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How the post-COVID-19 US economy lost and then regained momentum against the Eurozone economy

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Abstract

The objective of the paper is to assess and compare the resilience of the post-Covid US and Eurozone economies. Quarterly growth rates (annualized) of the Real GDP of US and the Eurozone are forecasted between Q4 2023 and Q4 2050. Two sets of forecasts are generated: forecasts using historical data including the pandemic (from Q4 1997 to Q3 2023) and not including the pandemic (from Q4 1997 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. Used as a benchmark, Eurozone (19 countries) shows a greater resilience to the Covid-19 pandemic (+0.27%) than the US (+0.17%) based on Q4 2023-Q4 2050 forecasts. However, the average of Q4 2023 - Q4 2050 quarterly (annualized) growth rate forecasts of the Eurozone is expected to be +0.87% with the Q4 1997 – Q3 2023 historical data whereas it is expected to be +1.49% for US. The US economy shows better prospects and greater momentum than the Eurozone economy.

JEL: C01; C5; C53; E3; E17; E37

Keywords: GDP; wavelet analysis; forecasting; US economy; Eurozone economy.

1. Introduction

A massive trade war has been looming since US President Donald Trump announced that he would "absolutely" impose tariffs on goods from the EU and the US main trading partners (Starcevic and Ruhiyyih Ewing, 2025). The political slogan "Make America Great Again" was recently used by President Trump during his successful 2024 presidential campaign, to assert that he would make America the political and economic leader of the world by using all the tools at his disposal, including tariffs and trade war.

In the context of the trade war initiated in 2025, the objective of the article is to assess and compare the resilience of the post-Covid US and Eurozone economies following the economic shock of the Covid-19 pandemic which hit the global economy in Q4 2019 and throughout 2020, 2021, 2022, officially ending during Q2 2023 and to benchmark the US economy to the EU economy using the Eurozone data as proxy, more precisely the Euroarea-19 aggregate (excluding Croatia, which joined the Eurozone in 2023).

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Regarding the methodology used in this paper, two sets of forecasts will be generated: forecasts using historical data including the pandemic and not including the pandemic. The computation of the difference of their averages will be an indicator of the resilience of the economies during the pandemic, the greater the difference the greater the resilience. The results will show that the post-Covid US economy lost then regain momentum against the Eurozone economy.

The Covid-19 pandemic began in late 2019 and spread to five continents, killing millions and causing a global recession. It forced governments to implement unpopular measures such as confinement of populations to contain its spread. The head of the WHO declared the end of COVID-19 as a global health emergency in May 2023 (United Nations, 2023). As of September 10, 2023, the number of recorded coronavirus cases worldwide was 695,098,423 people, with the coronavirus death toll at 6,913,927 (Worldometers, 2023). At the heart of the crisis, lockdowns crippled economies, leading to a global recession in 2020. To measure the resilience of economies, the authors apply a wavelet forecasting model to two historical datasets, including the Covid-19 pandemic, and excluding pandemic. Intuitively, the difference between the average GDP growth forecasts of the two forecast sets should measure the resilience of economies to the pandemic. Comparing the U.S. economy to that of the Eurozone by measuring their resilience can help governments, businesses, policymakers and international investors operating in the United States and/or the Eurozone better understand the dynamics underlying strains their savings. Below is a brief overview of facts related to the Eurozone.

The Eurozone or Euro area is the monetary union of 20 out of 28 European Union member states, all of which have adopted the Euro as their common 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, Lithuania and lately Croatia. The other eight members of the European Union continue to use their own national currencies, although the majority of them have undertaken to adopt the Euro in the future.

Why compare the US and Eurozone economies? The US and Eurozone Gross Domestic Products (GDPs) evolved in sync over the historical period under study, between Q4 1997 and Q3 2023, with a high and stunning correlation coefficient of 97.5%. In 2023, the GDP of the Eurozone was worth 15,780.69 billion US dollars, when the GDP of the United States was worth 27,720.71 billion US dollars, according to official data from the World Bank (Trading Economics, 2025a and 2025b), the US economy being the top global economy in 2023 followed by the ones of China (GDP of 17,794.78 USD Billion in 2023, World Bank, 2025) and the Eurozone as third economy.

The next section discusses the literature review on wavelet analysis versus traditional economic forecasting methods and regarding the resilience of the US economy during the Covid-19 pandemic. Sections on methodology, data, results and conclusions follow.

2. Literature Review

2.1. Wavelet analysis versus traditional economic forecasting methods

The assumption in this research is that GDPs propagate through time in waveforms. Wavelet analysis captures 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.

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 (Stoica and Moses, 2005), 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.

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 models have been detailed in Conejo et al. (2005). Gencay et al. (2005) proposed a wavelet multiscaling approach to estimating systematic risk. 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. Gencay et al. (2010) modeled regimes of volatilities at multiple time scales through wavelet-domain hidden Markov model. Kao et al. (2013) integrated wavelet transform, 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. Berger and Gencay (2018) presented a novel perspective on data filtering and an innovative wavelet-based approach that leads to improved Value-at-Risk forecasts. 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. The versatility of wavelet analysis was also demonstrated when applied to forecasting the growing number of European Muslim population (Rostan and Rostan, 2019), to assess the financial sustainability of the Spanish pension system (Rostan et al., 2015) as well as the Saudi pension system (Rostan and Rostan 2018b). Applying the wavelet analysis model to economic time series forecasting, research has targeted countries such as Spain (Rostan & Rostan, 2018c), Greece (Rostan & Rostan, 2018d), Saudi Arabia (Rostan & Rostan, 2021a, 2024c, Rostan et al., 2024), Austria (Rostan & Rostan, 2020), the Persian Gulf countries (2022a), Turkey (2022b), the United Kingdom (2022c), Australia (2024a), South Korea (2023b), Cyprus (2023c), Brazil, Mexico, and Argentina (2024b), Slovenia (2024d), China (2025a), Iraq (Alami et al., 2024), and the countries forming the Eurozone (Rostan et al., 2023). In addition, wavelet analysis forecasting modelling has been applied to interest rates (Rostan et al., 2017), fossil fuel prices (Rostan & Rostan, 2021b), solid waste estimates of OECD countries (2023d), population estimates (Rostan & Rostan, 2017), as well as global temperature estimates (Rostan & Rostan, 2023a), wars (Rostan & Rostan, 2024e and 2025c) and sea rising and flooding (Rostan & Rostan, 2025b). Berger and Gencay (2020) presented evidence that the application of wavelet-based covariance estimates from short-run information outperforms portfolio allocations that are based on covariance estimates from historical data.

2.2. Assessing the resilience of the US and Eurozone economies during the Covid-19 pandemic

As stated by OECD (2020), the Covid-19 outbreak lead to a crisis with considerable losses in terms of health with a death toll at 6,913,927 and 695,098,423 recorded coronavirus cases as of September 10, 2023 (Worldometers, 2023). It hit the global economy with a cascading collapse of entire production, financial, and transportation systems, due to a vicious combination of supply and demand shocks. The pandemic was accompanied by historic drops in output in almost all major economies. U.S. Real GDP fell by 31.56% (annualized) in Q1 2020, the largest single-quarter contraction in more than 70 years (BEA, 2021). Most other major economies fared even worse, for example the drop of 45.04% of the Eurozone Real GDP illustrated in Figure 10 of the Results section. After the significant drop in Q1 2020, and during the pandemic between Q2 2020 and Q2 2023, the quarterly US growth rate (annualized) was averaging +5.24% slightly lower than the one of the Eurozone economy (+5.85%). During the pandemic, the US recovery was robust, outpacing that of most of its major trading partners. However, 'inflation emerged as a challenge for the US and nearly all its major trading partners, as strong demand, skewed toward goods and away from services, interacted with the supply chain stresses (White House, 2022). As a result of the rapid US recovery relative to the rest of the world, the US trade deficit widened. The strength of the US recovery led to increased imports, as goods flowed in from abroad to satisfy resurgent demand from firms and consumers. Although exports hit record highs, they increased at a slower pace than imports because many of the countries that buy US goods have not recovered as fast'. Based on the readings of the first two quarters of 2022, US witnessed two consecutive quarters of negative real GDP growth: the -1.6% final estimate for Q1 2022 and -0.9% first estimate for Q2 2022 (Yandle, 2022). The shrinking GDP has been accompanied by raging inflation and tight labor markets, not to mention continuing energy uncertainties stemming from the invasion of Ukraine by Russia in 2022 as well as the lingering effects of the COVID-19 pandemic. America experienced a serious bout of inflation in 2022 and steps taken by the Fed to extinguish the inflationary fires have likely pushed the economy into recession territory. The CPI increased by 8.5% year over year in July 2022, well ahead of June's 5.3% year-over-year gain in wages and salaries being recorded. Working people, on average, were getting poorer (Yandle, 2022). Was America in a recession in September 2022? No, according to Yandle (2022). The recession will occur in the US soon. Will it be severe? Not likely. It should be mild and short lived, instead. Still, Yandle warned Americans to keep their seatbelts fastened. The Fed raised interest rates seven times in 2022 (for a total of +4.25%) to cool rising consumer prices (Forbes Advisor, 2024). Fed Chair Powell said that his inflation fight is "unconditional" and rate hikes will continue even if it means some "pain" for Americans (Daniel, 2022). Based on forecasts of market analysts, US should have experienced a recession induced by the Federal Reserve by the end of 2022. The year 2023 saw four more Federal rate increases (for a total of +1%) and the recession did not occur despite economists' predictions. Against all odds, ignoring the dire predictions of a recession after the Fed's aggressive hikes of the Federal rate reaching +5.5% on July 26, 2023, from a low of +0.25% on March 17, 2022, the U.S. economy grew a faster-than-expected 3.3% in Q4 2023, amid strong consumer spending, with full-year growth of 2.5%. By February 2024, Deutsche Bank no longer expected the US economy to slide into recession in 2024, given slowing inflation and the labor market returning to better balance without a significant increase in unemployment (Abraham, 2024). Deutsche Bank previously expected the economy to enter a mild recession as the Federal Reserve tightened interest rates to tame inflation, narrowing the window for a soft landing. Though the economy continued to face several headwinds in 2023– namely, still-tight credit conditions, rising consumer delinquency rates and a slowing labor market – the resilience to date pointed to a more benign slowdown in 2024 than previously projected. The Deutsche Bank still expected the Fed to start easing interest rates from June 2024 but was expecting 100 basis points (bps) of rate cuts in 2024, less than its earlier expectation of 175 bps. The U.S. economy was expected to grow by 1.9% in 2024, on a quarterly average basis, compared with its prior forecast of 0.3%.

