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MONEY GROWTH AND INFLATION IN THE EURO AREA: A TIME-FREQUENCY VIEW

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Money growth and inflation in the euro area: a time-frequency view

António Rua*

Abstract

This paper provides new insights on the relationship between money growth and inflation in the euro area over the last forty years. This highly relevant link for the European Central Bank monetary policy strategy is assessed using wavelet analysis. In particular, wavelet analysis allows to study simultaneously the relationship between money growth and inflation in the euro area at the frequency level and assess how it has changed over time. The findings indicate a stronger link between inflation and money growth at low frequencies over the whole sample period. At the typical business cycle frequency range the link is only present until the beginning of the 1980's. Moreover, there seems to be a recent deterioration of the leading properties of money growth with respect to inflation in the euro area. These results highlight the importance of a regular assessment of the role of money growth in tracking inflation developments in the euro area since such relationship varies across frequencies and over time.

Keywords: M3 growth; inflation; euro area; wavelets.

JEL classification: C40, E30, E40, E50.

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1 Introduction

The goal of the European Central Bank (ECB) is to maintain price stability, defined as a year-on-year increase in the Harmonised Index of Consumer Prices for the euro area below, but close to, 2 per cent over the medium term. The assessment of risks to price stability is based on the so-called two-pillar framework. The first pillar relies on economic analysis, where the focus is on real activity and financial conditions in the economy, to identify short to medium-term risks. The second pillar refers to monetary analysis to assess medium to long-term developments in inflation. Hence, for tracking shorter-run fluctuations of inflation, the ECB puts emphasis on the economic analysis while for medium to long-term trends the focus is on money growth. In this respect, the monetary aggregate M3 has a prominent role in the ECB's monetary policy strategy. One of the reasons for the key role of M3 growth in the ECB's monetary policy framework relates to its leading properties regarding inflation in the euro area. Nicolleti-Altimari (2001) and Trecroci and Vega (2002) show supporting evidence of such relationship but several authors have argued that such evidence does not hold with more recent data (see, for example, Hofmann (2006), Kahn and Benolkin (2007) and Alves *et al.* (2007)). In other words, M3 may be losing its information content about future price developments in the euro area.

Lucas (1980) pioneering work highlighted the importance of the frequency level when assessing the link between money growth and inflation. The idea that the determinants of inflation vary across frequencies with money growth and inflation more closely tied in the long-run (*i.e.*, low frequencies) set path to a growing literature assessing such relationships across frequency bands. Recent work includes Jaeger (2003), Haug and Dewald (2004), Bruggeman *et al.* (2005), Assenmacher-Wesche and Gerlach (2008a, 2008b), Benati (2009) among others.[1] While there is evidence that the link between money growth and inflation can vary across frequencies, such rela-

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[1] See Assenmacher-Wesche and Gerlach (2008a) for a summary of this literature.

tionship may also change over time (see, for example, Rolnick and Weber (1997), Christiano and Fitzgerald (2003), Sargent and Surico (2008) and Benati (2009)).

In this paper, I resort to wavelet analysis which accounts for both time and frequency domains allowing for the simultaneous assessment of how variables relate at different frequencies and how such relationship changes over time. Most of the literature taking the frequency perspective conditions the analysis on a somehow arbitrary cut-off of the frequency bands[2], whereas papers that focus on the time-varying nature of the relationship resort to the analysis of sub-samples with split dates more or less *ad-hoc*. Wavelet analysis avoids such problems as it provides a continuous assessment of the relationship between money growth and inflation in the time-frequency space. Other work drawing on wavelets includes, for example, Rua and Nunes (2009) who assess the international comovement of stock market returns, Rua (2010) resorts to wavelets for business cycle analysis, Rua (2011) use wavelets for forecasting purposes (see, for instance, Crowley (2007) for a survey).

The findings show both frequency and time-varying features concerning the link between money growth and inflation in the euro area. On one hand, the relationship between inflation and money growth is stronger at low frequencies than at the typical business cycle frequency range. On the other hand, such link is more robust at low frequencies over the whole sample period whereas there is supporting evidence at business cycle frequencies only up to the beginning of the 1980's. Concerning the leading properties of money growth with respect to inflation, there seems to be a recent deterioration. These results stress the importance of a regular assessment of the role attributed to the monetary aggregate M3 by the ECB within the two-pillar monetary policy framework for tracking medium to long-term developments

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[2] For example, Jaeger (2003) considers low frequencies as those associated with fluctuations longer than 8 years, Benati (2009) considers as low frequencies those associated with fluctuations longer than 30 years and Assenmacher-Wesche and Gerlach (2008a, 2008b) define the long run as fluctuations with a periodicity of more than 4 years.

in inflation.

