostan have previously applied wavelet analysis to the forecasts of fossil fuel prices (2021a) and to the forecasts of the Spanish (2018c), Greek (2018d), Austrian (2020), Saudi Arabian (2021b), Persian Gulf (2022a) and Turkish (2022b) economies. This paper is an extension of their work.

On the Covid-19 pandemic issue, present since late 2019 and having spread to the five continents in 2020, killing people by the millions and plunging the world economy into severe recession, this unexpected and dramatic event has forced governments to introduce unprecedented measures such as lockdowns of populations to contain its spread. By December 10, 2022, the recorded number of Coronavirus Cases in the world was 652,302,367 people with a Coronavirus death toll of 6,654,524 (Worldometers, 2022). The lockdowns have paralyzed economies across the five continents, shutting down factories and bringing manufacturing to a halt, with service sectors contracting on a massive scale, forcing millions of workers to leave the labor force. Globally, the economic activity has contracted at a rapid pace and put economies into recession.

Figure 1 illustrates the historical quarterly GDP time series of the Eurozone economy (19 countries) and UK from 1/1/1998 to 1/1/2022. It shows two almost identical patterns at the start of 2020 when the two economies have entered recession following the economic shock from the Covid-19 pandemic that hit the global economy. Since 1998, the GDP of UK seems to have grown at a more rapid pace with a steeper slope than the GDP of the Eurozone economy between 1998 and 2020, the two economies seem to have dived at an identical rate in 2020 and UK seems to have recovered at a more rapid pace in 2021 with a steeper slope.

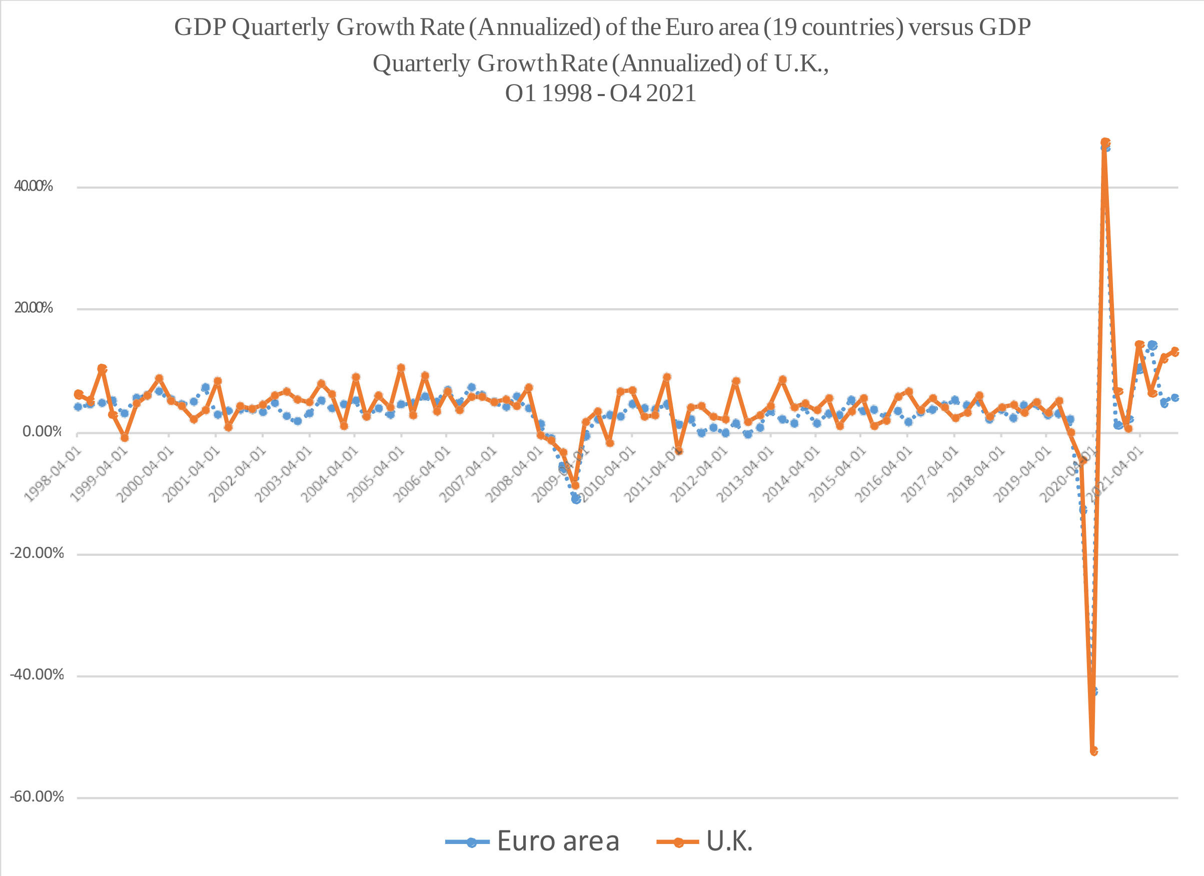
Figure 1: Quarterly GDPs time series of the Eurozone economy (19 countries) and UK from Q1 1998 to Q4 2021.



Sources: Authors' own elaboration. Gross Domestic Product for Eurozone (19 countries) [https://fred.stlouisfed.org/series/EUNNGDP] and UK [https://fred.stlouisfed.org/series/UKNGDP], retrieved from FRED, Federal Reserve Bank of St. Louis

Figure 2 illustrates the historical quarterly GDP growth rate (annualized) time series of the Eurozone economy (19 countries) and UK from Q1 1998 to Q4 2021.

Figure 2: Quarterly GDP growth rate (annualized) time series of the Eurozone economy (19 countries) and UK from Q1 1998 to Q4 2021.

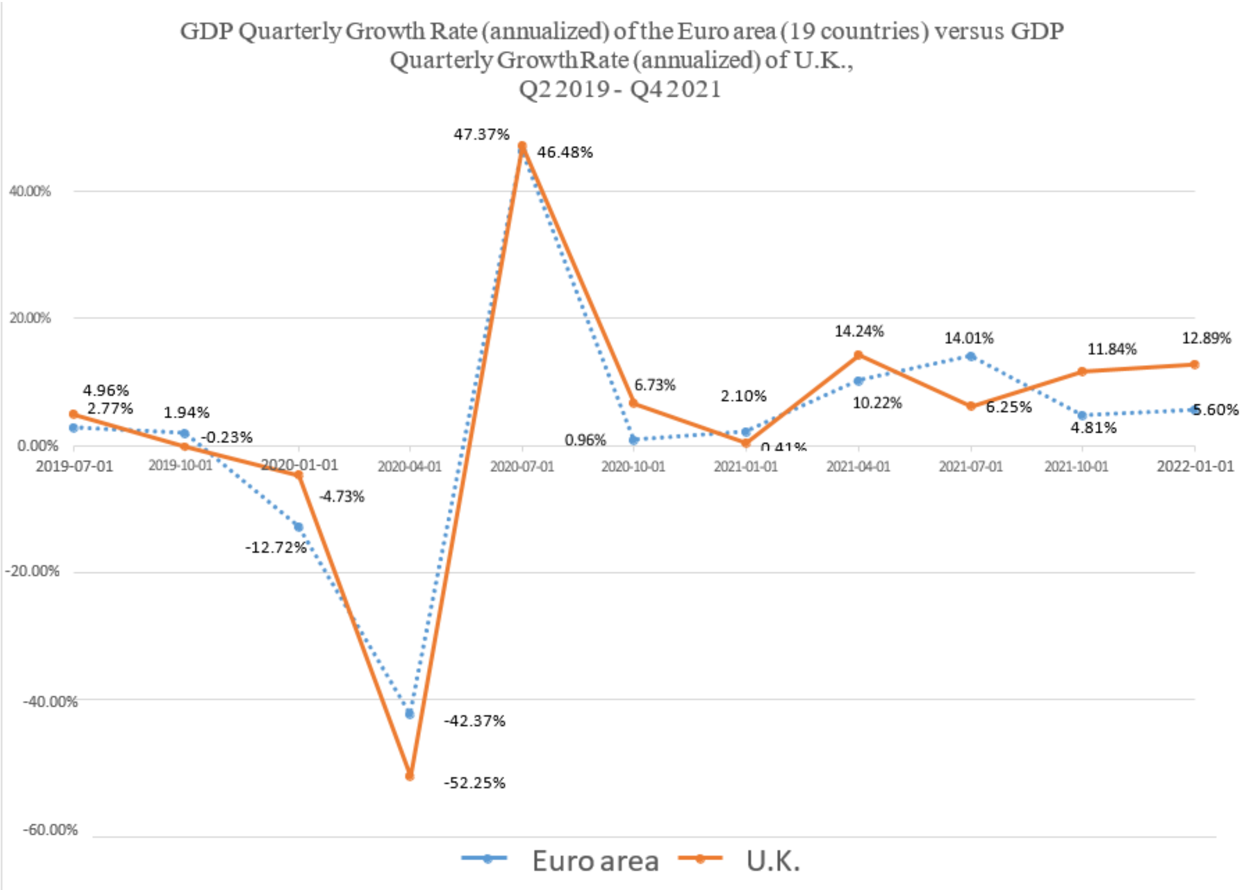


Sources: Authors' own elaboration. Real Gross Domestic Product for Eurozone (19 countries) [https://fred.stlouisfed.org/series/CLVMNACSCAB1GQEA19] and UK [https://fred.stlouisfed.org/series/UKNGDP], retrieved from FRED, Federal Reserve Bank of St. Louis.