Since early 2020, European governments implemented lockdowns that paralyzed manufacturing and contracted the service sector. Subsequently, governments decided to lift pandemic-related lockdowns and restrictions after a series of COVID-19 waves that diminished in magnitude over time. In early 2022, Europe decided to abandon all COVID-19 restrictions, desperately seeking to save its economies, which had been hit hard by restrictions and lockdowns (Rostan et al., 2024). At the beginning of the pandemic, the quarterly growth rate of real GDP (annualized) of the Eurozone economy (19 countries) decreased by 14.053% in the fourth quarter of 2019, decreased further by 46.858% in the first quarter of 2020, recovered in the second quarter of 2020 (+51.236%), dragged the Eurozone into recession in the third and fourth quarters of 2020 (-1.648% and -0.387% respectively) and finally recovered in the first quarter of 2021 (+8.249%) while remaining in positive territory.

2.3. Literature which assessed the resilience of economies during the Covid-19 pandemic

The literature assessing the resilience of economies during the Covid-19 pandemic and regarding quantitative measures is narrow. Diop et al. (2021) developed indexes measuring COVID-19 economic vulnerability and resilience using a global sample of 150 countries categorized into four principal regions: Africa, Asia-Pacific and the Middle East, America, and Europe. They used seven variables to build the vulnerability index and nine variables to build the resilience index. Based on their indices, they classified countries into four types: low vulnerability-low resilience, high vulnerability-low resilience, high vulnerability-high resilience, and low vulnerability-high0 resilience. A paper of Lee et al. (2022) assessed the economic resilience of 52 economies based on 16 indicators in three dimensions (including the government, enterprises, and the public) and computed their disaggregate output scores using the data envelopment analysis method to measure and compare their economic resilience in the early stage of the Covid-19 pandemic. The results showed that 23 of these economies had no room for further improvement in the overall economic resilience performance at that time. Germany's economic resilience performance, ranking 24th, was second only to these 23 economies, whereas Australia and Belgium were just behind Germany. They were the best performers among the 52 economies. A study of Li et al. (2023) investigated national economic resilience to the SARS and Covid-19 pandemics in 25 countries (region) and 46 countries, respectively. They used year-over-year quarterly economic growth data to measure the national economic resistance and economic recoverability in the recession-recovery cycles caused by the pandemics. They showed that the two pandemics caused evident economic fluctuations; there exists a negative relationship between economic resistance and economic recoverability across those infected countries; the typology of national economic resilience has shifted from weak resistance-good recoverability during the SARS period to good resistance-weak recoverability in the recent years of COVID-19; large variations of national economic policy response to the pandemic are found between high-income and middle-income countries.

2.4. Trade war initiated by the Trump administration against the world.

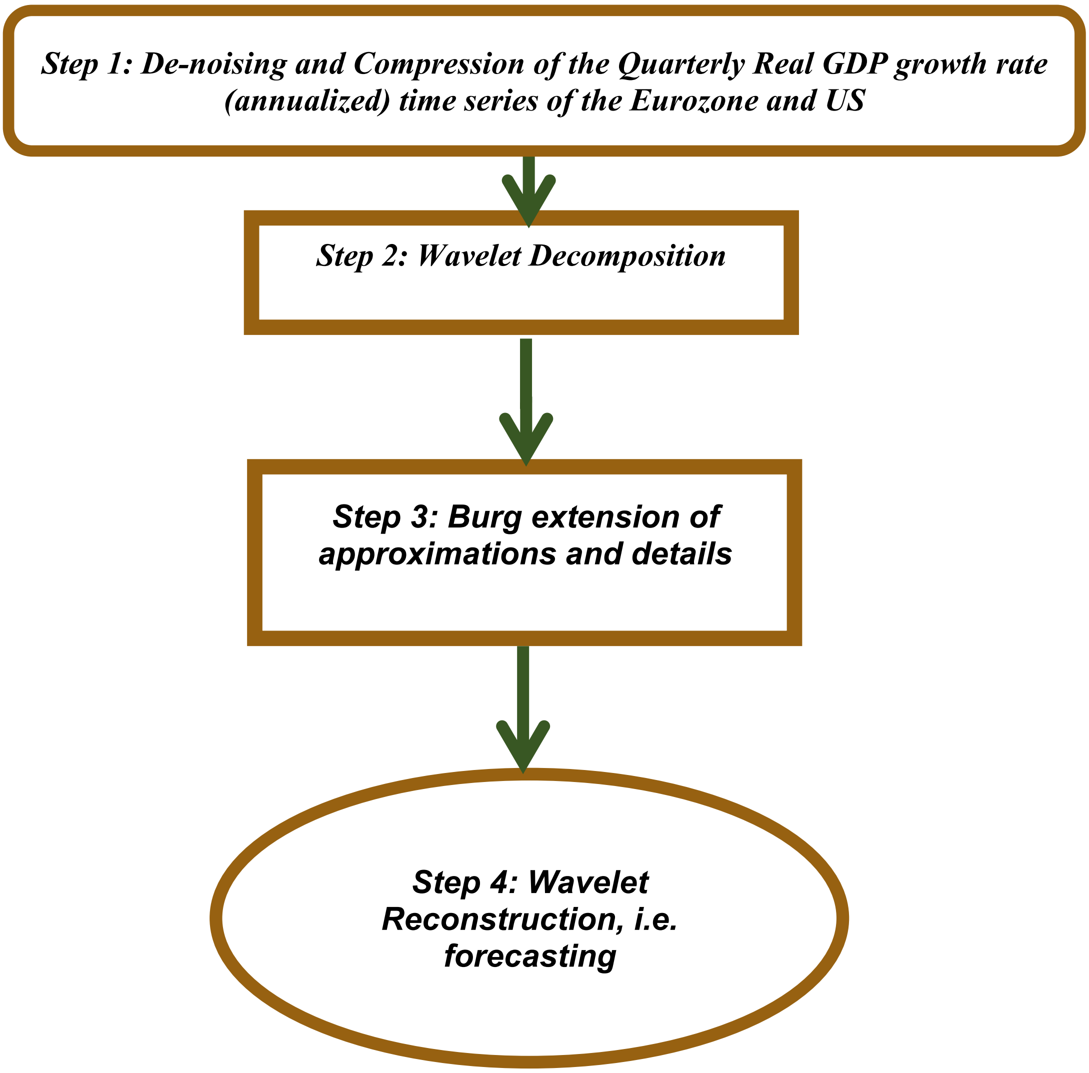
In April 2025, the US administration of President Trump wreaked havoc on international trade by initiating a drastic increase in tariffs on goods imported into the United States from nearly all of its major trading partners. This supply shock has sparked predictions about the imminence of a global recession. A violent U.S. Treasury selloff, evoking the COVID-era "dash for cash", has reignited fears of fragility in the world's biggest bond market (Banerjee & Cooper,2025). Stock markets crashed around the world. The S&P 500 stock index fell over 10% in two trading sessions, its worst performance since the end of the Second World War and rivaled by the 1987 stock market rout, the 2008 global financial crisis and the 2020 COVID shock (Reuters, 2025). On Black Monday (April 7, 2025), Japan's benchmark Nikkei 225 index tumbled 8%, Hong Kong's Hang Seng index slumped more than 10%, its largest daily fall since the 2008 global financial crisis (The Economic Times, 2025). Trump ratcheted up tariffs on Chinese imports, raising them effectively to 145%. China hit back, hiking its tariffs on U.S. goods to 125%. European markets slump as well (The Guardian, 2025a). On Black Monday, the FTSE 100 in London fell 4.38%, while Germany's Dax and France's CAC 40 also ended the day down more than 4%. By imposing 20% tariffs on goods imported from Germany, particularly targeting automobile manufacturing, which is Germany's largest industry, with the United States being the sector's largest export market, Germany could be the hardest hit of the 27 members of the European Union (Eddy, 2025). However, in a sudden reversal, reflecting the chaotic approach of Trump's administration, Trump announced a 90-day pause on reciprocal tariffs on dozens of countries, but maintained duties for China to 145% and kept 25% tariffs levied on aluminum, steel and autos in place (Martin, 2025). Global economic turmoil intensified in the week following Black Monday, unleashed by Trump's tariffs (Mason et al, 2025). U.S. stocks ended a volatile week higher, but the safe haven of gold hit a record high during the session and benchmark U.S. 10-year government bond yields posted their biggest weekly increase since 2001 alongside a slump in the dollar, signaling a lack of confidence in America Inc. US consumers are expected to suffer from inflation especially on clothing (37% increase in prices), toys and video games (+30%), computer parts (+30%), smartphones (+27%) and residential construction materials (+22%, Mason et al., 2025). Looking at the level of German exports of goods to the United States in 2024, Europe's largest economy exported goods worth 161.4 billion euros, or 178.4 billion dollars, according to the country's Federal Statistical Office. These drastic new tariffs are fueling fears that the stagnant German economy will fail to achieve growth below the 0.3% forecast in 2025. In March 2025, the German parliament agreed to ease the country's debt restrictions to revive the economy, which had been shrinking for two years. This decision allowed lawmakers to create a new €500 billion (nearly $550 billion) infrastructure fund, which has brought some optimism to markets and businesses. But Morgan Stanley's economists alerted that the impact of tariffs could undermine the potential growth generated by the plan (Eddy, 2025).

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 a wavelet analysis forecasting model, the resilience of the post-Covid US economy. Quarterly growth rates (annualized) of the Real GDP of US and the Eurozone are forecasted between Q4 2023 and Q4 2050. Two sets of forecasts are generated: forecasts using historical data including the pandemic (from Q4 1997 to Q3 2023) and not including the pandemic (from Q4 1997 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. Figure 1 illustrates the flowchart of the methodology related to the wavelet analysis forecasting model used in this research.

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



Source: Authors' own elaboration.

