A Spectral Representation of the Phillips Curve in Australia

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Abstract

We document evolving patterns in the inflation-unemployment relationship in Australia in the frequency domain under different monetary policy regimes and labor market regulations. The RBA adopted monetary targeting in 1976 and inflation targeting in 1993. There were important changes in the labor relations during mid-1980s-mid-1990s. We document an upward sloping medium-run Phillips curve in the pre-1977 period, a downward sloping long-run Phillips curve during 1977-1993, and a flattened Phillips curve from 1993 onwards. Inflation lags unemployment during the first period but leads during the second period. The Phillips curve at business-cycle frequencies is downward sloping in all periods. Similar patterns are also observed in several industrialized countries that adopted inflation targeting.

Keywords: Phillips curve, Long-run, Business-cycle, Frequency, Spectral method

JEL Classification Codes: E24, E31, E32, C49

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I. Introduction

In this paper, we document how the inflation-unemployment relationship in Australia has changed over time at different frequencies. More specifically, we document the long-run and business-cycle Phillips curves[1] for Australia for distinct periods using the spectral method. The Reserve Bank of Australia (RBA) adopted aggregate monetary targeting in 1976 and inflation targeting in 1993. There was a real wage shock in 1974 caused by the labor union that coincided with the first oil shock. There were also agreements between the Australian Labour Party and Australian Council of Trade Unions during the mid-1980s-mid-1990s on nominal wage setting to control inflation. These events may have contributed differently to the inflation-unemployment relationship at different points in time and also across frequencies. Australian experience is also interesting because it is a resourced-based small open economy highly integrated to the world economy but did not suffer from the recent global financial crises. In recent times, its international integration has shifted from the developed western economies to China.

The idea of Friedman (1968) and Phelps (1967) that a permanent change in inflation does not lead to a permanent change in unemployment, commonly known as the vertical long-run Phillips curve, has been accepted as one of the pillars of modern macroeconomics. However, recent empirical evidence suggests a non-vertical long-run Phillips curve and its changing slope over time depending on sample period considered. For example, in the case of the USA for which the inflation-unemployment relationship has been most extensively studied, King and Watson (1994; 1997) documented a strong negative correlation at low frequencies during 1954-1969, and no consistent relation during 1970-87, but an overall positive correlation during 1954-

[1] The business-cycle Phillips curve is also referred to the short-run Phillips curve. In this article, the business-cycle Phillips curve is defined at business cycle frequencies; the short-run Phillips curve is the one at very high frequencies that we do not analyze.

92. Berentsen, Menzio and Wright (2011), using data for longer periods during 1955-2005, also document a strong positive correlation at low frequencies.[2] In contrast, several recent commentators have documented a flattened downward sloping long-run Phillips curve as a results of anchored inflation expectations from 2000 onwards (Fuhrer, 2011; Benigno and Ricci, 2011). Akerlof et al. (2000) earlier predicted that low inflation may cause unemployment to persist at high levels, thus flattening the long-run Phillips curve. On the other hand, the business-cycle Phillips curve remains downward sloping although the degree of inflation-unemployment trade-off has changed over time. Kuttner and Robinson (2008) also observes a flattened long-run Phillips curve at low inflation in Australia.[3] Notwithstanding several studies documenting the Phillips curve in Australia for different periods, it is not well-understood whether and how the long-run and business-cycle Phillips curves have evolved over time. This paper is intended to fill this gap.

This paper departs from the extant literature in several ways. First, to the best of our knowledge, this is the first paper that documents both the long-run and business-cycle Phillips curve for Australia in a unified framework using the most recent data. It is important to mention that most studies in the context of Australia infer the long-run Phillips curve from the estimation of (time varying) the equilibrium unemployment rate (non-accelerating inflation rate of unemployment (NAIRU)) rather than directly estimating it. Second, the spectral method that we employ in this paper investigates the inflation-unemployment relationship without relying on any identifying restrictions on the relationship. In contrast, in the time domain, the long-run relationship depends on the short-run identifying restrictions.[4] Third, the spectral method is able

[2] Friedman (1977, p. 464) in his Nobel lecture also conjectured such an emerging positive relationship although he considered it as a transitional phenomenon that could last for somewhat longer periods but would eventually disappear as economic agents adjust not only their expectations but also their institutional and political arrangements to a new reality.

[3] Lundborg and Sacklén (2006) and Svensson (forthcoming) have also observed similar patterns in the case of Sweden.

[4] For example, King and Watson (1994; 1997) find that in the structural VAR under traditional Keynesian identification, there is a Phillips curve with a large long-run slope in both pre- and post-1970 data. If the identifying

to separate the relationship at each frequency, while in the time domain the estimated coefficient can be thought of an average over a particular frequency band. For example, regressions using the band- or low-pass filtered series estimate the coefficient averaged over a particular frequency band, such as 6 to 32 quarters (or 32 quarters and above). Cointegration method, in contrast, estimates the long-run relationship at zero frequency. Finally, the spectral method also allows to investigate the lead or lag in the relationship within the same framework.