As illustrated in Figure 2, between Q1 1998 and Q3 2019, the quarterly GDP growth rate (annualized) of the Eurozone economy (19 countries) was most of the time below the one of UK with an average growth rate of 3.03% for the Eurozone versus 3.92% for UK.

Figure 3 is a zoom of Figure 2 between Q3 2019 and Q4 2021. It illustrates the historical quarterly GDP growth rate (annualized) time series of the Eurozone economy (19 countries) and UK from Q2 2019 to Q4 2021.

Figure 3: Quarterly GDP growth rate (annualized) time series of the Eurozone economy (19 countries) and UK from Q2 2019 to Q4 2021.



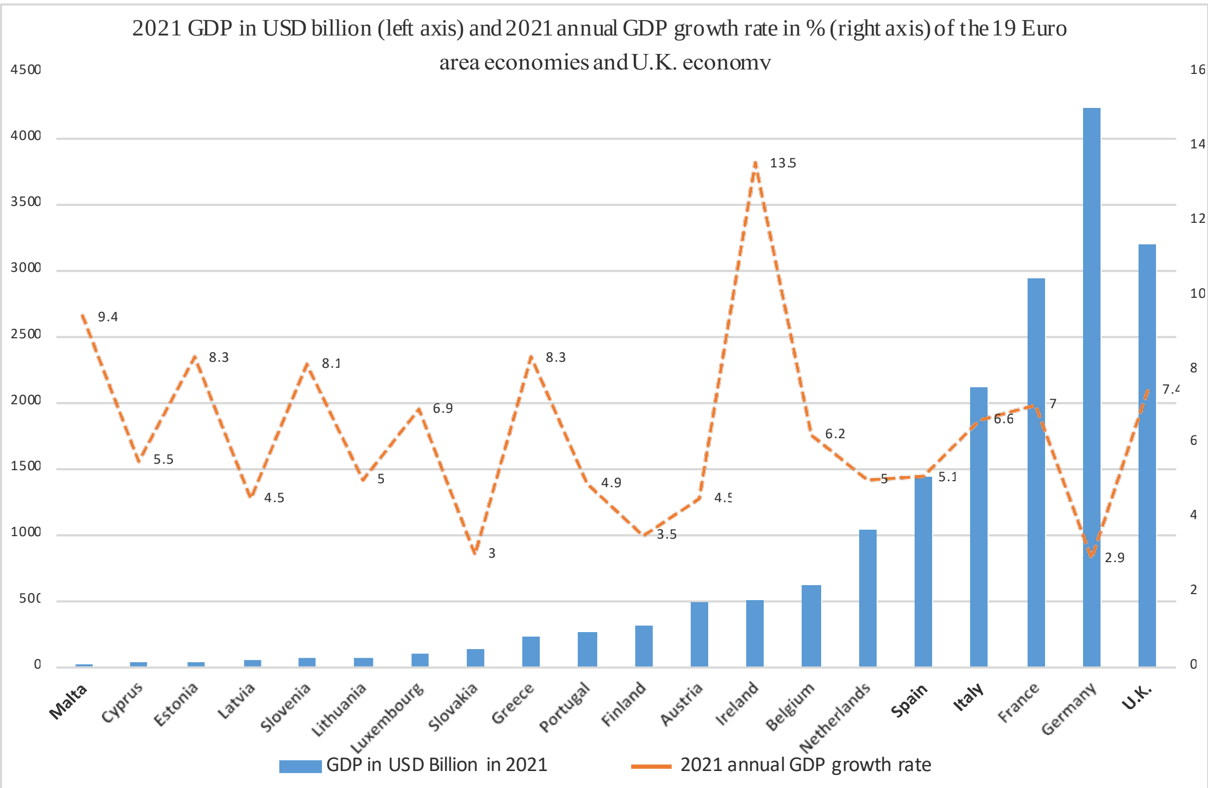
Sources: Authors' own elaboration. Real Gross Domestic Product for Eurozone (19 countries) [https://fred.stlouisfed.org/series/CLVMNACSCAB1GQEA19] and UK [https://fred.stlouisfed.org/series/UKNGDP], retrieved from FRED, Federal Reserve Bank of St. Louis.

As illustrated in Figure 3, during time of pandemic, between Q4 2019 (2020-01-01) and Q4 2021 (2022-01-01), the quarterly GDP growth rate (annualized) of the Eurozone economy (19 countries) was most of the time below the one of UK with an average growth rate of 3.23% for the Eurozone versus 4.75% for UK. It confirms the historical relationship between the 2 economies observed between 1998 and 2019.

In conclusion, the 2050 projections of these 2 economies are expected to respect this relationship, displaying a stronger and more resilient UK economy than the Eurozone economy in terms of GDP growth rate. However, we need to keep in mind that the size of the Eurozone economy (19 countries) was about 4.5 times the size of the UK economy in 2021. In the Eurozone, the growth of its economies varies widely. For example, based on Statista (2022) data, the top 5 economies based on the GDP annual growth rate in 2021 (year to year) were Ireland (+13.5%), Malta (+9.4%), Greece (+8.3%), Estonia (+8.3%) and Slovenia (+8.1%) when the 5 laggers were Germany (+2.9%), Slovakia (+3%), Finland (+3.5%), Austria

(+3.5%) and Latvia (+4.5%). The average annual GDP growth rate for the 19 economies of the Eurozone was 6.22% in 2021. The annual GDP growth rate for UK was 7.4% in 2021. Besides, as illustrated in Figure 4, the largest economy of the Eurozone, Germany, was the worst performer in 2021 with +2.9% of annual growth rate. The smallest economy of the Eurozone, Malta, was the second top performer in terms of 2021 annual growth rate (+9.4%). The 13 smallest economies from Malta to Ireland ranked in increasing GDP had an average 2021 annual growth rate of 6.56%, when the 6 top largest economies from Belgium to Germany had an average 2021 annual growth rate of 5.46%. The correlation coefficient between the size of the 2021 GDP and the growth rate of the 19 countries is -20%. This is not a strong relationship between the two variables, but the correlation is still negative, and it shows that small economies have copped better with the Covid19 pandemic crisis than large economies of the Eurozone. This rule applies to UK, since the size of its economy (3,187 USD billions) is almost equal to France’s economy (2,937 USD billions) and its 2021 annual growth rates (+7.4%) almost equal to the growth of France’s economy (+7.0%).

Figure 4: 2021 GDP in USD billion (left axis) and 2021 annual GDP growth rate in % (right axis) of the 19 Eurozone economies and U.K.UK’s economy



Sources: Authors’ own elaboration. Annual gross domestic product growth rate forecast in selected European countries in 2021 from https://www.statista.com/statistics/686147/gdp-growth-europe/ GDP | Europe in USD Billion in 2021 from https://tradingeconomics.com/country-list/gdp?continent=europe

This paper presents UK versus Eurozone 2050 GDP forecasts before (up to 2019) and during the pandemic (up to 2021) by using wavelets analysis. The following section will discuss the meaning of wavelets in signal processing and explore the ways signal processing has been applied in the literature.