The remainder of the paper is organised as follows. Section 2 provides an overview of wavelet analysis. In section 3, the empirical results for the euro area are presented. Section 4 concludes.

2 Wavelet analysis

The well-known Fourier transform is the conventional method for studying the frequency content of a signal. Despite its usefulness, the Fourier transform provides no information on how the frequency content of the signal changes over time. Although it tells us how much of each frequency is present in the signal, it is silent about when these frequency components occur. Since the time information about the signal is lost, the Fourier transform is unsuitable to study time-varying phenomena.

To overcome such limitation, the short-time Fourier transform (also known as Gabor or windowed Fourier transform) has been suggested in the literature. It consists in applying a short-time window to the signal and performing the Fourier transform within this window as it slides across all the data. The problem with the windowed Fourier transform is that it uses constant length windows, generating a uniform partition of the time-frequency plane. When a wide range of frequencies is involved, the fixed time window tends to contain a large number of high frequency cycles but only few low frequency cycles which results in an overrepresentation of high frequency components and an underrepresentation of the low frequency components. Hence, as the signal is examined under a fixed time-frequency window with constant intervals in the time and frequency domains, the windowed Fourier transform does not allow an adequate resolution for all frequencies.

In contrast, the wavelet transform uses local base functions that can be stretched and translated with a flexible resolution both in frequency and time domains. In the case of the wavelet transform, the time resolution is intrinsically adjusted to the frequency with the window width narrowing when focusing on high frequencies while widening when assessing low frequencies. Allowing for windows of different size improves the frequency resolution of the low frequencies and the time resolution of the high frequencies.[3]

The continuous wavelet transform of a time series $x(t)$ can be written as

$$W_x(\tau, s) = \int_{-\infty}^{+\infty} x(t)\psi^*_{\tau,s}(t)dt \tag{1}$$

where the * indicates the complex conjugate. Hence, the wavelet transform decomposes a time series $x(t)$ in terms of some basis functions (wavelets), $\psi_{\tau,s}(t)$, analogous to the use of sines and cosines in the Fourier analysis. The term wavelet means a small wave. The smallness refers to the condition that this function is of finite length while the wave means that it is oscillatory. These basis functions are obtained by translation and dilation of the so-called mother wavelet $\psi(t)$ and are defined as

$$\psi_{\tau,s}(t) = \frac{1}{\sqrt{s}}\psi\left(\frac{t-\tau}{s}\right) \tag{2}$$

where τ determines the time position (translation parameter), s corresponds to the scale (dilation parameter) and $\frac{1}{\sqrt{s}}$ is for energy normalization across the different scales. The term translation is related to the location of the window, as the window is shifted through the signal. The scale refers to the width of the wavelet. Changes in the scale parameter generate different versions of the mother wavelet: for $s < 1$ the wavelet is compressed; for $s = 1$ the wavelet corresponds to the mother wavelet; and for $s > 1$ the mother wavelet is stretched. In terms of frequency, low scales by a compressed wavelet function capture rapidly changing details (*i.e.* high frequencies)

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[3] According to the Heisenberg uncertainty principle there is always a trade-off between resolution in time and frequency when measuring a signal. That is, to get a better picture of the frequency composition one needs to consider a long period of the signal whereas if one wants to pinpoint a small sample period then it becomes difficult to determine the frequency makeup of the signal in that period.

whereas higher scales by a stretched wavelet function capture slowly changing features (*i.e.* low frequencies).

To be a mother wavelet, $\psi(t)$ must fulfil several criteria (see, for example, Percival and Walden (2000)): it must have zero mean, $\int_{-\infty}^{+\infty} \psi(t)dt = 0$; its square integrates to unity, $\int_{-\infty}^{+\infty} \psi^2(t)dt = 1$, which means that $\psi(t)$ is limited to an interval of time; and it should satisfy the so-called admissibility condition, $0 < C_\psi = \int_0^{+\infty} \frac{|\widehat{\psi}(\omega)|^2}{\omega} d\omega < +\infty$ where $\widehat{\psi}(\omega)$ is the Fourier transform of $\psi(t)$, that is, $\widehat{\psi}(\omega) = \int_{-\infty}^{+\infty} \psi(t)e^{-i\omega\tau}dt$. The latter condition allows the reconstruction of the signal without loss of information.