We first identify the periods over which patterns in the long-run relationship between CPI inflation and unemployment have changed.[5] Rather than identifying break(s) in the individual inflation or unemployment series, we identify break(s) in their relationship. The evolving patterns in the relationship can be visualized by displaying the data transformed by low-pass filter in which filter weights are derived based on Baxter-King (1999) band-pass filter. We find the first break during 1974-76 and a second sharp break in 1993. The timings of these breaks coincide with the adoption of aggregate monetary targeting in 1976 (abandoned in 1985) and inflation targeting in 1993 by the RBA, respectively. Therefore, the three distinct periods based on monetary policy regimes are: i) pre-1977, ii) 1977-1993, and iii) post-1993. However, the real wage shock in 1974 (due to union pressure) may also have contributed to the first break. In the pre-1977 period, the long-run Phillips curve is upward sloping; however, this positive relationship weakens considerably and a (near) vertical long-run Phillips curve emerges if the sample period is shortened to pre-1974. In the 1977-1993 period, a clear long-run trade-off (downward sloping long-run Phillips curve) emerges, and finally the long-run Phillips curve flattens becoming near horizontal in the post-1993 period. These evolving patterns warrant a separate analysis of the Phillips curve for each of these distinct periods. In contrast, the business-

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assumption is the real business cycle one, that is, there is little short run effect of inflation on unemployment, then there is also little effect at any horizon. Under the rational expectation monetarist identification, there is little a Phillips curve with a small long-run slope. Weber (1994) and Koustas and Serletis (2003) also used similar identification in the context of the European and G7 countries, respectively.

[5] The original Phillips (1958) curve stated the relationship between nominal wage change and unemployment. However, it has now been standard to express the Phillips curve in terms of CPI inflation and unemployment.

cycle Philips curve, drawn using the band-pass filtered data, is always downward sloping although the magnitude of the slope differs across periods.

After distinguishing these distinct periods, we proceed to analyzing the relationship in the frequency domain for each period. Our analysis is based on the gain, squared coherence and phase spectrum. The gain is analogous to the absolute value of the regression coefficient of unemployment on inflation in the time domain. Given that the gain is positive by definition, we complement it by the slope of the linear fit in the time domain after transforming the series by appropriate filter. The squared coherence is analogous to the *R*-square in a two-variable regression; in this case it is the *R*-square in the regression of unemployment on inflation (and also vice versa). The phase measures the lead or lag in the relationship. For example, if the phase of unemployment with inflation is negative, then it is inferred that inflation is a lagging variable; in other words, the causality runs from unemployment to inflation. The long-run frequency range is chosen as (0-0.196) and the business-cycle frequency range as (0.196-1.048), which are based on quarterly data and assuming business-cycle periodicities of 6-32 quarters.

Absent any permanent changes in inflation, the data will be uninformative about the long-run Phillips curve. Sargent (1971) and Lucas (1972) criticized testing such a curve using reduced form econometric methods based on the premise that if inflation is not an integrated process, there is no permanent change in the level of inflation following a shock, and the long-run relationship is not identified. On the other hand, application of the spectral method requires stationary series. To address this dilemma, we estimate the Phillips curve in its deviation form because unemployment and inflation gaps are considered to be stationary. The former is the deviation of actual unemployment from the time-varying NAIRU, and the latter is the deviation of actual inflation from its time-varying expected level. This is a reduced form expectations-augmented Phillips curve that examines how inflation deviates from its expected level at different frequencies when unemployment gap deviates from zero. The NAIRU and expected inflation, both of which are unobservable, are estimated employing the Unobserved Component Model.

The results show that in the pre-1977 period the gain is significant at the high frequency components in the long-run (32-56 quarter range—medium-run frequencies), while in the 1977-1993 period the gain is significant at all long-run frequencies (32 quarters and above). In the first period, the fit estimated in the time domain using the low-pass filtered series is upward sloping, while the same is downward sloping in the second period. We conclude a medium-run positively sloped Phillips curve in the pre-1977 period and a long-run negatively sloped Phillips curve in the 1977-1993 period. We suggest that important changes in the labor market relations rather than monetary targeting in 1976 was responsible for the downward sloping long-run Phillips curve. However, if the first period is shortened to pre-1974, the gain is significant at even higher frequency components in the long-run (32-42 quarters range) suggesting a weaker relationship than the pre-1977 period. For the post-1993 period, the gain is insignificant in the low frequency range. However, the difference from the pre-1974 period is that the time domain fit is now near horizontal (flat) rather than near vertical. The squared coherence also exhibits similar patterns as the gain. The phase indicates that inflation lags unemployment in the pre-1977 period but leads in the 1977-1993 period.[6] On the other hand, the business-cycle Phillips curve is downward sloping in all periods but the trade-off is relatively weak in the 1977-1993 period (the gain is significant at some but not all frequencies). However, the gain fluctuates enormously across frequencies in all periods. We finally document that the patterns of the inflation-unemployment relationship observed in Australia is not unique but resemble several other countries that adopted inflation targeting, such as Canada, Sweden, New Zealand and the UK.

The rest of the paper proceeds as follows. Section 2 briefly reviews the literature on the Phillips curve in Australia. Section 3 provides a brief history of Australian monetary policy that is useful to distinguish the sample periods in several distinct episodes. The long-run and business-cycle relationship in the time domain using filtered data is presented in Section 4. Section 5 discusses the Phillips curve model that we estimate in the frequency domain. The frequency domain estimation method, that include gain, squared coherence and phase spectrum

[6] Irving Fisher (1926; reprinted in 1973) first defined the inflation unemployment relationship in which the causality goes from inflation to unemployment.

are explained in Section 6. Section 7 presents the results graphically. Reasons for the evolving patterns in the long-run relationship is also discussed in this section. Inflation-unemployment relationship in several other countries are documented in Section 8. Finally, Section 9 concludes.