2. Literature Review

2.1. Spectral analysis versus traditional economic forecasting methods

Traditional economic forecasting methods include causal methods (regression analysis, logit, probit), time series methods (moving average, exponential smoothing, trend and seasonal decomposition, Box-Jenkins ARIMA used as a benchmark in this paper) and qualitative methods (Delphi Method, Jury of Executive Opinion, Sales Force Composite, Consumer Market Survey) (FHI, 2019). Signal processing used in this paper to forecast the Eurozone's GDPs belongs to time series methods. Signal processing, a field of physics, focuses on the analysis, synthesis, and modification of signals. The basic assumption of this paper is that economic time series behave like signals propagating through time instead of propagating through space as do the phenomena studied by physics such as audio, video, speech, geophysical, sonar, radar, medical and musical signals (IEEE, 2019). Wavelet analysis is a tool of signal processing. In physics, wavelets assume the practical applications of modeling physical phenomena such as electrical, audio or seismic signals which propagate through space in waveforms. Wavelets have specific properties that mimic signals, which makes them useful for signal processing. Signal processing focuses on the analysis, synthesis, and modification of signals. Spectral (or spectrum) analysis focuses on the data analysis of signals. More specifically, from a finite record of a stationary data sequence, spectral analysis estimates how the total power is distributed over frequency. In meteorology, astronomy and other fields, spectral analysis may reveal 'hidden periodicities' in data, which are to be associated with cyclic behavior or recurring processes (Stoica and Moses, 2005).

Regarding wavelet analysis, forecasters have focused on the Discrete Wavelet Transform (DWT, explained at step three of the methodology), directing attention to several non- tractable properties of continuous wavelet transform (CWT) such as highly redundant wavelet coefficients (Valens, 1999), the infinite number of wavelets in the wavelet transform and the absence of analytical solutions for many functions of the wavelet transforms. A wavelet-based forecasting method using the redundant "à trous" wavelet transform and multiple resolution signal decomposition was presented in Renaud et al. (2002). Challenges involved in forecasting day-ahead electricity prices based on the wavelet transform and ARIMA model has been detailed in Conejo et al. (2005). Schlüter and Deuschle (2010), capturing seasonalities with time-varying period and intensity, incorporated the wavelet transform to improve forecasting methods. Tan et al. (2010) proposed a price forecasting method based on wavelet transform combined with ARIMA and GARCH models. Kao et al. (2013) integrated wavelet transforms, multivariate adaptive regression splines (MARS), and support vector regression (SVR called Wavelet-MARS-SVR) to address the problem of wavelet sub-series selection and to improve forecast accuracy. Ortega and Khashanah (2013) proposed a wavelet neural network model for the short-term forecast of stock returns from high-frequency financial data. Kriechbaumer et al. (2014) showed the cyclical behavior of metal prices using wavelet analysis to capture the cyclicality by decomposing a time series into its frequency and time domain. They presented a wavelet-autoregressive integrated moving average (ARIMA) approach for forecasting monthly prices of aluminum, copper, lead and zinc. He et al. (2014) proposed an entropy optimized wavelet-based forecasting algorithm to forecast the exchange rate movement. Berger (2016) transformed financial return series into its frequency and time domain via wavelet decomposition to separate short-run noise from long-run trends and assess the relevance of each frequency to value-at-risk (VaR) forecast. Rostan and Rostan (2018a) illustrated the versatility of wavelet analysis to the forecast of financial time series with distinctive properties. Choosing two market indices with divergent properties of their time series—the S&P 500 Composite Index being nonstationary and the VIX (volatility) index being stationary—they proved that using wavelet analysis combined with the Burg model offers high accuracy in terms of forecasts of their time series, thus demonstrating the versatility of this model. Rostan et al. (2015) appraised the financial sustainability of the Spanish pension system, and Rostan and Rostan (2018b) did the same regarding the Saudi pension system using spectral analysis. With a refined methodology using multiscale principal component analysis to take into account the co-dynamics of age groups, Rostan and Rostan (2017) forecasted European and Asian populations with signal processing which resulted in original outcomes that might be contrasted with those of the more conformist population projections of the United Nations. In addition, Rostan and Rostan (2019) identified when the European Muslim population will become a majority in Europe. Rostan and Rostan applied wavelet analysis to the forecasts of Spanish (2018c), Greek (2018d), Saudi (2020b), Austrian (2020c), Persian Gulf (2022a) and Turkish (2022b) economies.

2.2. Assessing the resilience of the UK's economy after the Covid-19 pandemic and Brexit

As mentioned by the Bank of England (2021), the UK withdrawal from the European Union (EU) on 31 January 2020 was quickly superseded by the alarming spread of Covid-19 in early 2020, which caused the global economy to grind to a halt. The first UK national lockdown was implemented in March 2020 raising concerns about the pandemic's extensive impacts on the UK economy, such as job security. In August 2020, Bank of England panels began to consider the medium and long-term effects of Covid, particularly the structural changes to ways of working, business models, patterns of consumption, the housing market, the future of cities, and inequality.

Atkinson and Goodman (2022) pointed out that the shock of the Covid-19 pandemic on the economy made Boris Johnson the first victim when he was kicked out his job of Prime Minister in 2022. In 2022, the UK has seen the biggest headwinds since the 1970s, overwhelming an economy still struggling with Brexit and the pandemic. After suffering unprecedented shocks in recent years, the UK has succumbed to more intractable problems marked by sluggish growth, runaway inflation (annual inflation rate of 11.1% in October 2022, Trading Economics, 2022) and a series of damaging strikes. The result has been a plunge in consumer confidence that analysts warned could lead to a recession. Railway workers walked off the job in anger that their living standards were slipping, and criminal barristers were striking. In August 2022, nearly 2,000 dock workers at the UK's biggest container port of Felixstowe went on strike in a dispute over pay (Grant, 2022). More than 115,000 British postal workers employed by former state-run Royal Mail planed a four-day strike from the end of August (News Wires, 2022). At the end of 2022, UK was bracing for further disruption from strikes heading into the Christmas period, as ambulance drivers and nurses joined rail operators and postal workers in the worst wave of walkouts the country has endured for at least a decade (Ziady, 2022). More than 20,000 ambulance workers, including paramedics and call handlers, were expected to strike on December 21 in a dispute over pay. Teachers and doctors may be next.

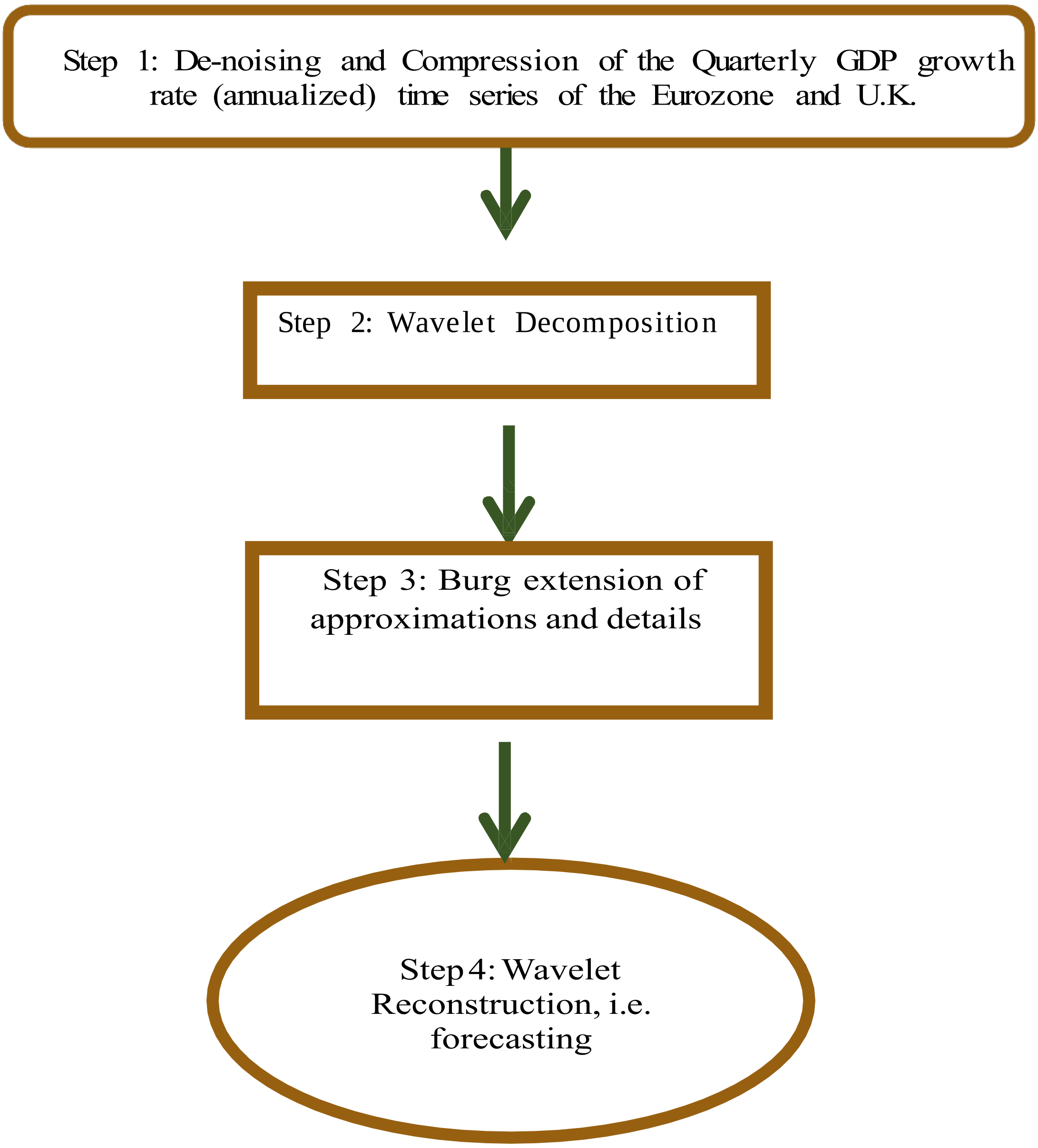
UK has experienced structural problems as well. The main problem has been productivity growth, which slowed after the financial crisis in 2008 and 2009. Low productivity limits the pace at which output can grow and depresses wage packets. Performance gaps in the UK were just as marked, with London consistently outperforming other regions, in part due to the concentration of financial services in the capital city. Atkinson and Goodman (2022) pointed out that Johnson failed to deliver on his 2019 promise to level up the poorest parts of the country. Brexit uncertainty has also seemed to have unsettled executives, with investment flat lining since the 2016 public vote to leave the European Union. Had executives continued to spend as they did before the Brexit referendum, investment would have been around 60% higher by the end of 2022. Life outside the EU has also had an impact on trade as importers and exporters contended with higher trade barriers. Despite a sharp fall in the pound since the vote, there was little evidence to suggest the external sector has benefited from increased competitiveness. UK lagged the trade performance of other big nations before the pandemic and has failed to fully share in the global trade rebound since then. As Andrade (2022) of Bloomberg Economics mentioned, Brexit's impact was plain to see after more than one year after Brexit, since the British pound depreciated about 16% against US$ and trade and investment declined substantially as well. In addition, prices of the housing market have risen almost without break since 1995, straining affordability for first-time buyers. Wages have been lagging too. Real wages adjusted for inflation have been falling at the fastest pace in 20 years. To conclude, Britain has experienced a serious economic crisis, damaging the life of millions of angry people.