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

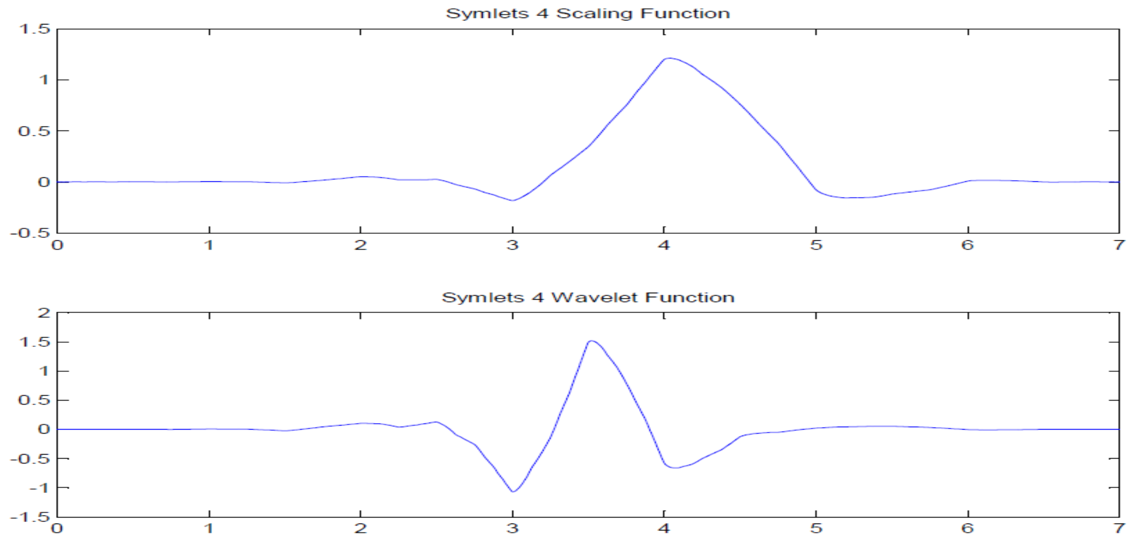
Each series is de-noised using a one-dimensional de-noising and compression-oriented function using wavelets. The function is called 'wdencmp' in Matlab (Misiti et al., 2015). The underlying model for the noisy signal is of the form:

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

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. 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 is the breaking down of 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 2. 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 2: 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. Step 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 US and the Eurozone Real GDPs, are decomposed into decomposed signals *cAs* named approximations and *cD*s 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 2. 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:

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

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:

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

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

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

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

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

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

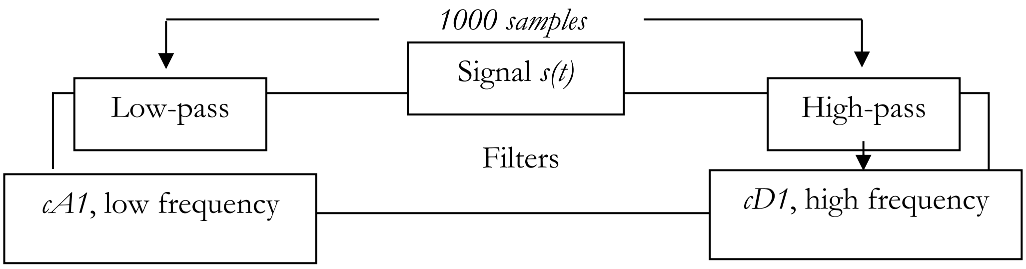
The signal *s(t)* is expressed as:

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

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 3).

Figure 3: 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.

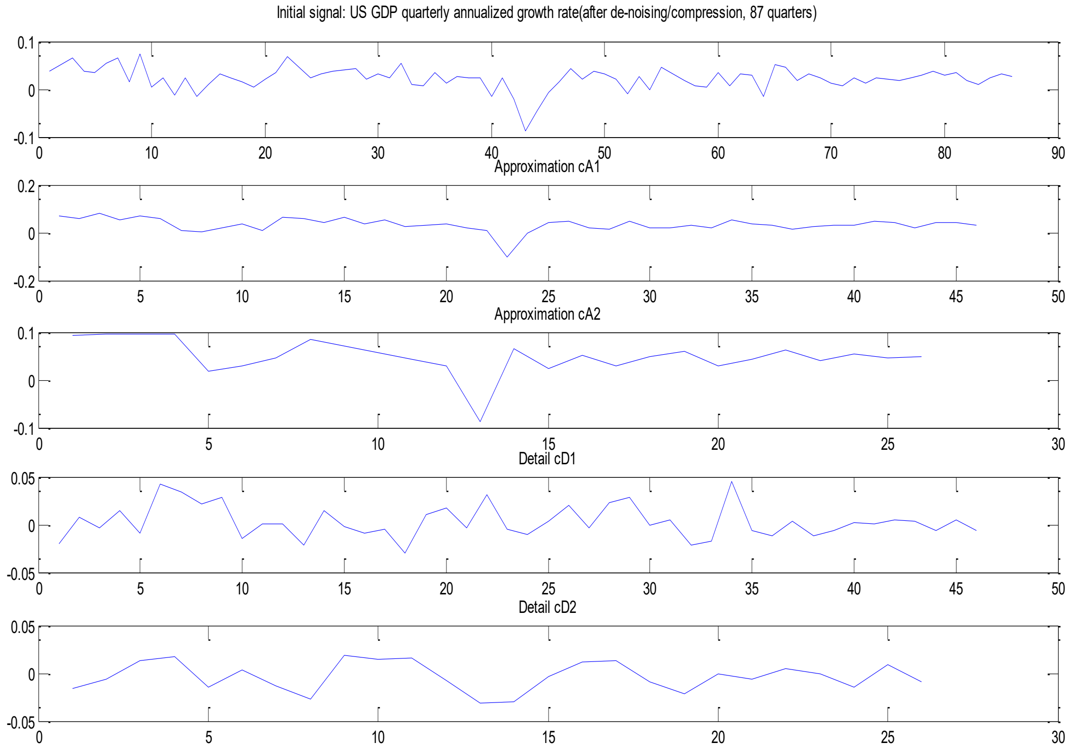


Source: Misiti et al. (2015)

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 Q1 1998-Q3 2019 period, the 87-quarter time series and, for the Q1 1998- Q3 2023 period, the 103-quarter time series of US Real 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 number of data of the signal. Figure 4 illustrates the 2nd-level decomposition of US Real GDP quarterly annualized growth rate (after de-noising/compression, 87 quarters). We observe in Figure 4 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 4: 2nd-level decomposition of US Real 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.

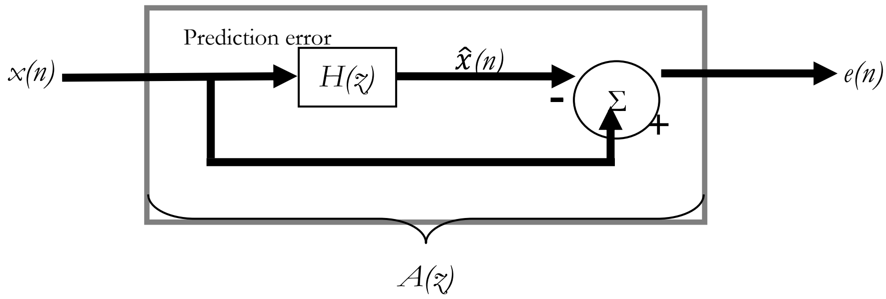
3.3. Step 3: Burg extension of approximations and details

We apply Burg extension to *cA* and *cD* as presented in Figure 1. To run the Burg extension, we apply an autoregressive p^{th} order from historical data, in this paper we choose a p^{th} order equal to the longest available order when forecasting. For example, in 2019, when forecasting US Real GDP growth rates for the subsequent 31 years until 2050 (125 quarters), the longest p^{th} order available is 87 out of 88 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 p^{th} 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*:

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

Since the method characterizes the input data using an all-pole model, the correct choice of the model order p is important. In Figure 5, the prediction error, e(n), can be viewed as the output of the prediction error filter

Figure 5: Prediction error filter to run the Burg extension



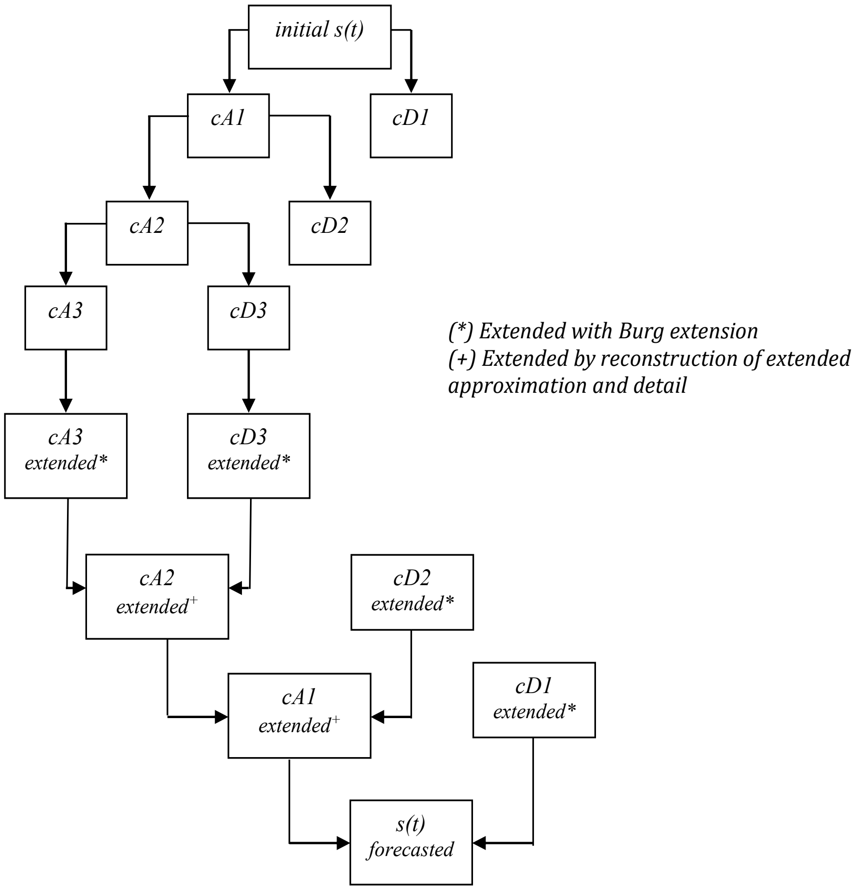
Source: Matlab.

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 6. We present the 3rd-level decomposition/reconstruction diagram in Figure 6. In our paper, we use a second-level decomposition/reconstruction that is, most of the time, the optimal level confirmed in the literature, and that is confirmed in the next section.