2. A brief review of the Phillips curve in Australia

In this section, we provide a brief summary of the studies on Phillips curve in Australia; a detail account can be found in Gruen Pagan and Thompson (1999) and Borland and McDonald (2000, Table 2, p. 20).

Although the study of Phillips curve in Australia dates back to Phillips (1959), Parkin (1973) is probably the first to estimate both the short- and long-run, and an expectations-augmented Phillips curve for Australia. Using the data for the 1960s and early 1970s, Parkin rejected a long-run trade-off between inflation and unemployment, a result that is fairly consistent with the other developed countries for similar time period. Parkin also pointed out a weak short-run trade-off. Although several studies also investigated the Phillips curve, there is scant research that focus on both the short- and long-run. Gruen, Pagan and Thompson (1999) correctly point out that the central issues for estimating Australian Phillips curves are addressing the distinction between the short- and long-run trade-off, which has been largely ignored.

Several authors have investigated the short-run Phillips curve but research on the long-run Phillips curve have proceeded mainly as a part of testing the NAIRU. Among the recent studies, Lim, Dixon and Tsiaplias (2009) estimate a Phillips Curve over the business cycle frequencies for the period 1960:Q1–2008:Q4 allowing for time varying unemployment rate, and document an inflation–unemployment tradeoff. They also document that the NAIRU changes over time; it had been roughly constant at around 2% till early 1970s; then began to drift upwards that continued till the mid-1990s and has been trending downwards since then, reaching a value of approximately 5% in 2008. Time varying NAIRU has also been estimated by Crosby and Olekalns (1998), Debelle and Vickery (1998), Gruen, Pagan and Thompson (1999) and Kennedy, Luu and Goldbloom (2008).

Kuttner and Robinson (2008) discuss the implications of flattened Phillips curve observed recently in Australia that a positive output gap would be less inflationary but with a larger cost of reducing inflation. The authors review the evidence and possible explanations for this flattening in the context of new-Keynesian economic theory. They consider a variety of reasons, such as data problems, globalization and alternative definitions of marginal cost, none of which they consider as entirely satisfactory.

3. Monetary policy regimes in Australia

In this section, we discuss milestones in the history of Australian monetary policy and then relate the long-run inflation-unemployment relationship with them. The turning points in monetary policy regimes are the adoption of aggregate monetary targeting in 1976 and inflation targeting in 1993 by the RBA.[7] However, the first policy change also coincides with the oil shock and real wage shock during 1973-74.

Since the Bretton-Wood, Australian currency was fixed with US dollar, which did not allow exercise of an effective independent monetary policy. It is not possible to pinpoint an exact date at which the fixed exchange rate was effectively abandoned. Parity adjustments with US dollar became frequent after the realignment of Australian dollar in 1971. There were six parity changes from 1971 to the adoption of the crawling peg system in November 1976, and the dollar was freely floated in December 1983. The expansionary monetary policy in the USA became increasingly a source of inflationary pressure in Australia. The effect was amplified in the early 1970s by rising commodity prices because of Australia's high exposure to commodity exports. Monetary policy had to loosen with the result that increase in inflation in Australia overtook that in the USA. The role of the 1973 oil shock was also important, but inflation in Australia had already reached double-digit rates before the shock. The real wages shock of 1974 pushed by labor union was no less important than the oil shock. It is important to mention that after the parity with US dollar broken, there was effectively no clear enunciated guiding principle behind

[7] The following discussions are drawn from the speeches of the then RBA governor, Mr. I. J. Macfarlane, in 1997 and 1998.

Australian monetary policy until the introduction of monetary targeting in 1976. The monetary targeting was based on around an annual target for M3. The era lasted for nine years (from April 1976 to January 1985). A period of discretion continued until the adoption of inflation targeting in 1993 (Macfarlane, 1997; 1998).

Based on the above discussions, the following three episodes can be distinguished over which inflationary behavior is expected to be different: i) pre-1977, ii) 1977-1993, and iii) post-1993. Additionally, we estimate for the pre-1974 period as an alternative to the first episode.

Insert Figures 1-3 here

4. Inflation-unemployed relationship in the time domain using filtered data

We document the long-run and business-cycle inflation-unemployment relationship in the time domain using filtered data that provides great insights about the relationship and complements our analysis in the frequency domain.

The raw inflation and employment series are plotted against time in Figure-1A.[8] Both series are non-stationary and follow random walk (statistical tests also support but not reported). The long-run or low frequency values (estimated by low-pass filtering) of inflation and employment are plotted in Figure-1B. Figure-1C displays the relationship between inflation and unemployment, and Figure-1D displays the same relationship at low frequencies. The last figure clearly indicates three distinct episodes: i) 1959-mid-1970s ii) mid-1970s-1993, and iii) 1994-2012, that are consistent with policy changes and shocks discussed earlier. During the 1959-1974

[8] Unemployment and inflation data are obtained from the Australian Bureau of Statistics (ABS). The unemployment series ID is A2454521V. CPI inflation series ID is A2325850V; however, this series reports only the first digit after decimal. So we construct the CPI inflation from the original CPI series (ID: A2325846C) as $[(CPI_t - CPI_{t-4})/CPI_{t-4}]*100$; both series are the same except the number of digits after decimal. The implicit GDP deflator inflation series is obtained from St. Louis Fed (http://research.stlouisfed.org/fred2/series/AUSGDPDEFQISMEI; accessed on October 31, 2014). The series ID is seasonally adjusted (Series ID: AUSGDPDEFQISMEI). This is quarterly inflation, so the series is multiplied by 4.