The most commonly used mother wavelet for the continuous wavelet transform is the Morlet wavelet, which can be defined as

$$\psi(t) = \pi^{-\frac{1}{4}} e^{i\omega_0 t} e^{\frac{-t^2}{2}} \tag{3}$$

The Morlet wavelet consists of a complex sine wave within a Gaussian envelope. The normalization factor, $\pi^{-\frac{1}{4}}$, ensures that the wavelet function has unit energy. The parameter ω_0 is the wavenumber and controls the number of oscillations within the Gaussian envelope. An increase (decrease) in the wavenumber allows for better (poorer) frequency localization but poorer (better) time localization. In practice, ω_0 is usually set to 6, which is argued to provide a good balance between time and frequency resolution. Moreover, since the wavelength for the Morlet wavelet is given by $\frac{4\pi s}{\omega_0+\sqrt{2+\omega_0^2}}$ (see, Torrence and Compo (1998)), then for $\omega_0 = 6$, the wavelet scale s is almost equal to the Fourier period which eases the interpretation of wavelet analysis. Another advantage of the Morlet wavelet is its complex nature which allows for both time-dependent amplitude and phase.

Likewise in Fourier analysis, several measures can be computed in the wavelet domain. For instance, one can define the wavelet power spectrum as $|W_x(\tau, s)|^2$. It measures the relative contribution at each time and each scale to the time series variance. The wavelet power spectrum can be integrated across τ and s to recover the total variance of the series as follows

$$\sigma_x^2 = \frac{1}{C_\psi} \int_0^{+\infty} \int_{-\infty}^{+\infty} |W_x(\tau, s)|^2 \frac{d\tau ds}{s^2} \tag{4}$$

Given two time series $x(t)$ and $y(t)$, with wavelet transforms $W_x(\tau, s)$ and $W_y(\tau, s)$ one can define the cross-wavelet spectrum as $W_{xy}(\tau, s) = W_x(\tau, s)W_y^*(\tau, s)$. As the mother wavelet is in general complex, the cross-wavelet spectrum is also complex valued and it can be decomposed into real and imaginary parts.

In a similar fashion to the Fourier analysis, one can define the wavelet squared coherency as the absolute value squared of the smoothed cross-wavelet spectrum, normalized by the smoothed wavelet power spectra

$$R^2(\tau, s) = \frac{\left|S\left(s^{-1}W_{xy}(\tau, s)\right)\right|^2}{S\left(s^{-1}\left|W_x(\tau, s)\right|^2\right) S\left(s^{-1}\left|W_y(\tau, s)\right|^2\right)} \tag{5}$$

where $S(.)$ denotes smoothing in both time and scale and s^{-1} converts to an energy density (see, for example, Torrence and Webster (1999)). As in Fourier analysis, smoothing is required, otherwise squared coherency would be always equal to one.

The idea behind the wavelet squared coherency is similar to the one of squared coherency in the Fourier analysis. The wavelet squared coherency measures the strength of the relationship between the two series over time and across frequencies (while the squared coherency in the Fourier analysis only allows assessing the latter). The $R^2(\tau, s)$ is between 0 and 1 with a high (low) value indicating a strong (weak) relationship. Hence, the plot of the wavelet squared coherency enables the distinction of regions in the time-frequency space where the link is stronger and allows for the identification of both time and frequency varying features.

Lastly, one can also compute the wavelet phase difference between x and y, which captures the lead-lag relationship between the variables in the time-frequency space. The wavelet phase difference is given by

$$\phi(\tau, s) = \tan^{-1}\left(\frac{\Im\left(W_{xy}(\tau, s)\right)}{\Re\left(W_{xy}(\tau, s)\right)}\right) \tag{6}$$

where $\Re$ and $\Im$ are the real and imaginary parts, respectively. The resemblance with the analogue measure in the Fourier analysis is clear since the phase difference provides information about the lead-lag relationship between the two series. However, besides providing information about the lead-lag across frequencies as the standard Fourier analysis, the wavelet phase difference also allows for the assessment of how such lead-lag relationship changes over time.

3 Empirical results for the euro area

This section proceeds with the computation of the above mentioned measures for money growth and inflation in the euro area. Data for the monetary aggregate M3 comes from the ECB and the long time series for the harmonized consumer price index in the euro area was obtained from the OECD Main Economic Indicators database.[4] Both series are monthly and range from January 1970 up to December 2007 (see figure 1).