Figure 6: Diagram of a 3rd-level wavelet decomposition/reconstruction tree to forecast the initial signal s(t).



Source: Authors' own elaboration using Matlab.

3.5. Identifying the optimal level of decomposition/reconstruction of the wavelet analysis forecasting model

With 104 historical data of US Real GDP from Q4 1997 to Q3 2023, the forecasting model is expected to generate 109 forecasts from Q4 2023 to Q4 2050, i.e. a ratio of 104/(104+109) = 49%. The optimal level of decomposition/reconstruction is obtained by 1)Spliting historical data into two sets to respect the 49% ratio: with 104 historical data, the set will be divided into 51 and 53, i.e. 51/(51+53) = 49%; 2)Generating 53 forecasts from 51 historical data at different levels of decomposition/reconstruction from 2 to 10; 3)Computing the RMSE (Root Mean Square Error, i.e. the square root of the mean of the square of all of the errors) between the 53 historical data and the 53 forecasts obtained from different levels of decomposition/reconstruction from 2 to 10. At levels 9 and 10, the forecasting model does not converge. Between levels 2 and 8, Table 1 gathers the RMSEs. It confirms the second-level decomposition/reconstruction as the optimal level since level 2 minimizes the RMSE.

Table 1: RMSE by levels of decomposition/reconstruction

			Level of Decomposition/Reconstruction				
	2	3	4	5	6	7	8
RMSE	701	994	1,072	1,070	1,070	1,073	1,073

Source: Authors' own elaboration using Matlab

3.6. Assessing the Forecasting Ability of the Wavelet Analysis model

The forecasting ability of the wavelet analysis model is assessed with the example of the US real GDP on an in-sample window of data, using the methodology of sections 3.1. to 3.5. As mentioned in section 3.5., the 104 historical data of US Real GDP from Q4 1997 to Q3 2023 are splitted into two sets of 51 data to generate 53 forecast estimates from Q3 2010 to Q3 2023 that will be compared to 53 in-sample historical data.

Wavelet analysis is benchmarked to a linear regression forecasting model ($y = 84.32x+13060$ that fits the data of the first in-sample of 51 data from Q4 1997 to Q2 2010, a 2nd-order polynomial model ($y = -1.17x^2+145.10x+12520$ that fits the data of the first in-sample, a 5th-order polynomial model ($y = 0.0003665*x^5-0.05019*x^4+2.421*x^3-49.41*x^2+494.7*x+11990$ that fits the data of the first in-sample), an exponential model ($y = 13200*e^{(0.005447*x)}$ that fits the data of the first in-sample). The correlation coefficient *r* and the Root Mean Square Error (RMSE) criteria are applied to 53 forecast estimates obtained from the various forecasting models versus 53 historical data; *r* and RMSE estimate the robustness and the error of forecasting of each forecasting model. Table 2 illustrates the results.

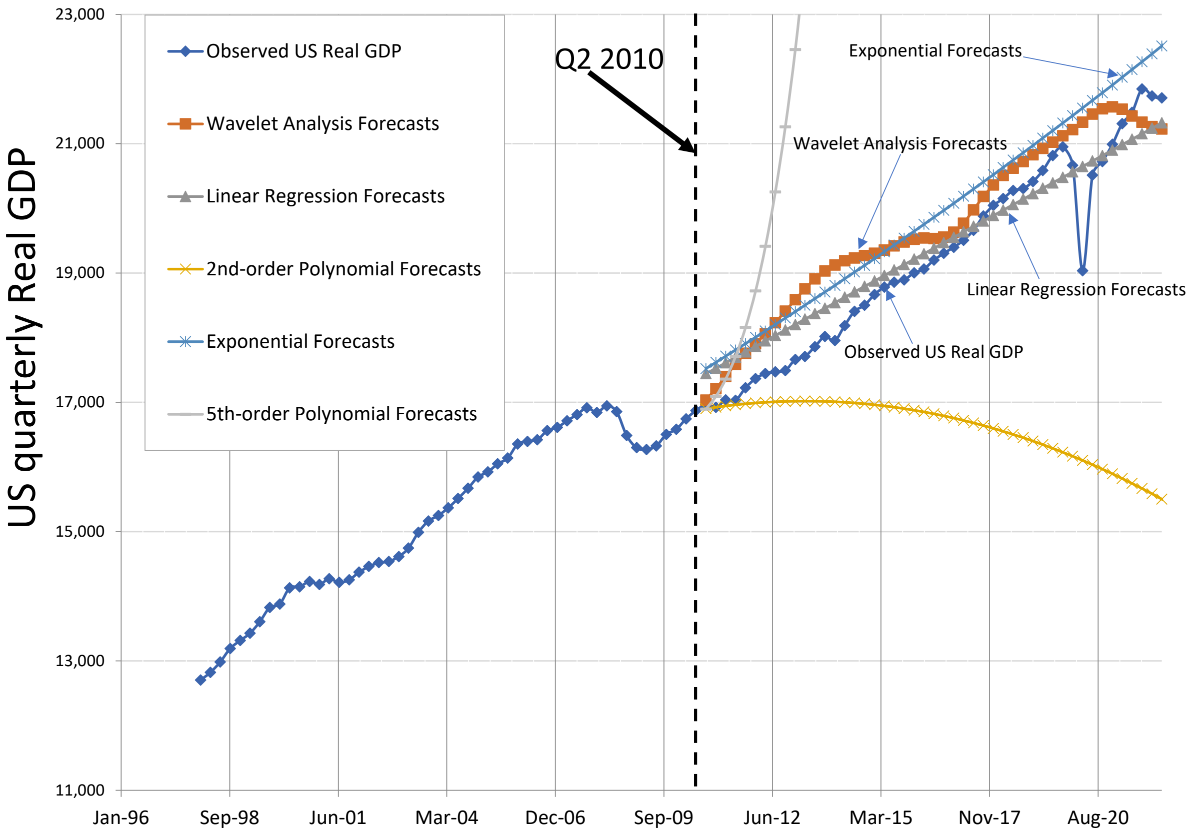
Table 2: Correlation coefficient and RMSE between forecast estimates obtained from various forecasting models and historical data over the forecasting period of 53 data from Q3 2010 to Q3 2023.

	Wavelet analysis Level-2	**Linear regression**	**2^{nd}-order polynomial model**	**5^{th}-order polynomial model**	**Exponential model**
Correlation coefficient	95%	98%	-92%	89%	99%
RMSE	701	474	3,845	296,035	762

Source: Authors' own elaboration using Matlab

The linear regression forecasting model beats all competing forecasting models including wavelet analysis with a correlation coefficient of 98% and a RMSE of 474, whereas wavelet analysis has a correlation coefficient of 95% and a RMSE of 701. The exponential model displays the highest correlation coefficient of 99% but the RMSE lags behind with a value of 762. Polynomial models are out of range.

Figure 7: US Real GDP forecast estimates from Q3 2010 to Q3 2023 (53 quarters), Linear Regression, 2nd-order Polynomial, 5th-order Polynomial, Exponential versus Wavelet Analysis.



Source: Authors' own elaboration using Matlab and Excel; FRED, Federal Reserve Bank of St. Louis https://fred.stlouisfed.org/series/GDPC1

Figure 7 illustrates US Real GDP forecast estimates obtained from five forecasting models. The linear regression forecasting model confirms its superiority during the 53-quarter estimate period because US GDP has grown linearly except during the Covid-19 pandemic period. For its outstanding in-sample forecasting ability, projections of GDPs and growth rates of the US and the Eurozone using linear extrapolation have been added to the Results section. Does the superiority of the Linear regression model over the four other models imply that linear extrapolation has the potential to be the preferred model of forecasting the US economy? Based on the observation and analysis of the US economy by the National Bureau of Economic Research (2024), from the trough of the recession of 1945 to the 2007-2008 recession, the National Bureau estimated that there have been eleven periods of expansion, lasting an average of about 20 quarters (59 months). It appears that the recession induced by the 2007-2008 credit crisis ended in June 2009. The recession induced by the Covid-19 pandemic started in February 2020. Surprisingly the period of expansion of the US economy between June 2009 and February 2020 lasted about 43 quarters, which is about two times the average time of an expansion of the US economy (20 quarters). As mentioned in the literature review, wavelet analysis is used in signal modeling in physics thanks to its outstanding property of capturing the cyclicality of signals, by decomposing their time series into frequency and time domain. Any economy, including the one of the US, follows a cycle of expansion, peak, contraction and trough, illustrated by a sinusoidal wave and is therefore a good candidate to be modelled and forecasted with wavelet analysis. This is the topic discussed in the next section.

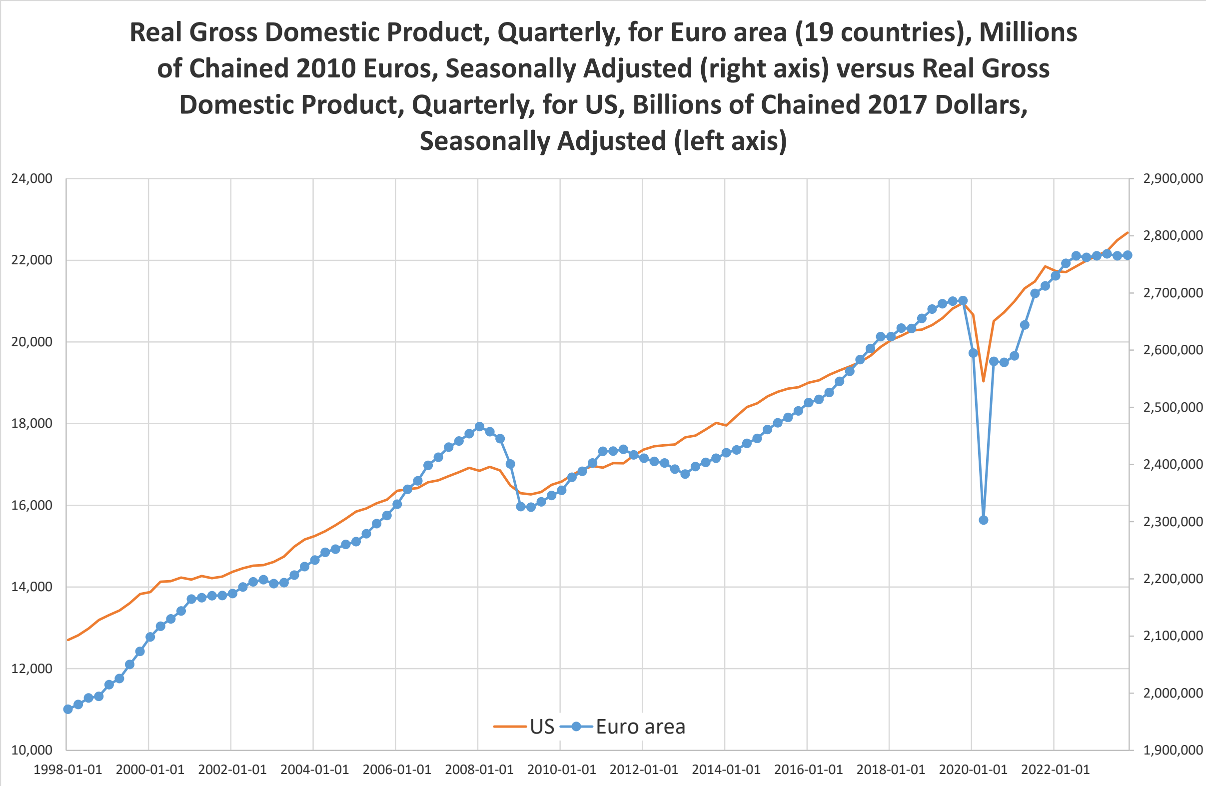
3.7. Is wavelet analysis a more suitable choice for the research question?