Section 3 presents the methodology of the paper. Section 4 gathers the results and section 5 concludes.

3. Methodology

The objective of the paper is to identify, using spectral analysis, the resilience of UK's economy following two economic shocks from the Covid-19 pandemic that hit the global economy in Q4 2019, in years 2020, 2021 and 2022 and from the Brexit that hit UK since 2020 when UK withdrew from the European Union. Quarterly growth rates (annualized) of the Real GDP of UK and the Eurozone are forecasted between Q1 2022 and Q4 2050. Two sets of forecasts are generated: forecasts using historical data including the pandemic and the Brexit (from Q1 1998 to Q4 2021) and not including the pandemic and the Brexit (from Q1 1998 to Q3 2019). The computation of the difference of their averages is an indicator of the resilience of the economies, the greater the difference the greater the resilience. Figure 5 illustrates the flowchart of the methodology related to the spectral analysis forecasting model used in this research.

Figure 5: Flowchart of the methodology from step 1 to 4.



Source: Authors' own elaboration.

3.1.Step 1: De-noising and Compression of the Quarterly GDP growth rate (annualized) time series of the Eurozone and UK

Each series is de-noised using a one-dimensional de-noising and compression-oriented function using wavelets. The function is called 'wdencmp' in Matlab (Misiti et al., 2015). The underlying model for the noisy signal is of the form:

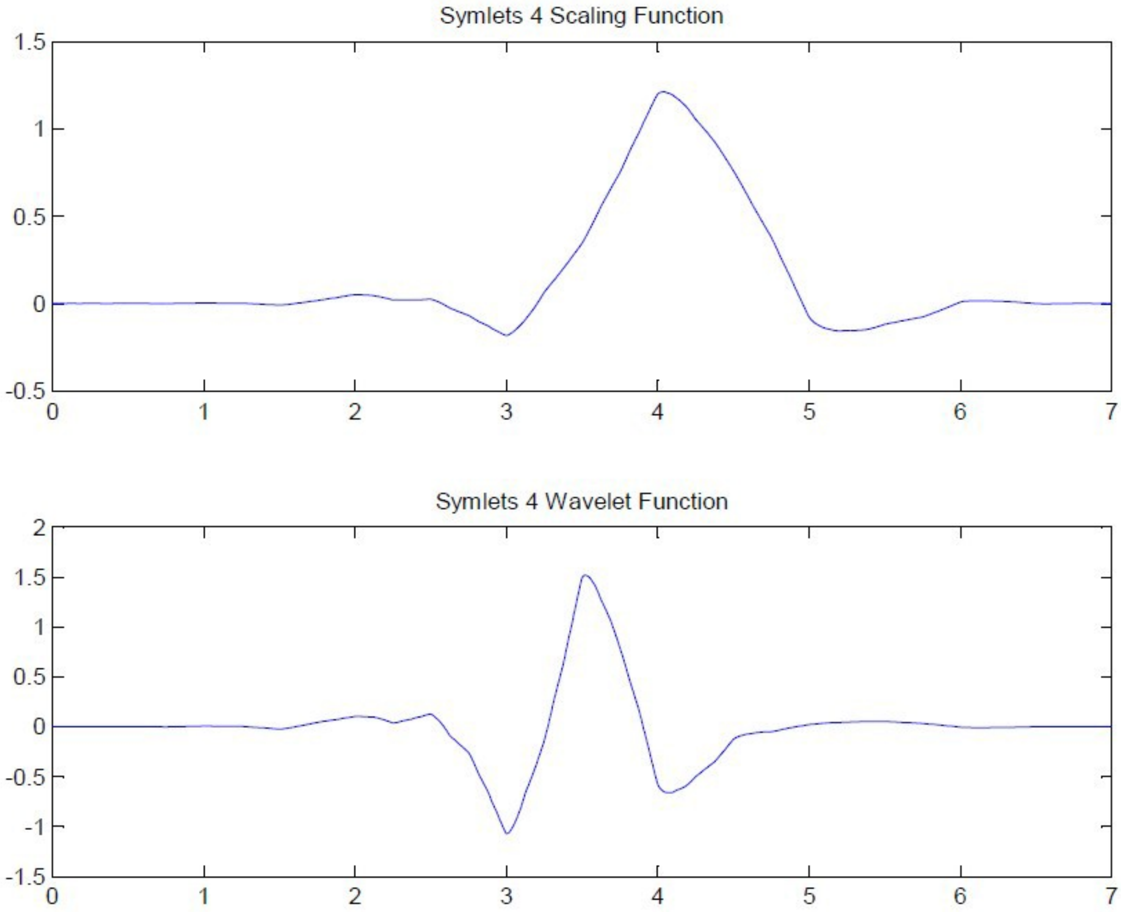
$$s(n) = f(n) + \sigma e(n) \quad (1)$$

where time point n is equally spaced, e(n) is a Gaussian white noise N(0,1) and the noise level σ is supposed to be equal to 1. The de-noising objective is to suppress the noise part of the signal s and to recover f. The de-noising procedure proceeds in three steps: 1) Decomposition, 2) Detail coefficients thresholding and 3) Reconstruction as detailed below.

1) Decomposition. Choose the wavelet sym4 and choose the level 2-decomposition. Wavelet analysis breaks a signal down into its constituent parts for analysis, in this case with a level 2-decomposition. The decomposition method is explained in section 3.2, step 2-Wavelet Decomposition.

Wavelet analysis breaks down a signal into shifted and scaled versions of the original mother wavelet. Sym4 is a Symlets wavelet of order 4 used as the mother wavelet for decomposition and reconstruction. It is a nearly symmetrical wavelet belonging to the family of Symlets proposed by Daubechies (1994). The scaling and wavelet functions of Symlets 4 are illustrated in Figures 6. Wavelets are defined by the wavelet function, also naming the mother wavelet and the scaling function, the latter also named the father wavelet in the time domain. The wavelet function is in effect a band-pass filter and scaling that for each level halves its bandwidth (Mallat, 2009).

Figures 6: Scaling Function and Wavelet Function of Symlets 4



Source: Source: Authors' own elaboration using Matlab

Wavelets are mathematical functions that cut up data into different frequency components and then study each component with a resolution matched to its scale (Graps, 1995). We compute the wavelet decomposition of the signal *s* at level 2.