period, the long-run value of inflation gradually increased from less than 2% to more than 12% with unemployment ranging around 1.7% to 3.7%. This indicates a (near) vertical long-run Phillips curve and thus almost no long-run inflation-unemployment trade-off (also shown by the linear fit). If the first period is extended to 1976, the fit becomes slightly flatter. Inflation slowly and gradually declined and unemployment increased secularly since 1974 that continued till 1993 with unemployment rate being close to 10%. During this period, there is a clear negative relationship indicating a downward sloping long-run Phillips curve. Since 1993, unemployment secularly decreased but inflation remained low suggesting flattening of the long-run Phillips curve. Figures 2A-D display the band-pass filtered series for the above three distinct sub-periods and also for the full sample period. These figures clearly indicate an inflation-unemployment trade-off (negatively sloped Phillips curve) at the business-cycle frequencies in all periods. It is also evident that the slope is much steeper in the 1994-2012 period (Figure-2C) than the previous two periods suggesting stronger response to inflation for a given change in unemployment, although inflation is almost non-responsive to unemployment at low frequencies in the same period.

A small open economy relies more on international trade than a close economy. Therefore, it is argued that change in the implicit GDP deflator captures economic activity better than the CPI inflation. However, imports of goods and services as a percentage of GDP in Australia is close to that in the USA and much smaller than that in similar small open economics. For example, the share of imports of goods and services in Australia was 21% of GDP in 2012 as opposed to 32% in Canada, 34% in the UK, 43% in Sweden and 29% in New Zealand; the comparable figure in the USA is 17% (World Bank, 2014). Nonetheless, we replicate the above exercise using the percentage change in the implicit GDP deflator instead of the CPI inflation. These are displayed in Figures 3A-F. Figure-3A shows that both the CPI and GDP deflator inflation move very closely although the latter is more volatile. The long-run inflation-unemployment relationship using the low-pass filtered series is presented in Figure-3B. This figure is almost indistinguishable from Figure-1D that exhibits the same relationship using the CPI inflation. The business-cycle relationship for different sub-periods are plotted in Figures-3C-

F. In all cases, there is a negative relationship as in Figures-2A-D although the slopes differ in magnitude for the two inflation measures. Given the similarities in the results, we use the CPI inflation for further analysis in the frequency domain.

5. The Phillips curve model

In the following, we discuss the Phillips curve model that we estimate in the frequency domain. We also compare this specification to alternatives employed in the literature. The expectations-augmented reduced form model is written as:

$$\pi_t = \pi_t^e - \delta\left(u_t - u_t^N\right) + e_t \,. \qquad \text{---(1)}$$

Here, π_t is the (CPI) inflation rate, π_t^e is the inflation expected at time *t*, u_t is the unemployment rate and u_t^N is the natural rate of unemployment (time-varying NAIRU). When unemployment is below (above) its natural rate, inflation will be higher (lower) than expected. This specification is closely related to both the New Classical (NCPC) and New Keynesian Phillips curve (NKPC). For example, it become the reduced-form NCPC if $\pi_t^e = E_{t-1}\left\{\pi_t\right\}$ with its coefficient (time discount factor) being one. On the other hand, it becomes the reduced-form NKPC if $\pi_t^e = E_t\left\{\pi_{t+1}\right\}$ with its coefficient being one. However, from the empirical point of view (2SLS estimation that accounts for endogeneity of expected future inflation using lagged variables as instruments), the NKPC is also a restricted version of the NCPC (Rudd and Whelan, 2005; 2007; Gordon, 2011). Equation (1) is expressed in deviation form as:

$$\hat{\pi}_t = -\delta\hat{u}_t + e_t \,. \qquad \text{---(2)}$$

The main challenge is to extract unobservable π_t^e and u_t^N. We extract them employing the univariate Unobserved Component Model (UCM) by modelling both expected (trend) inflation and NAIRU as driftless random walk process. For a series z_t (inflation or unemployment), the UCM is defined as:

$$z_t = \mu_t^z + \varepsilon_t^z \text{ , for } z = \pi \text{ and } u$$

$$\varepsilon_t^z \sim NID\left(0, \sigma_{\varepsilon^z}^2\right),$$

where μ_t^z is the trend component and is modeled as

$$\mu_t^z = \mu_{t-1}^z + \eta_t^z \text{, with } \eta_t^z \sim NID\left(0, \sigma_{\eta^z}^2\right).$$

The disturbances, ε_t^z and η_t^z are serially and mutually uncorrelated, and normally and independently distributed (*NID*) with mean zero and variance $\sigma_{\varepsilon^z}^2$ and $\sigma_{\eta^z}^2$, respectively. Chan, Koop and Potter (2014) also model both the trend inflation and NAIRU for Australia as driftless random walk process in a bivariate UCM.[9] Debelle and Vickery (1998) used a Phillips curve framework to estimate the NAIRU as a unit-root process using the Kalman filter. Both the inflation and output gaps, $\hat{z}_t = \left(z_t - \mu_t^z\right)$, for $z = \pi$ and u, are stationary processes, and thus equation (2) can be estimated in the frequency domain. Our specification examines how inflation deviates from its expected (trend) level at different frequencies when unemployment deviates from its natural rate.[10] Sevensson (forthcoming, equation (7)) also estimates a variant of equation (2) by adding lagged unemployment to recover the long-run coefficient. The 'triangle' model of Gordon (2011, equation (13)) adds in equation (2) deeper lags of inflation and unemployment

9 Cogley, Primiceri and Thomas (2010) and Harvey (2011) also model trend inflation as a driftless random walk for the USA. On the other hand, King and Morley (2007) estimate NAIRU in a SVAR model.