In the literature of parametric modeling -parametric models allow for a direct interpretation of the data, parameters being used to explain the movements within the different components and being used for forecasting- one school emerges, proponent of the Unobserved Components Model (UCM, Harvey 1989). The UCM belongs to the class of structural time series models set up in a state space context that takes advantage of the extraordinary flexibility of the recursive algorithms known as the Kalman filter and Fixed Interval Smoother (Pedregal, 2001). UCM is defined in terms of unobserved components with certain behavior attached to each component which then has a direct interpretation (Norwood, 2020). UCM uses previous statistical knowledge of the components and separates components which allow for new elements to be added given knowledge of events. On the flip side, UCM requires low level of previous knowledge of the behavior of the series to begin and evolved UCMs can have issues with stability and convergence if models are incorrectly specified. In the literature on nonparametric modeling of economic time series, that is, nonparametric models that make few or no assumptions about the underlying form of the data, a school of thought is emerging: wavelet analysis. Other nonparametric methods include neural networks, support vector regression, regression trees, Gaussian process, and long-short-term memory (Gautam & Singh, 2020). Examples of the wavelet analysis' followers include Gallegati et al. (2017), who demonstrated that wavelets provide a reliable and straightforward technique for analyzing long waves dynamics in time series exhibiting quite complex patterns such as historical data, by allowing simultaneous estimation of different unobserved components and Rhif et al. (2019) who underlined the ability of wavelet analysis to capture non-stationarity, multiresolution and approximate decorrelation which emerge from wavelet filters. Which school to choose? Unlike UCM, wavelet analysis is a non-parametric model that offers flexibility because it is to place little to no assumptions on the underlying form of the data. Since this article focuses on Real GDP time series where a reduced amount of prior information is assumed, reducing data assumptions may lead to a more unbiased approach (Norwood, 2020). In addition, the trend, seasonality, and cycle are embedded in Real GDP time series which are not directly observable in the data (Harvey and Koopman, 2010) but may be captured with both wavelets and unobserved components model. Fluctuations in economic activity are specifically captured by the cycle. Both models can once more capture this cycle. When hidden periodicities in data are associated with cyclical behavior or recurring processes, wavelet analysis and unobserved components model may again reveal these periodicities. In addition, wavelet analysis and unobserved components model aim to portray the features of a time series by assuming that they follow stochastic processes. In conclusion, there is no clear-cut study in the literature separating wavelet analysis and unobserved component model for forecasting economic time series, although unobserved component model is more fashionable. The authors believe that the wavelet analysis forecasting model is as suitable as its competitors.

4. Overview and analysis of the US and Eurozone historical data

Historical data have been retrieved from the Federal Reserve Bank of St. Louis website. Quarterly Real GDPs time series from Q4 1997 to Q3 2023 of the Eurozone economy (Euroarea-19 aggregate excluding Croatia, which joined the Eurozone in 2023, in Millions of Chained 2010 Euros, Seasonally Adjusted) and US (Billions of Chained 2017 Dollars Seasonally Adjusted) are illustrated in Figure 8. The US and Eurozone Gross Domestic Products (GDPs) evolved in sync over the historical period under study, between Q4 1997 and Q3 2023, with a high correlation coefficient of 97.5%. It shows two almost identical patterns at the start of 2020 when the two economies entered recession following the economic shock from the Covid-19 pandemic that hit the global economy.

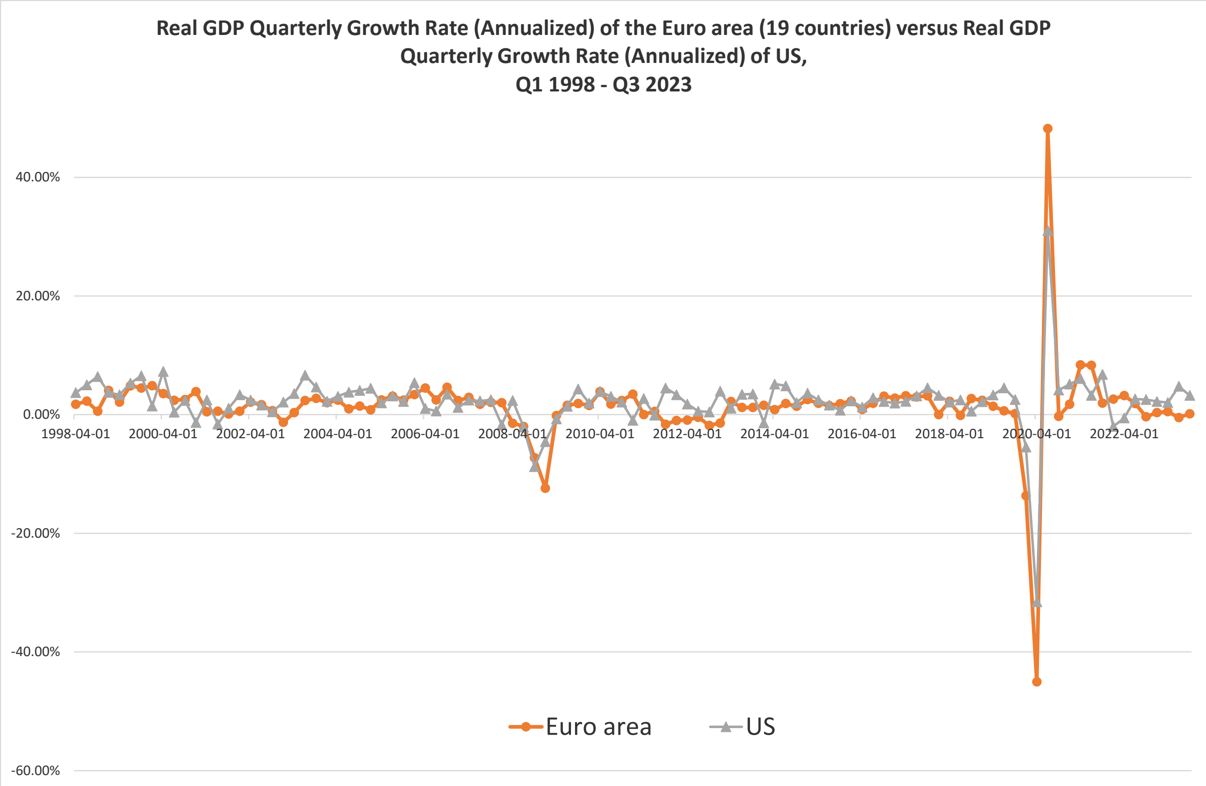
Figure 8: Quarterly Real GDPs time series of the Eurozone economy (19 countries, Millions of Chained 2010 Euros, Seasonally Adjusted) and US (Billions of Chained 2017 Dollars Seasonally Adjusted) from Q4 1997 to Q3 2023.



Sources: Authors' own elaboration. Gross Domestic Product for Eurozone (19 countries) [https://fred.stlouisfed.org/series/CLVMEURSCAB1GQEA19 and US [https://fred.stlouisfed.org/series/GDPC1], retrieved from FRED, Federal Reserve Bank of St. Louis

Figure 9 illustrates the historical quarterly GDP growth rate (annualized) time series of the Eurozone economy (19 countries) and the US from Q1 1998 to Q3 2023.

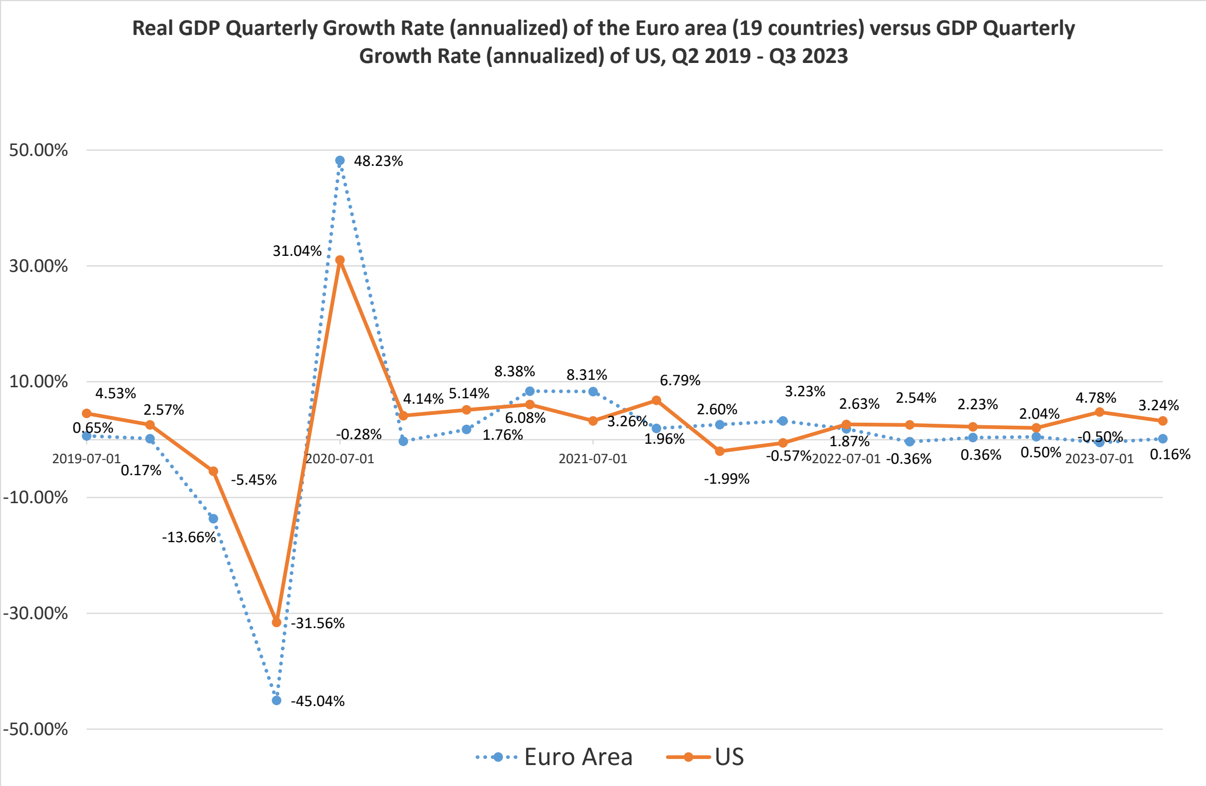
Figure 9: Quarterly Real GDP growth rate (annualized) time series of the Eurozone economy (19 countries) and US from Q1 1998 to Q3 2023.