Figures 2 and 3 present the wavelet spectra for the corresponding standardized series. Since there are three dimensions involved, the results are displayed in a 3-D surface plot. The x-axis refers to time and the y-axis to frequency. To ease interpretation, the frequency is converted to time units (years). The height of the surface represented by the z-axis corresponds to the value of the wavelet spectrum. The gray scale helps to visualize the magnitude, whereas the black areas of the surface denote the statistically significant regions at the usual significance level of five per cent.[5]

The figures show that both money growth and inflation have relatively

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[4] Prior to 1990, the OECD data refers to the euro area aggregate obtained by weighting CPI country level data. All the series are available from the author upon request.

[5] The critical values are based on the results of Torrence and Compo (1998) who showed that the wavelet spectrum of a white noise has a distribution that is proportional to a Chi-squared with two degrees of freedom in the case of the Morlet wavelet. All computations used Matlab.

high power at the typical business cycle frequency range - between two and eight years - and even higher power at longer cycles. This is in line with, for instance, Haug and Dewald (2004) who found that lower frequencies are the most relevant when explaining the variance of money growth and inflation for several countries. Also noteworthy is the time-varying behaviour of the variance in both series, which seems to confirm the changing volatility of macroeconomic time series over the last couple of decades. The phenomenon known as the "Great Moderation" has been extensively documented for the US and, to a lesser extent, for the euro area. In the case of money growth and inflation in the euro area, there seems to be an increase of the relative importance of low frequencies in both series over time. However, with respect to inflation, the power is not statistically significant at any frequency in the latter part of the sample. This result reflects the flattening of inflation in the more recent period as shown in figure 1. During the "Great Inflation" episode in the 1970's when oil price shocks played a significant role, inflation in the euro area was high and volatile whereas after the pronounced disinflation process observed in the euro area around the mid-1980's, inflation has become relatively low and stable.

Concerning the relationship between money growth and inflation, figure 4 shows a 3-D surface plot of the wavelet squared coherency. Through the inspection of the graph one can identify both the frequency bands (in the y-axis) and time intervals (in the x-axis) where the series move together. Moreover, one can also assess if the strength of the link has increased or decreased over time and across frequencies capturing possible varying features in the relationship between the two series in the time-frequency space. The black part of the surface denotes the statistical significant area at the usual significance level of five per cent.[6]

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[6] In this case, as the distribution is not known, the five per cent significance level was determined from a Monte Carlo simulation of wavelet squared coherency between 10 000 sets of two white noise time series with the same length as the series under analysis (see, for example, Torrence and Webster (1999)).

Disregarding the very high frequencies (*i.e.* short-term fluctuations), which, as mentioned earlier, do not receive much attention from the ECB analysis of the money growth and inflation relationship, one can clearly distinguish the results obtained for the typical business cycle frequency range and for the very low frequencies (*i.e.* long-term developments). The heterogeneity at the frequency level highlights the importance of such analysis when assessing the link between money growth and inflation which has its roots on the seminal work of Lucas (1980) for the United States. To take into account the frequency perspective, some authors conduct the analysis by using statistical filters, like a simple moving average or more elaborated filters such as the well-known Hodrick-Prescott filter and band-pass filters, in order to disentangle the series into different frequency components and then assess the relationship in the time domain for each frequency component. For example, Haug and Dewald (2004) and Benati (2009) resort to band-pass filters to extract components associated to specific frequency bands. However, as acknowledged by Benati (2009), such analysis ends up relying on a somehow arbitrary cut-off of the frequency bands. By resorting to wavelet analysis, one can capture frequency domain features without restricting the analysis to frequency bands with lower and upper bounds imposed *a priori*. Other authors resort to spectral analysis to unveil frequency domain features (see, for example, Jaeger (2003) and Assenmacher-Wesche and Gerlach (2008a, 2008b)). However, as discussed in the previous section, the Fourier analysis disregards any possible time information that might exist in the relationship and therefore is unable to capture time-varying features (although, for instance, Benati (2009) circumvents this drawback by computing rolling estimates). This constitutes an important caveat of the Fourier analysis in the study of the link between money growth and inflation as there is by now evidence that such relationship can evolve over time (see Rolnick and Weber (1997), Christiano and Fitzgerald (2003), Sargent and Surico (2008), Benati (2009), among others). Therefore, wavelet analysis is particularly suitable to study the relationship between money growth and inflation as it can capture both frequency and time-varying features within a unified framework.