10 Zhu (2005) transform the data using the Hodrick-Prescott and Baxter-King filters to estimate Phillips curve in the frequency domain for the USA. Pakko (2000) examines the price-output relationship for the USA in the frequency domain across different sample periods.

gaps. Spectral method that we employ estimates parameter at each frequency including the long-run without specifying any lag structure.[11]

6. Estimation method in the frequency domain

In this section, we discuss estimation of the gain, squared coherence and phase spectrum that we use to analyze inflation-unemployment relationship.

The spectrum of a covariance-stationary series, x_t, at frequency ω is given by:

$\hat{g}_x(\omega) = \frac{1}{2\pi} \sum_{j=-(T-1)}^{T-1} \hat{\gamma}_x^j e^{-i\omega j} = \frac{1}{2\pi}\left[\hat{\gamma}_x^0 + 2\sum_{j=1}^{T-1} \hat{\gamma}_x^j \cos(\omega j)\right]$, where $\hat{\gamma}^j$ is the *j*-th order sample autocovariance given by $\hat{\gamma}_x^j = \frac{1}{T}\sum_{t=j+1}^{T}(x_t - \bar{x})(x_{t-j} - \bar{x})$, for *j* = 0, 1,2, -------, (*T*-1). Here, $\bar{x}$ is the sample mean given by $\bar{x} = \frac{1}{T}\sum_{t=1}^{T} x_t$. By symmetry, $\hat{\gamma}_x^j = \hat{\gamma}_x^{-j}$. The spectrum of y_t is defined similarly.

The cross-spectrum between y_t and x_t at frequency ω is given by:

$$\hat{g}_{yx}(\omega) = \frac{1}{2\pi}\sum_{j=-(T-1)}^{T-1} \hat{\gamma}_{yx}^j e^{-i\omega j} = \frac{1}{2\pi}\left\{\left[\hat{\gamma}_{yx}^0 + \sum_{j=1}^{T-1}\left(\hat{\gamma}_{yx}^j + \hat{\gamma}_{yx}^{-j}\right)\cos(\omega j)\right] - i\left[\sum_{j=1}^{T-1}\left(\hat{\gamma}_{yx}^j - \hat{\gamma}_{yx}^{-j}\right)\sin(\omega j)\right]\right\},$$

where the cross-covariogram between y_t and x_t is given by $\hat{\gamma}_{yx}^j = \frac{1}{T}\sum_{t=j+1}^{T}(y_t - \bar{y})(x_{t-j} - \bar{x})$. Note that the cross-covariogram is not symmetric so that $\hat{\gamma}_{yx}^j \neq \hat{\gamma}_{yx}^{-j}$, but satisfies $\hat{\gamma}_{yx}^j = \hat{\gamma}_{xy}^{-j}$. The cross-spectrum has a real and an imaginary part. The real part is called co-spectrum and the imaginary

[11] McCallum (1984) criticizes the tests for the long-run Phillips curve by frequency domain method (specifically band-pass regression or regression by filtered series) as being uninformative due to the problem of observational equivalence. The low frequency measures are not designed to reflect the distinction between anticipated and unanticipated fluctuations of inflation that is crucial for accurately characterizing inflation-unemployment relationship in a dynamic model. Our specification is immune to this critique.

part is called quadrature spectrum. We denote these two by $\hat{c}(\omega) = \hat{\gamma}_{yx}^{0} + \sum_{j=1}^{T-1}\left(\hat{\gamma}_{yx}^{j} + \hat{\gamma}_{yx}^{-j}\right)\cos(\omega j)$ and $\hat{q}(\omega) = \sum_{j=1}^{T-1}\left(\hat{\gamma}_{yx}^{j} - \hat{\gamma}_{yx}^{-j}\right)\sin(\omega j)$, respectively. The gain is defined as $\hat{G}(\omega) = \left[\hat{c}^2(\omega) + \hat{q}^2(\omega)\right]^{1/2} / \hat{g}_x(\omega)$. Therefore, the gain is positive by definition. The coherence is defined as $\hat{C}(\omega) = \left\{\left[\hat{c}^2(\omega) + \hat{q}^2(\omega)\right] / \hat{g}_x(\omega) * \hat{g}_y(\omega)\right\}^{1/2}$. It is analogous to the correlation between y_t and x_t, and is interpreted in a similar way. The greater the coherence the more closely related the two series are. The "coherence inequality" $\hat{c}^2(\omega) + \hat{q}^2(\omega) \leq \hat{g}_x(\omega) * \hat{g}_y(\omega)$ ensures that $0 \leq \hat{C}(\omega) \leq 1$. The squared coherence, $\hat{C}(\omega)^2$, is analogous to the *R*-square in a regression of two variables. The phase of y_t with x_t is defined as $\hat{\psi}(\omega) = \tan^{-1}\left(-\hat{q}(\omega) / \hat{c}(\omega)\right)$. It measures the lead or lag in the relationship between y_t and x_t at frequency ω (Hause, 1971).[12]