2) Detail coefficients thresholding. For each level from 1 to 2, we select a threshold and apply soft thresholding to the detail coefficients.

3) Reconstruction. We compute wavelet reconstruction based on the original approximation coefficients of level 2 and the modified detail coefficients of levels from 1 to 2.

Like de-noising, the compression procedure contains three steps: 1) Decomposition. 2) Detail coefficient thresholding. For each level from 1 to 2, a threshold is selected and hard thresholding is applied to the detail coefficients. 3) Reconstruction. The difference with the de-noising procedure is found in step 2. The notion behind compression is based on the concept that the regular signal component can be accurately approximated using a small number of approximation coefficients (at a suitably selected level) and some of the detail coefficients.

The de-noising technique works in the following way: 'When a data set using wavelets is decomposed, filters act as averaging filters and others that produce details. Some of the resulting wavelet coefficients correspond to details in the data set. If the details are small, they might be omitted without substantially affecting the main features of the data set. The idea of thresholding, then, is to set to zero all coefficients that are less than a particular threshold. These coefficients are used in an inverse wavelet transformation to reconstruct the data set' (Graps, 1995, p.12).

3.2.Wavelet Decomposition

Wavelet analysis breaks a signal down into its constituent parts for analysis. Signals are decomposed after being differentiated, de-noised and compressed at step 2. The signals, i.e., the quarterly time series of UK and the Eurozone GDPs, are decomposed into decomposed signals cAs named approximations and cDs named details. To understand this process, a quick review of wavelet theory is presented.

A wavelet dictionary (Mallat, 1999) is constructed from a mother wavelet ψ of zero mean:

$$\int_{-\infty}^{+\infty} \psi(t)dt = 0 \quad (2)$$

To analyze a non-stationary signal, wavelet analysis identifies the correlation between the time and frequency domains of this signal (Wavelet.org, 2019). The wavelet transform allows exceptional localization in both the time domain via translations of the mother wavelet, and in the scale domain, also called frequency domain via dilations. The translation and dilation operations applied to the mother wavelet are performed to calculate the wavelet coefficients, which represent the correlation between the wavelet and a localized section of the signal. The wavelet coefficients are calculated for each wavelet segment, giving a time-scale function relating the wavelet correlation to the signal.

The mother wavelet ψ represented by equation 2 is dilated with a scale parameter b, and translated by a:

$$D = \left\{ \psi_{a,b}(t) = \frac{1}{\sqrt{b}} \psi\left(\frac{t-a}{b} \right) \right\}_{a \in \Re, b>0} \quad (3)$$

The present methodology uses Sym4, symlets wavelet of order 4, as the mother wavelet ψ for decomposition and reconstruction. It is a nearly symmetrical wavelet belonging to the family of Symlets proposed by Daubechies (1994) and illustrated in Figures 6. We tested many other wavelets including the ones belonging to the Daubechies family with equal or lower performance.

The discrete form of the wavelet (Mallat, 1999) is defined as:

$$\psi_{j,n}(t) = \frac{1}{\sqrt{s_0^j}}\psi\left(\frac{t - n\tau_0 s_0^j}{s_0^j}\right) \qquad (4)$$

with j and n integers, $s_0 > 1$ is a fixed dilation step and the translation factor τ_0 depends on the dilation step.

The continuous wavelet transform of a signal s at any scale b and position a is the projection of s on the corresponding wavelet atom:

$$Ws(a,b) = \langle s, \psi_{a.b} \rangle = \int_{-\infty}^{+\infty} s(t)\frac{1}{\sqrt{b}}\psi\left(\frac{t-a}{b}\right)dt \qquad (5)$$

The reconstruction of the original signal s(t) is obtained by inverse wavelet transform (Mallat, 1999, p.111):

$$s(t) = \frac{1}{C_\psi}\int_0^{+\infty}\int_{-\infty}^{+\infty} ws(a,b)\psi_b(t-a)\frac{db}{b^2}da \qquad (6)$$

The scaling function and the wavelet function of a discrete wavelet transform (DWT) are defined as

$$\varphi(2^{j}t)=\sum_{i=1}^{n}h_{j+1}(n)\varphi\left(2^{j+1}t-n\right) \qquad (7)$$

$$\psi(2^{j}t)=\sum_{i=1}^{n}g_{j+1}(n)\varphi\left(2^{j+1}t-n\right) \qquad (8)$$

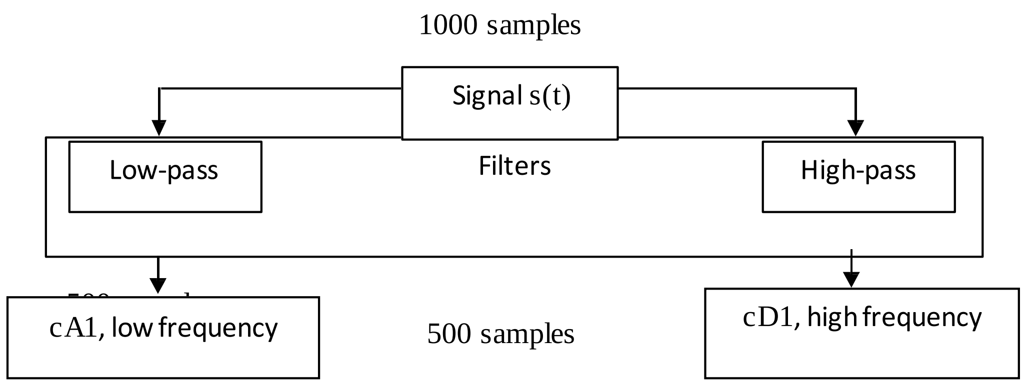
The signal s(t) is expressed as:

$$s(t)=\sum_{i=1}^{n}\lambda_{j-1}(n)\varphi\left(2^{j-1}t-n\right)+\sum_{i=1}^{n}\gamma_{j-1}(n)\psi\left(2^{j-1}t-n\right) \qquad (9)$$

The discrete wavelet transform (DWT) is evaluated by passing the signal through lowpass and highpass filters (Corinthios, 2009), dividing it into a lower frequency band and an upper band. Each band is subsequently divided into a second level lower and upper bands. The process is repeated, taking the form of a binary, or "dyadic" tree. The lower band is referred to as the approximation cA and the upper band as the detail cD. DWT decomposes the signal into mutually orthogonal set of wavelets.

Misiti et al. (2015) illustrated the filtering process with a simple diagram (Figure 7).

Figure 7: Diagram of a one-level decomposed signal s(t) using one-dimensional discrete wavelet analysis—illustration of the process of downsampling from 1,000 to 500.

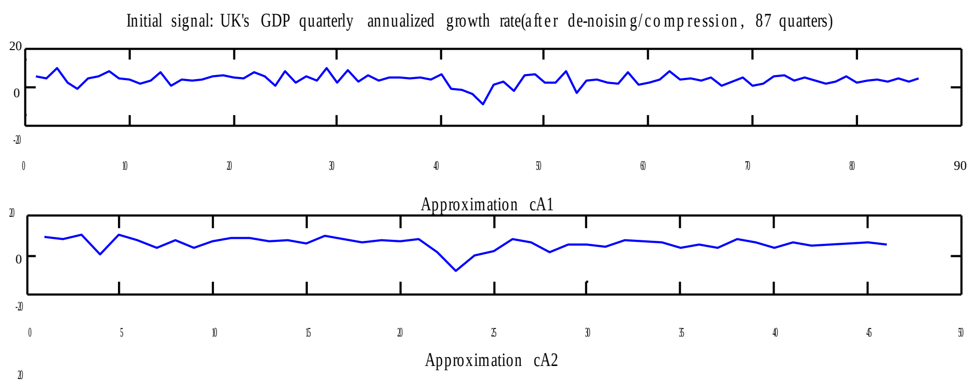


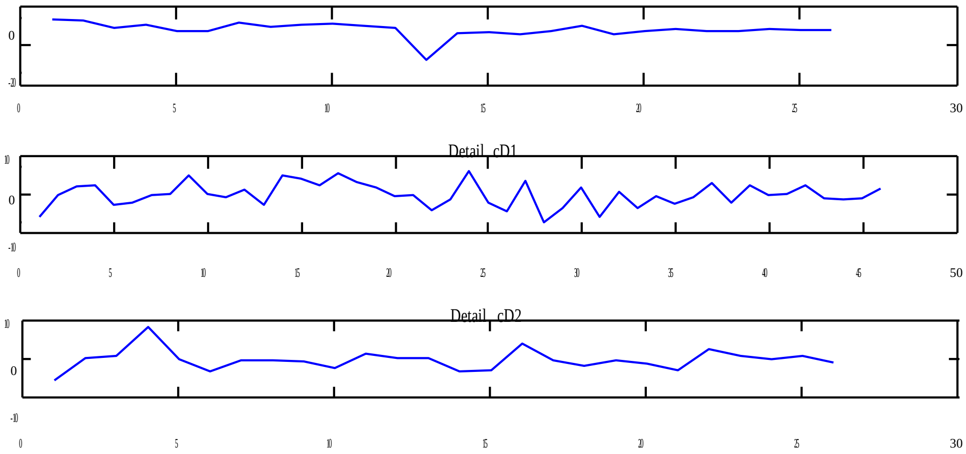
Source: Misiti et al.