Figure 4 shows that money growth and inflation in the euro area presented a high and significant link at the business cycle frequency range only up to the beginning of the 1980's. Thereafter, fluctuations in money growth of a periodicity of less than eight years appear not to matter much for inflation. This finding reinforces the results of Neumann and Greiber (2004) and Alves *et al.* (2007) who did not find any evidence of a link between the two variables at business cycle frequencies, using quarterly data only from 1980 onwards for the euro area as a whole. However, it is interesting to note that there was a noteworthy link between money growth and inflation in the euro area at business cycle frequencies during the 1970's and at the beginning of the 1980's which disappeared thereafter. Naturally, Neumann and Greiber (2004) and Alves *et al.* (2007) could hardly detect this feature due to the sample period considered but for Jaeger (2003), who uses euro area annual data for the period 1961-1998, this fact was undetected due to the above mentioned limitation of the method used. A tentative explanation for such time-varying behaviour in the euro area can be related to the fact that during the 1970's and early 1980's the euro area experienced a high inflation whereas since the mid-1980's has remained in a regime of low inflation. In fact, it has been argued that the relationship between money growth and inflation can be weaker in a low inflation environment (see, for example, Estrella and Mishkin (1997) and De Grauwe and Polan (2005)).

Concerning long-term movements, there is a more robust link between money growth and inflation in the euro area over the whole period considered. This is in line with the widespread evidence that there is a long-run link between money growth and inflation which dates back to the pioneering work of Lucas (1980) for the United States. More recently, several authors have presented empirical evidence of such relationship for other countries, including the euro area (see, for example, Jaeger (2003) and Benati (2009)). From figure 4, one can see that, for very low frequencies, the wavelet squared coherency obtained is close to 0.9. This figure is similar to the findings of Jaeger (2003), who using pre-EMU data since 1961 obtained a coherence around 0.9 at low frequencies. Haug and Dewald (2004) also obtained a coherence of around 0.9 for several European countries while Benati (2009) reports an even higher value for the euro area in the last four decades. Besides the evidence of a strong link between money growth and inflation in the euro area at low frequencies, another finding relates to the fact that it has been relatively stable throughout the whole sample period. This evidence supports the claim by Benati (2009) that coherence has exhibited little time variation at very low frequencies. Nevertheless, one should note that the link between money growth and inflation in the euro area at low frequencies has been slightly stronger during the 1990's while weakening a bit in the more recent period. This may explain why Alves *et al.* (2007) found evidence in favour of such link at low frequencies using data up to the beginning of 2000's which disappears when more recent data is included.

Figure 5 presents the wavelet phase difference between the two series in the time-frequency space. To ease the reading of the figure, the phase difference is presented in time units (years) and only for the positive part of the z-axis (corresponding to a lead time of money growth *vis-à-vis* inflation), as this is the focus of the ECB. One can see that, at the typical business cycle frequency range and for the sample period where the link is stronger (*i.e.,* during the 1970's and up to the beginning of the 1980's), money growth is leading inflation by a lead time up to around two years. For longer-term developments, money growth also presents leading properties throughout the whole sample. In this respect, Haug and Dewald (2004) and Bruggeman *et al.* (2005) found that money growth leads inflation by 1 to 3 years and around 1.5 years, respectively. However, one should note that since the end of the 1990's such property seems to be weakening. This is in line with the finding of the recent deterioration of money growth as leading indicator of inflation in the euro area.

In sum, it is found that money growth has lost information content for tracking medium term movements in inflation while for longer-term developments, the relationship does not seem to be as strong as it was when the euro area was launched. Moreover, the leading properties of money growth *vis-à-vis* inflation seem to have deteriorated in the more recent period. The role played by money growth as an indicator of inflation developments in the euro area should therefore be interpreted with caution. These results highlight the importance of a regular assessment of the role of money growth in tracking inflation developments in the euro area since such relationship varies across frequencies and over time. Furthermore, this should also be taken into account when modelling the link between money growth and inflation.

4 Conclusions

This paper assesses the link between money growth and inflation through wavelet analysis. Wavelet analysis is a very promising tool as it represents a refinement in terms of analysis in the sense that both time and frequency domains are taken into account. The motivation for using wavelet analysis to assess such link comes naturally as there is evidence in the literature that such relationship varies across frequencies and over time. In particular, the focus is on the euro area as the ECB attributes a privileged role to money growth within the two-pillar monetary policy framework. Against this background, a time-frequency view of the relationship between money growth and inflation in the euro area over the last forty years is provided.