To estimate a 95% confidence interval of the coherence (both $C(\omega)$ and $\hat{C}(\omega)^2$), we need its variance. However, the variance of $\hat{C}(\omega)$ depends on the population coherence $C(\omega)$ in the same way as that of a correlation coefficient depends on the theoretical correlation. The hyperbolic arctan (*arctanh*) transformation makes the variance approximately constant, i.e., $\text{var}\left\{\text{arctanh}\hat{C}(\omega)\right\} \cong g^2/2$, where *g* is a composite function depending on the weights used to smooth the periodogram (sample counterpart of the spectrum) (for example, a symmetric moving average with the sum of the weights equal to one) and a correction factor if data were tapered (or windowed) before the periodogram was calculated (for detail, see Bloomfield, 1976, p. 224). In our case, no such weight or tapering is relevant but since we use Bartlett window, *g* involves a correction term (2*M*/3*T*) where *M* is the number of ordinates and *T* is the sample size (see, Priestley, 1981, p. 463). A 95% confidence interval for $C(\omega)$ is then given by $\tanh z_1 \leq C(\omega) \leq \tanh z_2$, where z_1 and z_2 are

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[12] The phase of y_t with x_t is the same in magnitude as that of x_t with y_t but with the opposite sign.

$\text{arctanh}\hat{C}(\omega) \pm \left(1.96g/\sqrt{2}\right) = (1/2)\ln\left\{\left(1+\hat{C}(\omega)\right)/\left(1-\hat{C}(\omega)\right)\right\} \pm \left(1.96g/\sqrt{2}\right)$. The 95% confidence interval of the phase is given by $\hat{\psi}(\omega) \pm 1.96g\left[(1/2)\left\{1/\left(\hat{C}(w)\right)^2\right\}-1\right]^{1/2}$ (Bloomfield, 1976, p. 224-25). The 95% confidence interval of the gain is given by: $\hat{G}(\omega) \pm \hat{G}(\omega)\left\{\left[\hat{\sigma}^2/\left(1+2\hat{\sigma}^2\right)\right]2F_{2,2n-2}\right\}^{1/2}$, where $\hat{\sigma}^2 = \left(1/\hat{C}(\omega)^2 - 1\right)/\left(4T/M\right)$ and F is the F-statistics (Walden, 1986, equations 3.15, 4.4 and 4.3).

The frequency is inversely related to periodicity or cycle length according to $p = 2\pi/\omega$. The frequency ranges of the long-run, business cycle and short-run are given, respectively, by $0 \le \omega \le \omega_1$, $\omega_1 \le \omega \le \omega_2$, and $\omega_2 \le \omega \le \pi$. These cut-off frequencies are chosen following the modern business cycle literature in that the long-run corresponds to cycles of 32 quarters or longer, and the business cycle corresponds to cycles of 6 to 32 quarters. Therefore, low frequency is related to long-run with the relevant frequency range being $[0,\ \omega_1 =\ 0.196]$ and the relevant frequency range for business-cycles being $[\omega_1 = 0.196,\ \omega_2 = 1.048]$.

7. Results

In the following, we document the Phillips curve for different periods in terms of the gain, squared coherence and phase spectrum. Since, the gain is positive by definition, it does not inform about the true sign of the relationship; we supplement it by the sign of the linear fit of inflation on unemployment in the time domain transforming the data by appropriate filtering (Figures 1D and 2A-D). If the phase of unemployment with inflation is negative, then it is inferred that inflation is a lagging variable; in other words, the causality runs from unemployment to inflation.

7.1 The long-run Phillips curve

In the sub-section, we analyze the long-run relationship in the $[0,\ \omega_1 =\ 0.196]$ frequency range separately for the distinct sub-periods.

The results for the 1959:3-1976:4 are presented in Figures 4A-D. Panel A displays the gain along with its 95% confidence intervals (CIs). The gain secularly increases from 0.35 to 1.1 along frequency in the relevant range. However, it is statistically significant (lower confidence line lying above zero) only at relatively higher frequencies $[0.113,\ \omega_1]$ in the range (implying a periodicity ranging between 32 and 56 quarters). This coupled with the secular increase of gain along frequencies suggests a Phillips curve at higher frequency component of the long-run (or a medium-run Phillips curve). The relationship is positive as suggested by the time domain fit in Figure-1D. The squared coherence, displayed in Panel B, also secularly increases and is significant in similar frequency range $[0.125,\ \omega_1]$. The phase is positive and significant in the [0, 0.113] frequency range but negative and significant in the $[0.113,\ \omega_1]$ range (Panel C). Since the gain is significant in the later range, we conclude that inflation lags unemployment in the medium run; in other words, the causality runs from unemployment to inflation in the medium run.

It is important to mention that if the alternative period of 1959:3-1973:4 is chosen (Figures-5A-D), the gain is significant at higher frequency range $[0.15,\ \omega_1]$, or equivalently at the 32-42 quarter range. This suggests a Phillips curve at even higher frequency component of the long-run (close to business-cycle frequencies)—this is also supported in Figure-1D. No lead or lag in the relationship between inflation and unemployment exists.