Sources: Authors' own elaboration. Real Gross Domestic Product for Eurozone (19 countries) [https://fred.stlouisfed.org/series/CLVMEURSCAB1GQEA19 and US [https://fred.stlouisfed.org/series/GDPC1], retrieved from FRED, Federal Reserve Bank of St. Louis

As illustrated in Figure 9, between Q1 1998 and Q4 2019, the quarterly GDP growth rate (annualized) of the Eurozone economy (19 countries) was most of the time below the one of US with an average growth rate of 1.43% for the Eurozone versus 2.31% for US. When the Covid-19 pandemic hit the two economies in Q1 2020, the two GDPs dived, with a quarterly growth rate (annualized) reaching -31.56% in the US and -44.04% in the Eurozone. Figure 10 is a zoom of Figure 9 between Q2 2019 and Q3 2023. It illustrates the historical quarterly GDP growth rate (annualized) time series of the Eurozone (19 countries) and of the US economies from Q2 2019 to Q3 2023.

Figure 10: Quarterly Real GDP growth rate (annualized) time series of the Eurozone (19 countries) and the US economies from Q2 2019 to Q3 2023.



Sources: Authors' own elaboration. Real Gross Domestic Product for Eurozone (19 countries) [https://fred.stlouisfed.org/series/CLVMEURSCAB1GQEA19 and US [https://fred.stlouisfed.org/series/GDPC1], retrieved from FRED, Federal Reserve Bank of St. Louis

As illustrated in Figure 10, during the time of the pandemic, between Q4 2019 and Q2 2023, the quarterly GDP growth rate (annualized) of the Eurozone economy (19 countries) was most of the time below the one of the US, averaging +1.16% in the Eurozone versus +2.07% in the US. However, the rebound of the growth rate in Q2 2020 was greater in the Eurozone than in the US (+48.23% versus +31.04%). It is relevant to keep in mind that the size of the US economy in 2023 with a GDP of 27,720.71 USD Billion (Trading Economics, 2025a) was about 1.81 times the size of the Eurozone economy (19 countries) with a GDP of 15,780.69 USD Billion (Trading Economics, 2025b), so the Eurozone offers greater flexibility, based on the assumption that the smaller the economy, the greater its flexibility. In addition, in the Eurozone, the growth of its economies varies widely. For example, based on Statista (2024) data, the top 5 economies based on the GDP annual growth rate in 2023 (year to year) were

Malta (+3.8%), Greece (+2.5%), Spain (+2.5%), Portugal (+2.3%) and Cyprus (+2.2%) when the 5 laggers were Germany (-0.5%), Luxembourg (-0.4%), Lithuania (-0.2%), Finland (-0.1%) and Austria (+0.1%). The Eurozone annual GDP growth rate for the 19 economies was +0.7% in 2023. The annual GDP growth rate for US was 2.50% in 2023. One interesting fact is that the largest economy of the Eurozone, Germany, was the worst performer in 2023 with -0.5% of annual growth rate when the smallest economy of the Eurozone, Malta, was the top performer in terms of 2023 annual growth rate (+3.8%). As stated by the Bundesbank in February 2024, Germany was likely in recession at the start of 2024 due to weak external demand, consumers remaining cautious and domestic investment held back by high borrowing costs (Koranyi, 2024). As expected, the German economy contracted for the second consecutive year in 2024, highlighting the extent of the economic slowdown affecting Europe's largest economy. The German economy contracted by 0.2% in 2024—in line with economists' forecasts—and by 0.1% in the last quarter, according to the Federal Statistical Office, suggesting little sign of an imminent respite. (Martinez, 2025).

Table 3 gathers the descriptive statistics of the historical growth rates (quarterly and annualized) of the US and the Eurozone between Q1 1998 and Q3 2023. A comparative analysis with the descriptive statistics of the forecast estimates of the growth rates over the period Q4 2023 to Q4 2050 is presented in the next section.

Table 3: Descriptive statistics of the historical growth rates (quarterly and annualized) of the US and the Eurozone between Q1 1998 and Q3 2023.

Descriptive statistics of the historical growth rates (quarterly and annualized) of the Eurozone and the US between Q1 1998 and Q3 2023			
Eurozone		US	
Mean	0.013793	Mean	0.022877
Standard Error	0.007015	Standard Error	0.004971
Median	0.018509	Median	0.024776
Mode	#N/A	Mode	#N/A
Standard Deviation	0.071197	Standard Deviation	0.050446
Sample Variance	0.005069	Sample Variance	0.002545
Kurtosis	35.58379	Kurtosis	29.37072
Skewness	-0.08523	Skewness	-1.31707
Range	0.932626	Range	0.62601
Minimum	-0.45036	Minimum	-0.31564
Maximum	0.482263	Maximum	0.310369
Sum	1.420664	Sum	2.356305
Count	103	Count	103

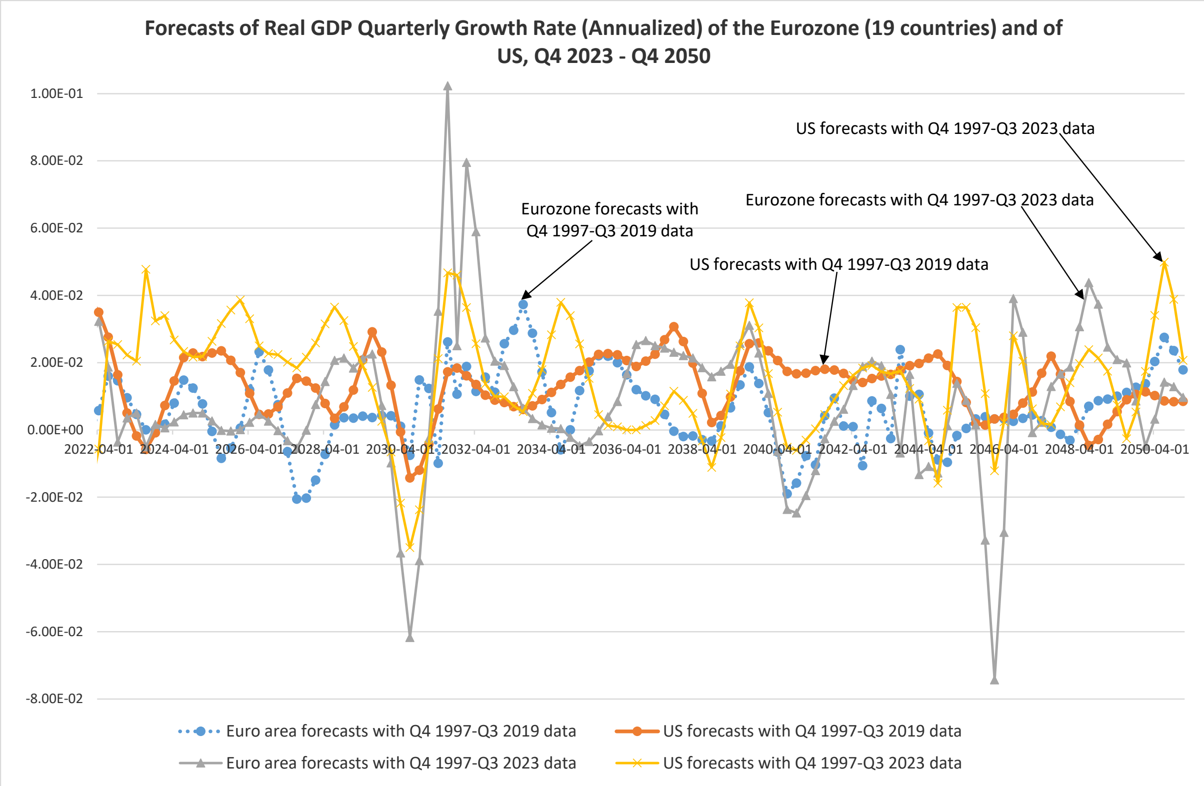
5. Results

The objective of the article is to assess and compare the resilience of the post-Covid US and Eurozone economies following the economic shock of the Covid-19 pandemic which hit the global economy in Q4 2019 and throughout 2020, 2021, 2022, officially ending during Q2 2023 (United Nations, 2023). Section 4.1 illustrates and analyzes GDP and growth rate time-series of the US and Eurozone. Sections 4.2 and 4.3 illustrate 2050 projections of the US and Eurozone quarterly Real GDPs and annualized Real GDP growth rates and section 4.4 assesses the resilience of the US economy and its benchmark, the Eurozone.

Section 4.2 presents 2023-2050 forecast estimates of US versus Eurozone quarterly annualized Real GDP growth rates using wavelet analysis.