The findings indicate that the link between monetary growth and inflation in the euro area presents both frequency and time-varying features. On one hand, the relationship between inflation and money growth has been stronger at long-term developments than at frequencies associated with business cycle fluctuations. On the other hand, this link is more robust at low frequencies over the whole sample period whereas there is supporting evidence at the business cycle frequency range only up to the beginning of the 1980's. In terms of the lead-lag relationship, in time-frequency areas where the link is stronger, money growth has shown leading properties. However, there seems to be a deterioration of money growth as leading indicator of inflation in the more recent period. These results highlight the importance of a regular monitoring of the usefulness of money growth for tracking medium to long-term developments in euro area inflation since such relationship is frequency and time-varying.

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Figure 1 - M3 growth and inflation in the euro area

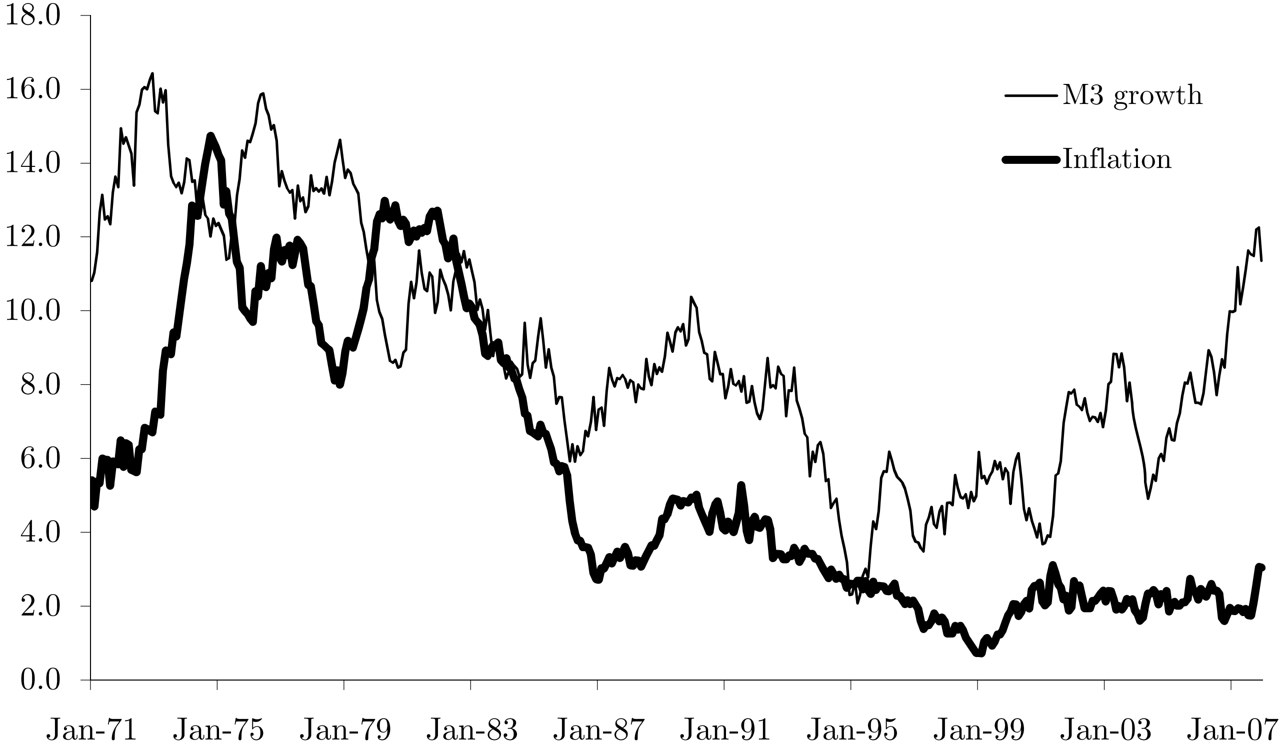
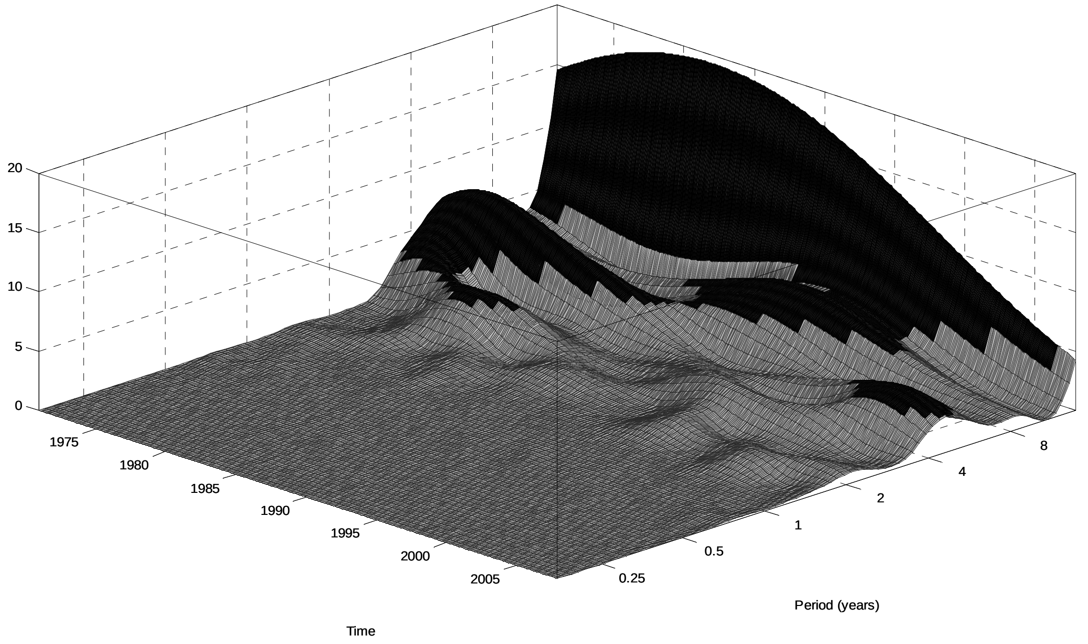
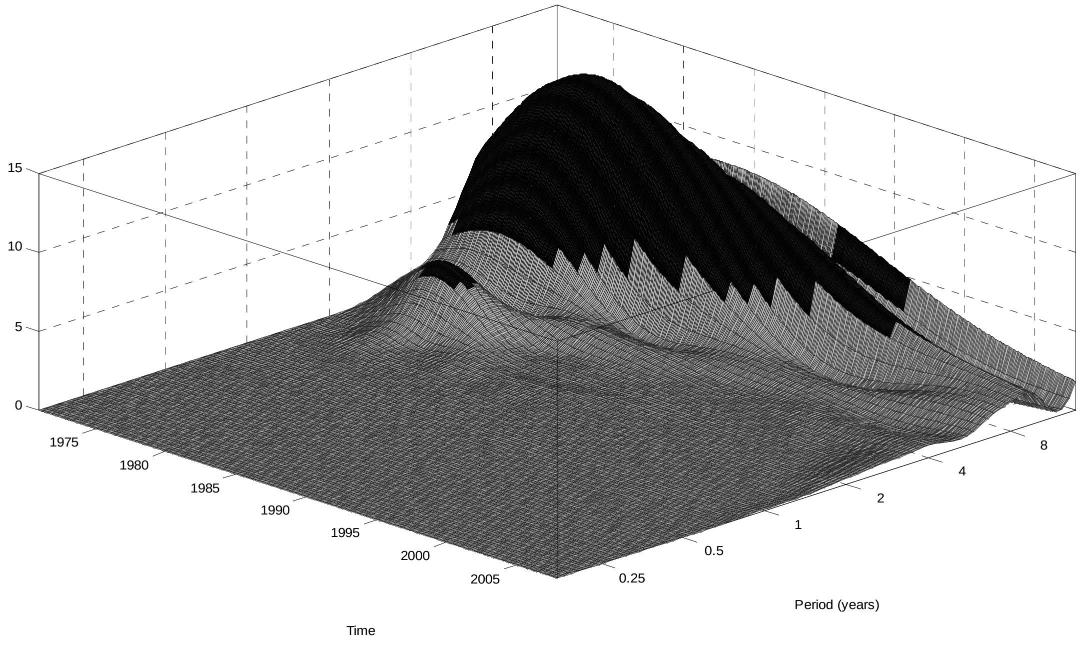