The relationship for the 1977:1-1993:4 period is shown in Figures-6A-D. The gain, displayed in Panel A, secularly increases from 0.32 to 0.58 along frequencies, and is significant at all frequencies over the relevant range. Combining with the fit in Figure-1D, it is suggested a long-run downward sloping Phillips curve in this period. The squared coherence follows a similar secularly increasing pattern except that it is not significant at some very low frequencies. The phase is significant in the $[0.025,\ \omega_1]$ range but now positive implying that inflation leads unemployment. This direction of causality may seem opposite to that suggested by the standard Phillips curve model. Gordon (2013) argues the lead of inflation ahead of unemployment in the mid-1970s to early 1980s because of adverse supply shocks during this period. This argument may also apply to Australia (real wage and two oil shocks) but there are additional factors at work for Australia, such as the role of labor union that we discuss in next section. It is also evident from Figures-5 and 6 that in the pre-1977 and 1977-1993 periods the gain increases along frequencies implying a stronger relationship in the medium- than in the long-run.

In the 1994:1-2012:4 period, gain, squared coherence and phase are insignificant at all frequencies suggesting no long-run Phillips curve (Figures-7A-C). In this period inflation remains persistently low. Therefore, the results is consistent with the arguments by Sargent (1971) and Lucas (1972) that the long-run Phillips curve does not exist in the absence of permanent change in inflation.

Insert Figures 4-7 here

7.2 Explanation of varying slopes of the long-run Phillips curve

In this section, we attempt to explain different slopes of the long-run Phillips curve in different periods. Our explanations are only suggestive because they are not empirically tested here.

In the short-run, the upward sloping aggregate supply curve (alternatively, downward sloping Phillips curve) is derived under the sticky wage assumption. In the long-run when wages (and also expectations) adjust, the short-run supply curve shifts so that output moves back to its natural level (unemployment to its natural rate), and long-run supply curve becomes vertical. This is the explanation of Friedman (1968) and Phelps (1967) of the vertical Phillips curve, which applies to major industrialized countries including Australia during the first period in our sample. However, as Gordon (2013) shows, the Phillips curve can be upward sloping for some time as a result of supply shocks. For Australia this shock is the real wage shock in 1974 caused by labor union (the oil shock in 1973 may not have much impact, mentioned in Section 3). Our results are consistent with the above argument— there is an upward-sloping medium-run Phillips curve in the 1959-1976 period (shortly after realization of the real wage shock that increased unemployment) but there is no long-run Phillips curve for the 1959-1974 period (before realization).[13] This result is also important in the sense that the nature of the important macroeconomic relationship crucially depends on the sample period chosen for analysis.

The sticky wage assumption actually implies that wages are adjusted slowly. However, if the adjustment process becomes slower over time, then the upward sloping aggregate supply curve can also persist over the long-run as well; in other words, the long-run Phillips curve can be downward sloping over some periods in the presence of increasing sluggishness in wage adjustment. Lim, Dixon and Tsiaplias (2009, Figure 2, p. 375) estimate (retrieve) time-varying wage rigidity for Australia.[14] The wage rigidity remained almost unchanged until the mid-1970s and since then gradually increased that continued till 1993. The variations in wage rigidity are the result of changes in labor market regulation and institutions rather than the monetary targeting introduced in 1976.

The increase in real wages relative to productivity following the 1974 wage shocks lasted around 12 years and it took nearly two business cycles before firms and labor corrected their mistaken price expectations (Cockerell and Russell, 1995). The monetary targeting in 1976 was not successful in correcting expectations and controlling inflation. This policy brought some order to Australian monetary policy after several years of unconstrained discretion but only with limited success. Monetary targeting presupposes a stable money demand but money demand in Australia was unstable mainly because of the financial deregulation in the early 1980s (Hoarau, 2006, p. 47-48). Consequently, monetary targeting was abandoned in 1985. In contrast, development in the labor market relations was more important for controlling inflation. There were successive agreements (known as Accords) between the Australian Labour Party (ALP) and Australian Council of Trade Unions (ACTU) during the 1983–1996 period. Chapman (1998)

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[13] Berentsen, Menzio and Wright (2011) provide an alternative argument for upward sloping long-run Phillips curve. They develop a model appropriate for low frequency with micro-foundations in which an increase in inflation (or interest rate) raises the effective tax on cash-intensive goods market which reduces profit and employment. The initial impact of a change in interest rate is to reduce real money balances, which affects revenue and ultimately employment. For Australia, the long-run Phillips curve is upward-sloping only if the sample period includes the aftermath of the 1974 shock, so our results are consistent with the supply shock argument of Gordon (2013).

[14] It is inverse of the β_t plotted in their middle figure.

document that the emphasis until 1993 was on limiting nominal wage increases with the aim of achieving sustained decreases in inflation without increase in unemployment. Pressure on nominal wage increase also slowed down real wage increase (Dyster and Meredith, 2012).

Prior to the Accords, international economic environment and domestic policies also caused slowdown of the economy. Inflation was very high in the late 1960s and early 1970s. However, the "long boom" of the Australian economy was over in the mid-1970s. Slow growth in other developed countries also negatively impacted on Australian economy through declining demand on Australian commodity. In order to rein inflation, the government implemented a series of policies in early and mid-1980s in addition to the Accords mentioned earlier (Dyster and Meredith, 2012; Chapter 11). To achieve fiscal consolidation, the government cut budget deficit. Interest rate, which was already high, was also raised; for example, bank loan rates increased from 11.5% in 1983-84 to as high as 17% in 1988-89. These policies were intended to give the economy a soft landing— sustained decreases in inflation with little or no increase in unemployment. However, the landing was rather hard (Dyster and Meredith, 2012). Therefore, although inflation declined, sluggish growth caused unemployment rate to gradually increase, which is reflected in a downward sloping Phillips curve.