4.1 Forecasts of Q4 2023 to Q4 2050 of US and Eurozone quarterly annualized Real GDP growth rates.

Figure 11: 109 forecasts with wavelet analysis of the US and the Eurozone quarterly annualized Real GDP growth rates from Q4 2023 to Q4 2050



Source: Authors' own elaboration using Matlab.

Figure 11 illustrates increasing negative quarterly growth rates of the Eurozone Real GDP until 2050 whereas quarterly growth rates of the US Real GDP are more frequently in positive territory.

Table 4 gathers the descriptive statistics of the forecast estimates of the growth rates over the period Q4 2023 to Q4 2050, using Wavelet Analysis and obtained from 1) Q4 1997 to Q3 2023 historical data and from 2) Q4 1997 to Q3 2019 historical data.

Comparing 109 growth rate forecast estimates over the period Q4 2023-Q4 2050 using Wavelet Analysis (obtained from 104 historical data from Q4 1997 to Q3 2023) to 103 historical data from Q1 1998 and Q3 2023, the forecast estimates for the Eurozone and the US are more pessimistic on average (+0.87% versus +1.38% for the Eurozone and +1.49% versus 2.29% for the US). Policymakers need to be aware of the reduced growth rate expected from these two economies over the next 26 years compared to the past 26 years.

Table 4: Descriptive statistics of the forecast estimates of the growth rates over the period Q4 2023 to Q4 2050, using Wavelet Analysis and obtained from 1) Q4 1997 to Q3 2023 historical data and from 2) Q4 1997 to Q3 2019 historical data.

Descriptive statistics of the forecasted growth rates (quarterly and annualized) of the Eurozone and the US between Q4 2023 and Q4 2050, using Wavelet Analysis and obtained from Q4 1997 to Q3 2019 historical data			
Eurozone		US	
Mean	0.005979	Mean	0.0132469
Standard Error	0.001075	Standard Error	0.000805
Median	0.00446	Median	0.014506
Mode	#N/A	Mode	#N/A
Standard Deviation	0.011226	Standard Deviation	0.008411
Sample Variance	0.000126	Sample Variance	7.076E-05
Kurtosis	0.080163	Kurtosis	0.514846
Skewness	0.087318	Skewness	-0.596368
Range	0.057878	Range	0.044966
Minimum	-0.020570	Minimum	-0.01428
Maximum	0.037308	Maximum	0.030682
Sum	0.651790	Sum	1.443916
Count	109	Count	109

In addition, based on Tables 3 and 4, the volatility of Real GDP growth rates should decline in the next 26 years for both the Eurozone (+2.24% future standard deviation versus +7.11% past standard deviation) and the US (+1.57% versus 5.04%) offering more opportunity of investments for institutional investors if we assume that lower GDP volatility has a positive impact on investment. When higher volatility leads to lower rates of investment, output and consumption, the result will be slower economic growth and lower levels of welfare for society at large (Carneiro et al., 2016) and vice versa.

Based on the 109 forecasts for the period Q4 2023-Q4 2050 generated with the Q4 1997-Q3 2023 historical data (including the pandemic), the Eurozone forecast estimates are more pessimistic than the US, with an average quarterly (annualized) growth rate of +0.87% for the Eurozone, versus +1.49% for the US. Based on the 109 forecasts for the period Q4 2023-Q4 2050 generated with the Q4 1997-Q3 2019 historical data (excluding the pandemic), the Eurozone forecast estimates are more pessimistic than the US, with an average quarterly (annualized) growth rate of +0.60% for the Eurozone, versus +1.32% for the US. It shows that thanks to the pandemic, US had a better outlook and a higher growth rate until 2050 (+1.49% for US versus

+0.87% for the Eurozone). In conclusion, the Covid-19 pandemic after Q3 2019 has badly hit the US and the Eurozone economies, but both economies seem to have been resilient beyond expectations since the forecasts estimates generated with historical data including the pandemic show better prospects than the ones generated with historical data not including the pandemic. Why does the US have a better Q4 2023-Q4 2050 average forecast (+1.49%) including pandemic data than the Eurozone, +0.87%?

In section 3.6., the linear regression model proved to be an out-performer forecasting model compared to wavelet analysis in an in-sample testing. In a last exercise, the descriptive statistics of the forecasted growth rates (quarterly and annualized) of the Eurozone and the US between Q4 2023 and Q4 2050 using linear extrapolation and obtained from Q4 1997 to Q3 2023 historical data are presented.

Table 4: Descriptive statistics of the of the forecast estimates of the growth rates over the period Q4 2023 to Q4 2050, using linear extrapolation and obtained from Q4 1997 to Q3 2023 historical data.

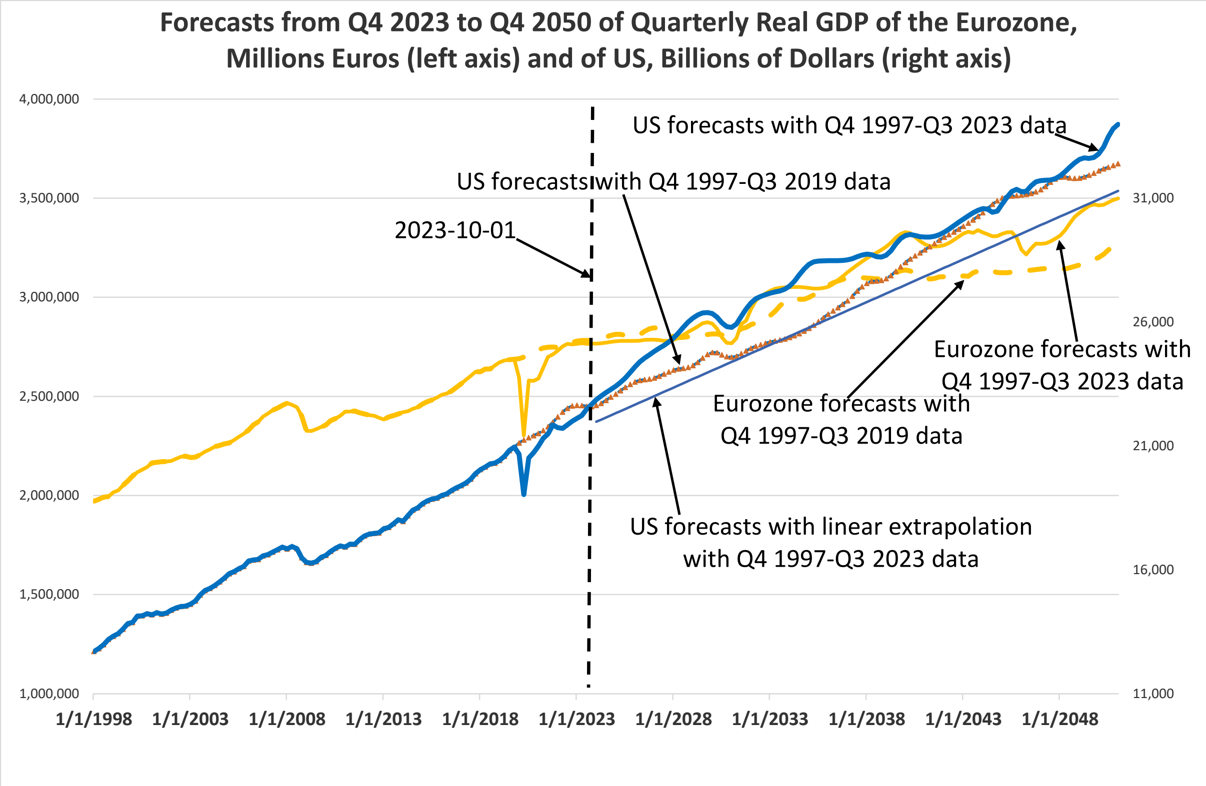
Descriptive statistics of the forecasted growth rates (quarterly and annualized) of the Eurozone and the US between Q4 2023 and Q4 2050 using linear extrapolation obtained from Q4 1997 to Q3 2023 historical data			
Eurozone, best fit linear equation of Q4 1997 to Q3 2023 historical data: Y = -511471.98+ 71.9510861*X		US, best fit linear equation of Q4 1997 to Q3 2023 historical data: Y = -20822.13157 + 0.944899*X	
Mean	0.008193688	Mean	0.01186390
Standard Error	0.00032905	Standard Error	0.00125766
Median	0.008463974	Median	0.01295620
Mode	#N/A	Mode	#N/A
Standard Deviation	0.003435382	Standard Deviation	0.01313040
Sample Variance	1.18018E-05	Sample Variance	0.00017240
Kurtosis	102.9375894	Kurtosis	106.659122
Skewness	-10.0049576	Skewness	-10.272948
Range	0.036444805	Range	0.13895003
Minimum	-0.02685282	Minimum	-0.1232488
Maximum	0.009591978	Maximum	0.01570122
Sum	0.893111963	Sum	1.29316518
Count	109	Count	109

Comparing 109 growth rate forecast estimates over the period Q4 2023-Q4 2050 using Linear extrapolation (obtained from 104 historical data from Q4 1997 to Q3 2023) to 109 growth rate forecast estimates over the period Q4 2023-Q4 2050 using Wavelet Analysis (obtained from 104 historical data from Q4 1997 to Q3 2023), the forecast estimates for the Eurozone and the US are more pessimistic on average using Linear extrapolation than Wavelet Analysis (+0.82% versus +0.87% for the Eurozone and +1.19% versus 1.49% for the US). Figure 12 illustrates the linear extrapolation applied to the US GDP and confirms the fact that Linear extrapolation offers more conservative and lower projections of GDPs than Wavelet Analysis for both economies.

Forecasts of Q4 2023 to Q4 2050 of the US and Eurozone quarterly Real GDPs

Figure 12 illustrates 115 quarterly Real GDP forecasts with wavelet analysis of US and the Eurozone from Q3 2024 to Q4 2050. The rebound of both economies in Q2 2020 (refer to Figure 10), +31.04% in US versus +48.23% in the Eurozone, following the huge contraction in Q1 2020, -31.56% in US and -45.04% in the Eurozone, clearly explains the positive outlook of the forecasts generated with the historical data including the pandemic versus the ones not including the pandemic because both the US and the Eurozone displayed resilience during the pandemic. Comparing the average growth rate of each economy during the pandemic (Q4 2019 to Q2 2023) to the average of the historical period not including the pandemic (Q1 1998 to Q3 2019), the averages are surprisingly just a bit lower during the pandemic (+2.07% versus +2.31% in the US and +1.16% versus +1.43% in the Eurozone).