Figure 2 - Wavelet spectrum of M3 growth



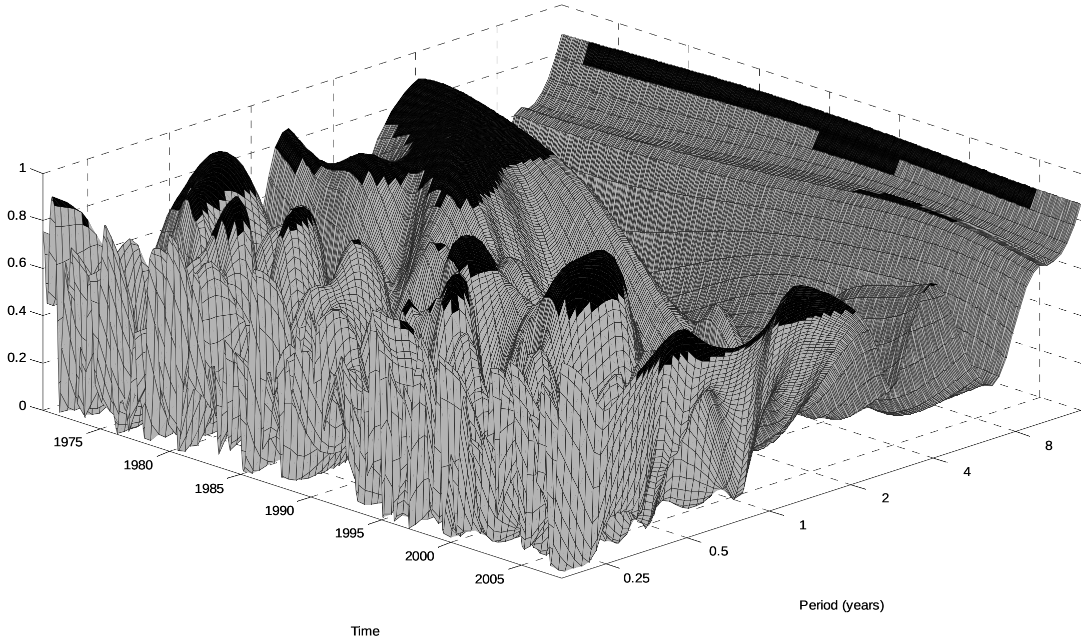
Note: The black part of the surface denotes the statistical significant area at the usual significance level of five per cent.

Figure 3 - Wavelet spectrum of inflation



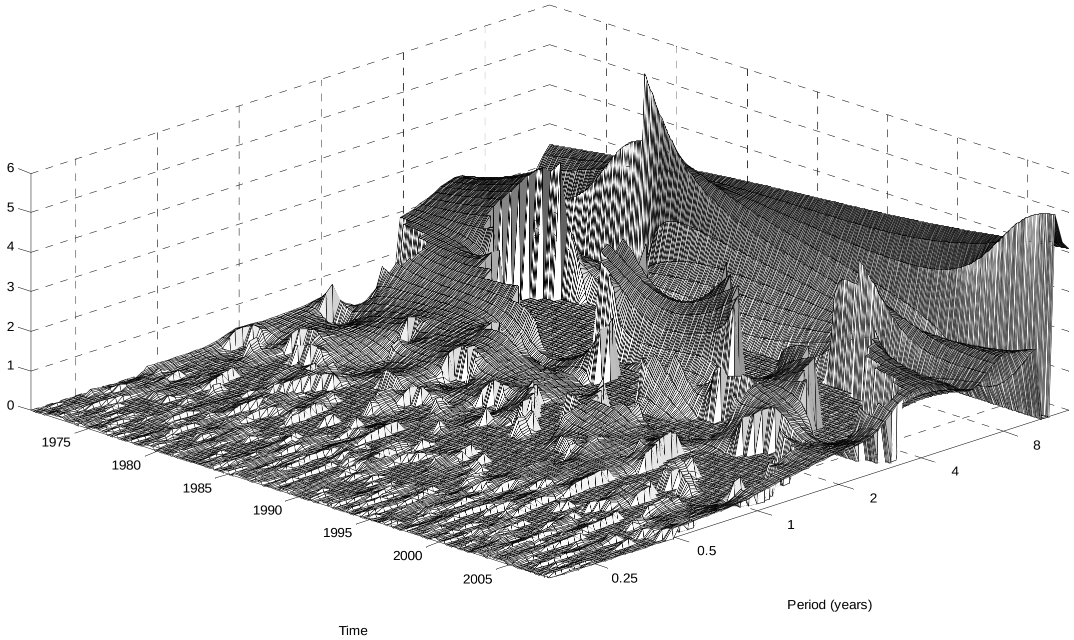
Note: The black part of the surface denotes the statistical significant area at the usual significance level of five per cent.

Figure 4 - Wavelet squared coherency



Note: The black part of the surface denotes the statistical significant area at the usual significance level of five per cent.

Figure 5 - Wavelet phase



Note: The phase difference between the series is presented in time units (years) and only the positive part of the z-axis is displayed (corresponding to a lead time of money growth vis-à-vis inflation).

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