(2015)

The model produces two sequences called cA and cD, which are downsampled. The signal is decomposed after being differentiated, de-noised and compressed. The signal, i.e. for the 1998-2019 period the 87-quarter (for the 1998-2021 period the 96-quarter) time series of UK GDP quarterly annualized growth rate transformed at step 1, is decomposed into decomposed signals cAs named approximations and cDs named details. The Discrete Wavelet Transform is a kind of decomposition scheme evaluated by passing the signal through lowpass and highpass filters (Corinthios, 2009), dividing it into a lower frequency band and an upper band. Each band is subsequently divided into a second level lower and upper bands. The process is repeated, taking the form of a binary, or "dyadic" tree. The lower band is referred to as the approximation cA and the upper band as the detail cD. The two sequences cA and cD are downsampled. The downsampling is costly in terms of data: with multilevel decomposition, at each one-level of decomposition the sample size is reduced by half (in fact, slightly more than half the length of the original signal, since the filtering process is implemented by convolving the signal with a filter. The convolution "smears" the signal, introducing several extra samples into the result). Therefore, the decomposition can proceed only until the individual details consist of a single sample. Thus, the number of levels of decomposition will be limited by the initial amount of data of the signal. Figure 5 illustrates the 2nd-level decomposition of UK GDP quarterly annualized growth rate (after de- noising/compression, 87 or 96 quarters). We observe in Figure 8 that details cDs are small and look like high-frequency noise, whereas the approximation cA2 contains much less noise than does the initial signal. In addition, the higher the level of decomposition, the lower the noise generated by details. For a better understanding of signal decomposition using discrete wavelet transform, refer to the methodology section of Rostan and Rostan (2018a).

Figure 8: 2nd-level decomposition of UK's GDP quarterly annualized growth rate (after de- noising/compression, 87 quarters from Q1 1998 to Q3 2019) using one-dimensional discrete wavelet analysis





Source: Authors' own elaboration using Matlab.

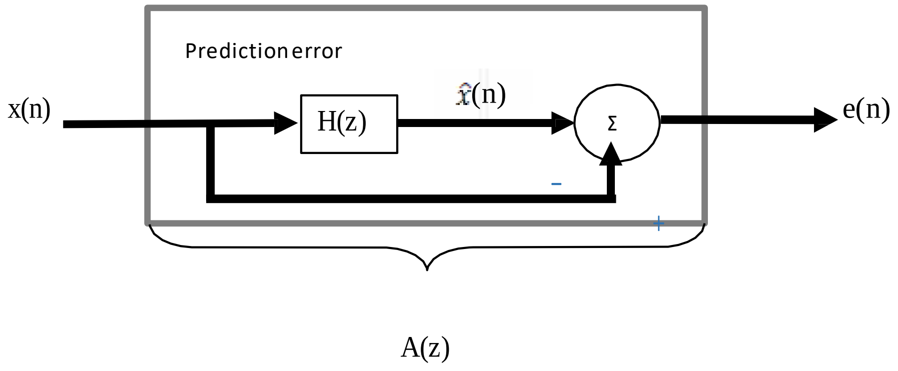
3.3. Step 3: Burg extension of approximations and details

We apply Burg extension to cA and cD as presented in Figure 8. To run the Burg extension, we apply an autoregressive pth order from historical data, in this paper we choose a pth order equal to the longest available order when forecasting. For instance, in 2019, when forecasting UK GDP returns for the subsequent 31 years until 2050 (4*31=124 quarters), the longest pth order available is 86 out of 87 historical data. Given x the decomposed signal (which is cA or cD), a vector a of all-pole filter coefficients is generated that models an input data sequence using the Levinson-Durbin algorithm (Levinson, 1946; Durbin, 1960). The Burg (1975) model is used to fit a pth order autoregressive (AR) model to the input signal, x, by minimizing (least squares) the forward and backward prediction errors while constraining the AR parameters to satisfy the Levinson-Durbin recursion. x is assumed to be the output of an AR system driven by white noise. Vector a contains the normalized estimate of the AR system parameters, A(z), in descending powers of z:

$$H(z) = \frac{\sqrt{e}}{A(z)} = \frac{\sqrt{e}}{1 + a_2 z^{-1} + \ldots + a_{(p+1)} z^{-p}} \qquad (10)$$

Since the method characterizes the input data using an all-pole model, the correct choice of the model order p is important. In Figure 9, the prediction error, e(n), can be viewed as the output of the prediction error filter.

Figure 9: Prediction error filter to run the Burg extension



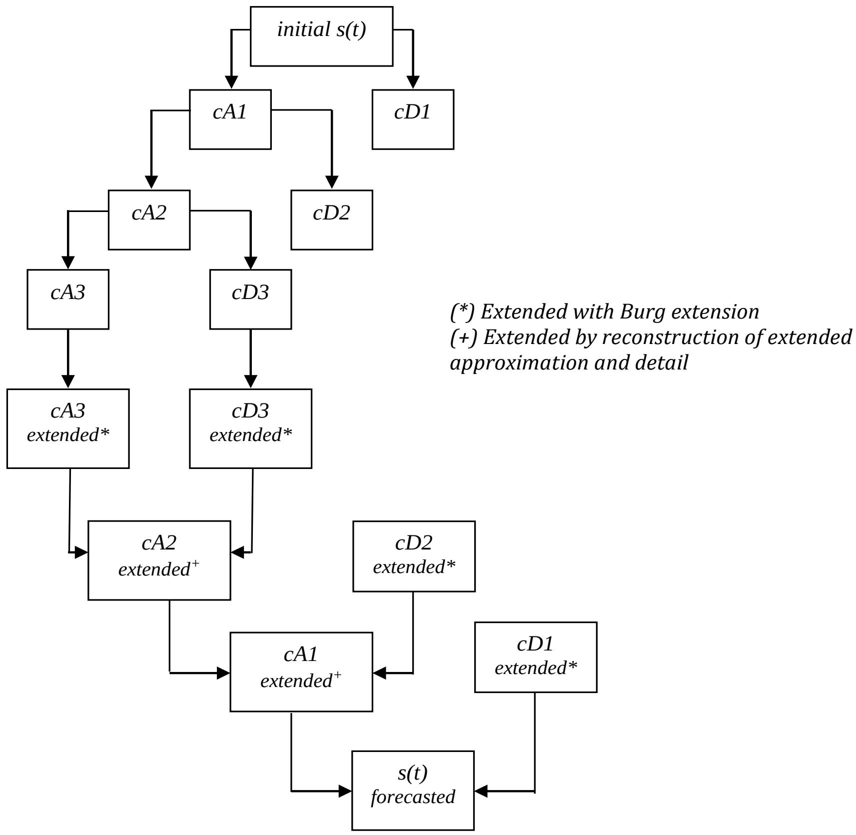
Source: Matlab.

In a last step, the Infinite Impulse Response (IIR) filter extrapolates the index values for each forecast horizon. IIR filters are digital filters with infinite impulse response. Unlike finite impulse response (FIR) filter, IIR filter has the feedback (a recursive part of a filter) and is also known as recursive digital filter.

3.4.Step 4: Wavelet Reconstruction

We recompose/reconstruct the forecasted signals after Burg extension using the methodology illustrated in Figure 5. We present the 3rd-level decomposition/reconstruction diagram in Figure 10. In this paper, the second-level decomposition/reconstruction that is on average the optimal level confirmed in the literature.

Figure 10: Diagram of a 3rd-level wavelet decomposition/reconstruction tree to forecast the initial signal s(t).



Source: Authors' own elaboration using Matlab.