Figure 12: Historical data and forecasts with wavelet analysis between Q4 2023 and Q4 2050 of the US and Eurozone quarterly Real GDPs



Source: Authors' own elaboration using Matlab.

As illustrated by Figure 12, the quarterly Real GDPs of the US and the Eurozone are expected to grow steadily until Q4 2050, the forecast estimates generated with historical data including the pandemic showing a more sustainable growth for both economies than the forecast estimates generated with historical data not including the pandemic. Both countries have benefited from the pandemic, which gave a boost to their economies.

Assessing the resilience of the US economy following the economic shock from the Covid-19 pandemic

To recall, the objective of the paper is to assess and compare the resilience of the post-Covid US and Eurozone economies following the economic shock of the Covid-19 pandemic that hit the global economy in Q3 2019, in years 2020, 2021, 2022 and ending in Q2 2023.

To answer the question, using the Q4 2023-Q4 2050 forecasts of both economies, by subtracting the average forecast estimate of the Q4 2023-Q4 2050 Eurozone quarterly Real GDP growth rates (annualized) generated with the Q1 1998-Q3 2023 data (including the pandemic), +0.87%, by the one obtained from the Q1 1998-Q3 2019 data (excluding the pandemic), +0.60%, the difference is +0.27%, when with the US the difference is +0.17% [1.49% - 1.32%]. Thus, the Eurozone showed a greater resilience to the Covid-19 pandemic (+0.27%) than the US (+0.17%) based on Q4 2023-Q4 2050 forecasts. However, the authors pointed out that the average of the Q4 2023-Q4 2050 quarterly (annualized) growth rate forecast estimates of the US is expected to be +1.49% when generated with the Q4 1997-Q3 2023 historical data including the pandemic whereas it is expected to be only 0.87% for the Eurozone. It is relevant to note that the ratio 1.49%/0.87% = 1.7 respects the historical ratio during the period Q1 1998 to Q3 2023 of the US versus the Eurozone, 2.29%/1.38% = 1.7. History repeats itself.

6. Conclusion and Discussion

This paper presents 2023 to 2050 forecasts of US and Eurozone quarterly Real GDP and growth rate generated from historical data not including the Covid-19 pandemic (from Q4 1997 up to Q3 2019) and including the pandemic (from Q4 1997 up to Q3 2023) by using a wavelet analysis forecasting model. Wavelet analysis is used for its ability to analyze changing transient physical signals. Extending the analysis to complex-behavior economic signals such as GDPs, the originality of this paper is to apply wavelet analysis to economic variables subject to common dynamics such as Real GDP time series. The forecasts cover 109 quarters from Q4 2023 to Q4 2050 and derive from historical quarterly data extending from Q4 1997 to Q3 2023. The US economy is benchmarked to the Eurozone (19 countries) since the US and the Eurozone Real GDPs evolved in sync over the historical period under study, between Q4 1997 and Q3 2023, with a high and stunning correlation coefficient of 97.5%. The 2023 US GDP was the world's largest, while the Eurozone's GDP was third behind China.

Wavelet analysis methodology follows four steps that lead to Real GDP quarterly (annualized) growth rate forecasts: the Quarterly Real GDP growth rate (annualized) time series of the US and Eurozone 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 p^{th} 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 forecast estimates.

The objective of the article is to assess and compare the resilience of the post-Covid US and Eurozone economies following the economic shock of the Covid-19 pandemic that hit the global economy in 2020, 2021, 2022 and ending in Q2 2023. During the pandemic, between Q4 2019 and Q2 2023, the quarterly GDP growth rate (annualized) of the Eurozone economy (19 countries) was most of the time below the one of US, however experiencing a greater rebound of the growth rate in Q2 2020. The average growth rate was +1.16% in the Eurozone versus +2.07% in the US during the pandemic between Q4 2019 and Q2 2023, below the historical averages between Q1 1998 and Q4 2019 of the Eurozone (+1.43%) and of the US (+2.31%). Using the Q4 2023-Q4 2050 forecasts of both economies, by subtracting the average forecast estimate of the Q4 2023-Q4 2050 Eurozone quarterly Real GDP growth rates (annualized) generated with the Q1 1998-Q3 2023 data (including the pandemic), +0.87%, by the one obtained from the Q1 1998-Q3 2019 data (excluding the pandemic), +0.60%, the difference is +0.27%, when with the US the difference is +0.17% [1.49% - 1.32%]. Thus, the Eurozone showed a greater resilience to the Covid-19 pandemic (+0.27%) than the US (+0.17%) based on Q4 2023-Q4 2050 forecasts. However, the authors pointed out that the average of the Q4 2023-Q4 2050 quarterly (annualized) growth rate forecast estimates of the US is expected to be +1.49% when generated with the Q4 1997-Q3 2023 historical data including the pandemic whereas it is expected to be only 0.87% for the Eurozone. It is relevant to note that the ratio 1.49%/0.87% = 1.7 respects the historical ratio during the period Q1 1998 to Q3 2023 of the US versus the Eurozone, 2.29%/1.38% = 1.7. History repeats itself.

In addition, comparing 109 growth rate forecast estimates for the period Q4 2023-Q4 2050 (obtained from 103 historical data from Q1 1998 to Q3 2023) to 103 historical data from Q1 1998 and Q3 2023, the forecast estimates for the Eurozone and the US are more pessimistic on average (+0.87% versus +1.38% for the Eurozone and +1.49% versus 2.29% for the US). Policymakers need to be aware of the reduced growth rate expected from these two economies over the next 26 years compared to the past 26 years. In addition, based on Table 3, the volatility of Real GDP growth rates should decline in the next 26 years for both the Eurozone (+2.24% future standard deviation versus +7.11% past standard deviation) and the US (+1.57% versus 5.04%) offering more opportunity of investments for institutional investors if we assume that lower GDP volatility has a positive impact on investment. When higher volatility leads to lower rates of investment, output and consumption, the result will be slower economic growth and lower levels of welfare for society at large (Carneiro et al., 2016) and vice versa.

Focusing on the quarterly Real GDP forecast estimates of the US and the Eurozone, they are expected to grow steadily until Q4 2050, the forecast estimates generated with historical data including the pandemic showing a more sustainable growth for both economies than the forecast estimates generated with historical data not including the pandemic. Both countries have benefited from the pandemic, which gave a boost to their economies.

The results of this study converge with the expectations of market analysts. During the first half of 2022, the US witnessed two consecutive quarters of negative real GDP growth, -1.6% final estimate for Q1 2022 and -0.9% estimate for Q2 2022. By mid-2022, raging inflation emerged as a challenge for the US, as strong demand, skewed toward goods and away from services, interacted with the supply chain stresses. The CPI increased by 8.5% year over year in July 2022, well ahead of June's 5.3% year-over-year gain in wages and salaries being recorded. The shrinking GDP has been accompanied by inflation and tight labor markets, not to mention continuing energy uncertainties stemming from the invasion of Ukraine by Russia in 2022 as well as the lingering effects of the COVID-19 pandemic. To counter inflation, the Fed raised interest rates seven times in 2022, Fed Chair Powell saying that his inflation fight was unconditional, and rate hikes will continue even if it means some pain for Americans. The year 2023 saw four more Federal rate increases (for a total of +1%) and the recession did not occur despite economists' predictions. Against all odds, ignoring the dire predictions of a recession after the Fed's aggressive rate hikes, the U.S. economy grew a faster-than-expected 3.3% in Q4 2023, amid strong consumer spending, with full-year growth of 2.5%. By February 2024, Deutsche Bank no longer expected the US economy to slide into recession in 2024, given slowing inflation and the labor market returning to a better balance without a significant increase in unemployment (Abraham, 2024). Though the economy continued to face several headwinds in 2023 such as still-tight credit conditions, rising consumer delinquency rates and a slowing labor market, the resilience pointed to a more benign slowdown in 2024 than previously projected. The U.S. economy was expected to grow by 1.9% in 2024, on a quarterly average basis, compared with its prior forecast of 0.3%. Based on this study's projections, US quarterly real GDP was expected to grow by 2.4% in 2024, slightly more than Deutsche Bank's forecast (+1.9%). Based also on this study, the annual growth rate should average 2.54% until 2030 and no recession will occur until year 2030. By 2030, the recession should last 5 quarters. Growth will come back until 2038 with an annual growth rate of 1.55%. In 2038, recession will last 3 quarters, coming back in 2040 for 3 quarters and in 2044 for 2 quarters. No more recession will occur between 2044 and 2050 with a steady annual growth rate of 1.70% of the US economy. This outlook was converging with most financial reports of leading newspapers, such as Wall Street Journal (2024), "America's Remarkably Resilient Economy", Voice of America News (2024), "Productivity Surge Helps Explain US Economy's Surprising Resilience" and Financial Times (2023) "Why is the US economy so resilient?". But these financial reports from major newspapers, as well as the forecasts in this study, have not taken into account the trade war launched by the Trump administration in 2025. Unexpectedly, a massive supply shock caused by the trade war has threatened the global economy since US President Donald Trump announced that he would "absolutely" impose tariffs on goods from its major trading partners in 2025. The political slogan "Make America Great Again" was recently used by President Trump to assert that he would make America the world's political and economic leader by using all the tools at his disposal, including tariffs and a trade war. The announcement of the tariffs caused significant volatility in financial markets and forced the European central bank to continue cutting interest rates for third time in 2025 as Europe has braced for slowing growth and Trump's tariffs (The Guardian, 2025b) and will force the Federal Reserve to drive rates lower as top concern has shifted from inflation to growth (Caldwell, 2025) and widespread predictions of an imminent global recession. From a more technical perspective, another limitation lies in the assumption that GDP is an aggregate indicator of economic growth in the United States and the Eurozone; in fact, many economic variables should be used to enhance the forecasting model, for example CPI, Monthly Unemployment report, industrial production, capacity utilization. In addition, this paper presents a method to assess economic resilience and should be compared to other methods to test consistency especially when comparing countries. Future research may consider addressing these issues.

Additional research may deal with other economic indicators of the US to identify weaknesses and strengths of the US and Eurozone economies and how to enhance them. Comparing and measuring the resilience of the United States and the Eurozone can help governments, businesses, policymakers and international investors operating in these economic zones better understand the dynamics underlying their economies, their links and interactions. Finally, using a forecasting model always involves assumptions that limit forecast accuracy.

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