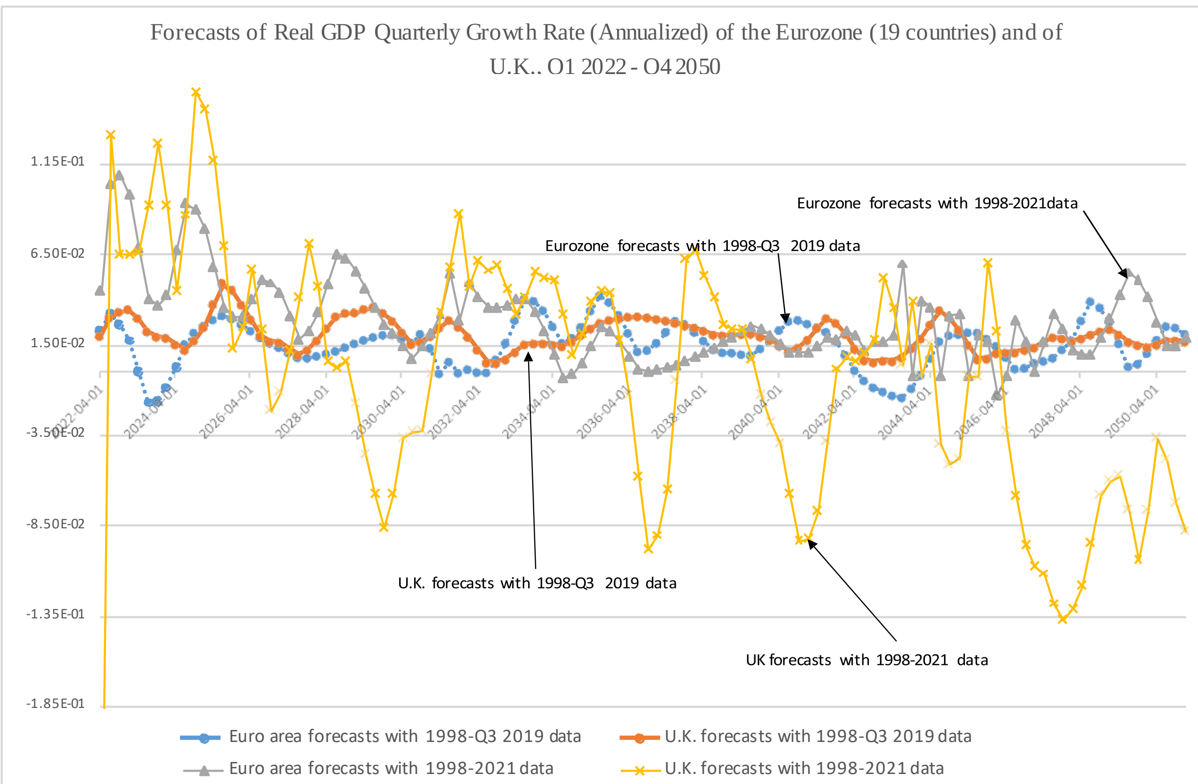
4. Results

The objective of the paper is to assess the resilience of UK's economy towards two economic shocks: the Covid-19 pandemic that hit the global economy in Q4 2019, in years 2020, 2021 and 2022 and the Brexit following the withdrawal of UK from the European Union on 31 January 2020. To assess the resilience of UK's economy towards these two economic shocks, two sets of forecasts are generated: forecasts using historical data including the pandemic and the Brexit (from Q1 1998 to Q4 2021) and not including the pandemic and the Brexit (from Q1 1998 to Q3 2019). The computation of the difference of their averages is an indicator of the resilience of UK's economy after the pandemic and Brexit, the greater the difference the greater the resilience. In this section, UK's 2050 GDP and growth rate quarterly forecasts are illustrated and the resilience of the UK economy after the Covid-19 Pandemic and Brexit is assessed. Eurozone's GDP and growth rate quarterly forecasts are used as benchmarks.

4.1. Forecasts of Q1 2022 to Q4 2050 of UK and Eurozone quarterly annualized GDP growth rates

Figure 11 illustrates 116 forecasts with spectral analysis of UK and Eurozone quarterly annualized GDP growth rates from Q1 2022 to Q4 2050.

Figure 11: 116 forecasts with spectral analysis of UK and Eurozone quarterly annualized GDP growth rates from Q1 2022 to Q4 2050



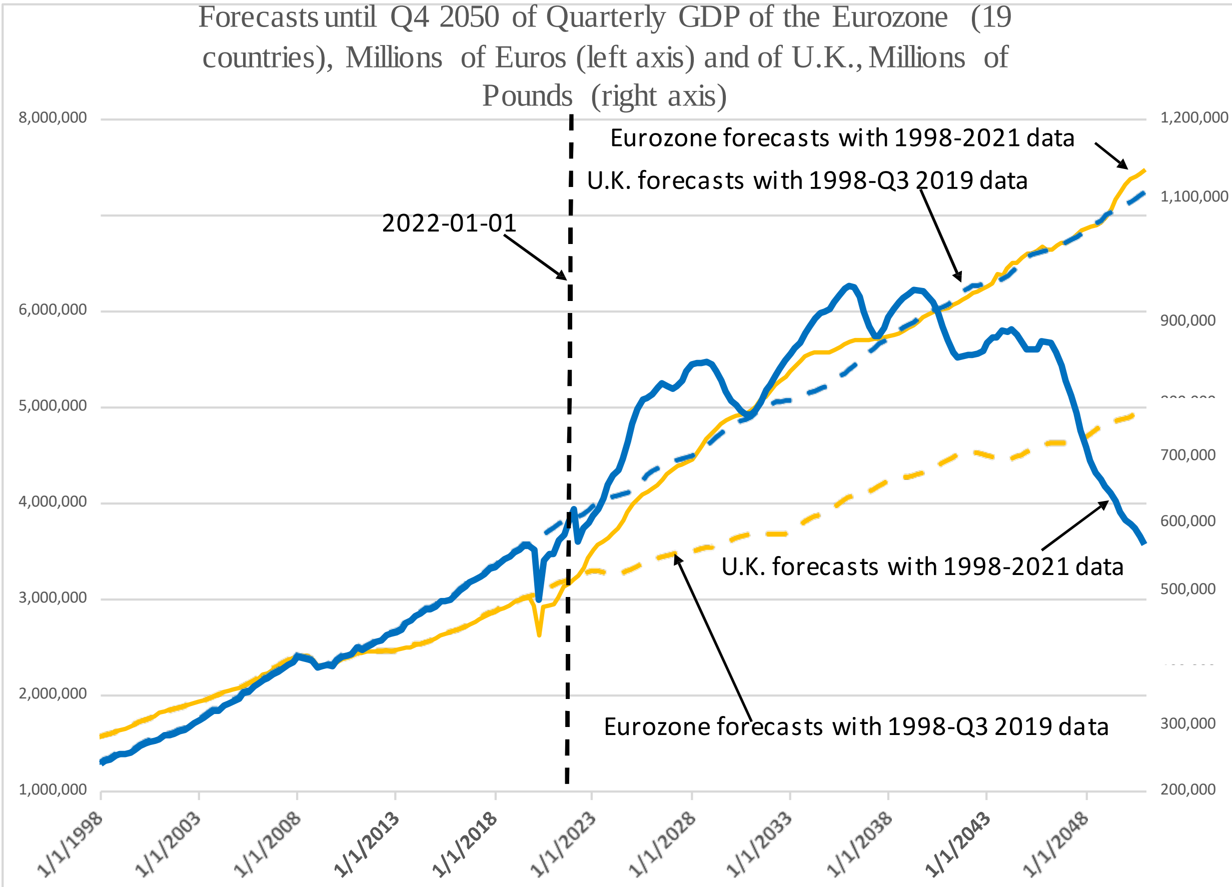
Source: Authors' own elaboration using Matlab

Based on the 116 forecasts for the period Q1 2022-Q4 2050, UK forecasts are more pessimistic than the Eurozone, with an average quarterly (annualized) growth rate of +2.03% for UK, forecasts generated with the Q1 1998-Q3 2019 data versus -0.24% for UK with the forecasts generated with Q1 1998-Q4 2021 data. Eurozone forecasts have an average quarterly (annualized) growth rate of +1.52% with Q1 1998-Q3 2019 data versus +2.93% with Q1 1998-Q4 2021 data. It shows that without pandemic, UK would have had a better outlook and a higher growth rate until 2050 (+2.03% for UK versus +1.52% for the Eurozone). The Covid-19 pandemic after Q3 2019 and the Brexit in 2020 have hit badly UK, being less resilient than the Eurozone, UK economy has a forecasted average quarterly (annualized) growth rate of -0.24% versus +2.93% for the Eurozone. Why the Eurozone has a better Q1 2022-Q4 2050 average forecast (+2.93%) including the pandemic than UK, - 0.24%? UK forecasts including the pandemic show a greater volatility than Eurozone forecasts (standard deviation of the forecasted returns equal to 7% for UK versus 2.33% for the Eurozone). Besides, Figure 11 illustrates increasing negative quarterly growth rates of UK GDP until Q4 2050.

Figure 12 illustrates 116 quarterly GDP forecasts with spectral analysis of UK and the Eurozone from Q1 2022 to Q4 2050. The rebound of both economies in Q2 2020 (refer to Figure 3), +47.37% in UK and +46.48% in the Eurozone, following the huge contraction in Q1 2020, -52.25% in UK and -42.37% in the Eurozone, clearly explains the divergent trend of the forecasts with Q1 1998-Q3 2019 historical data and with Q1 1998-Q4 2021 historical data for both UK and Eurozone since the model is sensitive to the most recent data. However, with forecasted returns of UK's GDP presenting more volatility and having increased negative returns as illustrated in Figure 11 and mentioned in the previous section, the quarterly GDP of UK is expected to diverge from the positive trend sustained by the Eurozone GDP until 2050 by starting a downtrend in Q2 2040 and plunging after Q1 2046 to reach the level of Q2 2019 in Q4 2050.

4.2.Forecasts of Q1 2022 to Q4 2050 of UK and Eurozone quarterly GDP

Figure 12: Historical data and forecasts with spectral analysis until Q4 2050 of UK and Eurozone quarterly GDPs



Source: Authors' own elaboration using Matlab.

4.3. Assessing the resilience of UK's Economy after the Covid-19 Pandemic and Brexit

To recall, the objective of the paper is to assess the resilience of UK's economy towards two economic shocks: the Covid-19 pandemic that hit the global economy in Q4 2019, in years 2020, 2021 and 2022 and the Brexit following the withdrawal of UK from the European Union on 31 January 2020.

To assess the resilience of UK's economy towards these two economic shocks, two sets of forecasts are generated: forecasts using historical data including the pandemic and the Brexit (from Q1 1998 to Q4 2021) and not including the pandemic and the Brexit (from Q1 1998 to Q3 2019). The computation of the difference of their averages is an indicator of the resilience of the economies during the pandemic, the greater the difference the greater the resilience. By subtracting the average forecasted 2022-2050 Eurozone quarterly GDP growth rate (annualized) obtained with the Q1 1998-Q4 2021 data, +2.93%, by the one obtained with the Q1 1998-Q3 2019 data, +1.59%, the difference is +1.33%, whereas with UK the difference is -2.33% [-0.24% - (-2.09%)]. Thus, Eurozone shows a greater resilience (+1.33%) than the UK (-2.33%) based on 2022-2050 forecasts. In addition, the authors pointed out that the average of the 2022-2050 quarterly (annualized) growth rate forecasts of the Eurozone is expected to be +2.93% with the 1998-2021 data whereas it is expected to be only -2.09% for UK.

5. Conclusion and Discussion

This paper assesses the resilience of UK's economy towards two economic shocks: the Covid-19 pandemic that hit the global economy in Q4 2019, in years 2020, 2021 and 2022 and the Brexit following the withdrawal of UK from the European Union on 31 January 2020. The paper presents UK's 2050 GDP and growth rate quarterly forecasts before (up to 2019) and during the pandemic and the Brexit (up to 2021) by using spectral analysis. UK economy is benchmarked to the Eurozone economy (19 countries). Spectral analysis can analyze changing transient physical signals. Extending the analysis to complex-behavior economic signals, the originality of this paper is to apply spectral analysis to economic variables subject to common dynamics such as GDP time series. The forecasts cover 116 quarters from Q1 2022 to Q4 2050 and derive from historical quarterly data extending from Q1 1998 to Q4 2021.

Spectral analysis methodology follows four steps that lead to GDP quarterly (annualized) growth rate forecasts: the Quarterly GDP growth rate (annualized) time series of the Eurozone and UK are de-noised and compressed, then decomposed in simpler signals called approximations and details in the framework of the one-dimensional discrete wavelet analysis. Third, the decomposed series are extended with the Burg (1975) model which fits a pth order autoregressive (AR) model to the input signal by minimizing (least squares) the forward and backward prediction errors while constraining the AR parameters to satisfy the Levinson-Durbin recursion. Finally, the series are reconstructed, the extensions being the forecasts.

As illustrated in Figure 3, between Q4 2019 and Q4 2021, the quarterly GDP growth rate (annualized) of the Eurozone economy (19 countries) was most of the time below the one of UK with an average growth rate of 3.23% for the Eurozone versus 4.75% for UK. Therefore, UK was looking more resilient during the Covid-19 pandemic than the Eurozone. However, based on Q1 2022-Q4 2050 forecasts of both economies, by subtracting the average forecasted 2022-2050 Eurozone quarterly GDP growth rate (annualized) obtained with the 1998-2021 data, +2.93%, by the one obtained with the 1998-Q3 2019 data, +1.59%, the difference is +1.33%, whereas with UK the difference is -2.33% [-0.24% - (-2.09%)]. Thus, Eurozone economy shows a greater resilience after the Covid-19 pandemic and the Brexit (+1.33%) than the UK economy (-2.33%) based on Q1 2022-Q4 2050 forecasts. In addition, the average of the Q1 2022-Q4 2050 quarterly (annualized) growth rate forecasts of the Eurozone is expected to be +2.93% with the Q1 1998-Q4 2021 data whereas it is expected to be only -2.09% for UK, which is quite pessimistic for UK.

A relevant question raised by the authors, which may have troubled the minds of British politicians, is “was it worth it for the UK to leave the European Union (EU) of 27 members?” UK joined the EU in 1973 and withdrew from the EU on 31 January 2020. As Andrade (2022) of Bloomberg Economics mentioned, Brexit’s impact was plain to see after more than one year after Brexit, since the British pound depreciated about 16% against US$ and trade and investment declined substantially as well. In 2022, the UK has seen the biggest headwinds since the 1970s. After suffering unprecedented shocks in recent years, the UK has succumbed to more intractable problems marked by sluggish growth, runaway inflation (annual inflation rate of 11.1% in October 2022, Trading Economics, 2022) and a series of damaging strikes. The result has been a plunge in consumer confidence that analysts warned could lead to a recession. Railway workers walked off the job in anger that their living standards were slipping, and criminal barristers were striking. At the end of 2022, UK was bracing for further disruption from strikes heading into the Christmas period, as ambulance drivers and nurses joined rail operators and postal workers in the worst wave of walkouts the country has endured for at least a decade (Ziady, 2022). More than 20,000 ambulance workers, including paramedics and call handlers, were expected to strike on December 21 in a dispute over pay.

UK has experienced structural problems as well. The main problem has been productivity growth, which has slowed after the financial crisis in 2008 and 2009. Brexit uncertainty has also seemed to have unsettled executives, with investment flat lining since the 2016 public vote to leave the European Union (EU). Had executives continued to spend as they did before the Brexit referendum, investment would have been around 60% higher by the end of 2022. Life outside the EU has also had an impact on trade as importers and exporters contended with higher trade barriers. Despite a sharp fall in the pound since the vote, there was little evidence to suggest the external sector has benefited from increased competitiveness. UK lagged the trade performance of other big nations before the pandemic and has failed to fully share in the global trade rebound since then. To conclude, UK has experienced a serious economic crisis, damaging the life of millions of angry people. Therefore, based on the conclusions of analysts and on the 2050 GDPs' projections presented in this paper, under the Kingship of Charles III since September 8, 2022, and the leadership of Prime Minister Sunak who has served as Prime Minister of the UK and Leader of the Conservative Party since October 2022, following the brief appearance of Prime Minister Liz Truss from September to October 2022, UK should consider rejoining the EU, move that may improve the performance of its economy by mimicking the positive and steady performance of the Euro area forecasted for the next 30 years. Belonging to a trade block adds constraints to the member state because it is costly, member states providing billions in support to the EU every year; in addition, members are constrained by economic and political decisions taken outside their countries by the most influential members such as Germany and members of the Euro area (using Euro currency as sole legal tender) loose flexibility in their monetary policy (Rostan and Rostan, 2022b). However, the main advantages of belonging to a trade block are waving of tariffs between member countries implying rising exports, economies of scale, higher GDP growth, less volatility of the currency if Euro is used as sole tender and a lower country risk that attracts international investments. UK leadership do need to reassess all these factors and should perceive the net advantage of rejoining the EU.

Further research may focus on additional economic indicators of UK to identify the areas of strengths and weaknesses of the UK economy and how to improve them.

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