Since 1993, the long-run Phillips curve became flat. The RBA followed a policy of inflation targeting since 1993. This policy changed the inflationary expectations. Inflation has remained low, while unemployment has gradually decreased. Several other industrial countries that adopted inflation targeting have also experienced similar trends (see Section 8 for empirical evidence). Svensson (forthcoming) argues and provides evidence for Sweden that the reason for non-vertical (downward sloping) long-run Phillips curve is that inflation expectations become firmly anchored at the inflation target but average inflation deviates from the target. Paradiso and Rao (2012) argue for a lower inflation target to be reason for flattening Phillips curve in Australia.[15]

[15] Benigno and Ricci (2011) show that a long-run Phillips curve (relating average output gap to average wage inflation) is virtually vertical at high inflation and flattens at low inflation. Macroeconomic volatility shifts the curve outwards and reduces output. The output gap is zero at very high inflation because desired wage and flexible-price-

7.3 The business-cycle (short-run) Phillips curve

The gain, squared coherence and phase at the business-cycle frequencies [0.196-1.048] for the 1959:3-1976:4, 1977:1-1993:4 and 1994:1-2012:4 periods are displayed in Figures 8, 9 and 10, respectively. In all periods, the gain fluctuates considerably. For example, in the 1959:3-1976:4 period, the gain increases from 1.117 to a maximum of 2.931 at frequency of 0.513 (12 quarters) and then slides down to 0.61 at frequency 0.78 (8 quarters) before rising again (Figure-8A). However, it is significant at relative lower frequencies [0.196, 0.78] in the relevant range. In this period, the squared coherence and phase is significant at similar frequency range. The phase is negative and significant in the similar range suggesting inflation as the lagging variable (Figure-8C).

In the 1977:1-1993:4 period, the gain fluctuates between 0.597 and 1.126 but is significant only in the [0.196, 0.575] frequency range. This suggests a weak relationship at the business-cycle frequencies. No definite lead or lag in the inflation-unemployment relationship can be inferred from the phase (Figures-9A-C). In the 1994:1-2012:4 period, the gain is significant at all frequencies and fluctuates between 0.467 and 1.759. Squared coherence follows similar pattern. The sign of the phase changes across frequencies suggesting the causal direction varies across frequencies—it is positive in the [0.196, 0.538] and [0.838, 1.1048] frequency ranges and negative in between (Figure-10A-C).

Combining with the fits in Figures-2A-C, we suggest downward sloping Phillips curve at the business-cycle frequencies but the relationship is weak in the 1977:1-1993:4 period.

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equilibrium wage are almost equal resulting in small costs of downward rigidities. Hence, the Phillips curve is almost vertical at high inflation rates. In contrast, the Phillips curve becomes flatter at low inflation, and depends heavily on the volatility of the economy. The higher the volatility of nominal-spending growth and of the idiosyncratic shocks, the more a fall in the inflation rate worsens the output gap (generating a more negative gap), and flattens the Phillips curve. Daly and Hobijn (2013) also show that, in a model of monetary policy with downward nominal wage rigidities, the slope and curvature of the both the long-run and the short-run Phillips curve depend on the level of inflation and the extent of downward nominal wage rigidities.

Insert Figures 8-10 here

In is important to stress that the variations in the value of the gain (which is the absolute value of the regression coefficient) across frequencies within a particular frequency band (long-run or business-cycle) cannot be captured in the time domain.

8. Some international evidence

In the following, we briefly compare the changing patterns in the long-run Phillips curve in Australia with some other industrialized countries that adopted inflation targeting. These countries are Canada, Sweden, New Zealand, and the UK. The dates for their announcement of inflation targeting are 1991, 1993, 1990 and 1992, respectively (Roger, 2010). Although the US Fed announced a target of 2 percent inflation only in January 2012, a widely held perception is that the Fed had long before (around 2000) an unofficial target for core inflation of about 2 percent (Svensson, forthcoming). Another turning point for the USA can be 1982, the second of the two consecutive (Volker) recessions that might have changed the inflationary expectations even in the absence of any formal announcement on inflation targeting.

Insert Figures 11-15 here

Long-run and business-cycle inflation-unemployment relationship drawn from the low- and band-pass filtered series for these countries are displayed in Figures 11-15. The figures show enormous similarity in the long-run relationship among these countries and Australia. In all countries, long-run Phillips curve is flat since they adopted inflation targeting, and since 1983 in the case of the USA. On the other hand, for the period from mid-1970s to the date of inflation targeting, the long-run Phillips curve is downward sloping. The business-cycle Phillips curve, on the other hand, is always downward sloping for all countries and sub-periods with varying slopes. Recently, some commentators (e.g., Beyer and Farmer, 2007; Russell and Banerjee, 2008; Berentsen, Menzio and Wright, 2011; Haug and King, 2011) have argued for an upward sloping long-run Phillips curve in the USA. It is indeed upward sloping if the entire post-1960 period is considered, but this examination masks the changing patterns in its shape over time.

These findings suggest that there is striking similarities among inflation-targeting countries in their inflation-unemployment relationship— a negative long-run correlation since mid-1970s till inflation targeting and a persistent low inflation since then. It is likely that the same explanation for the flattened long-run Phillips curve— anchored inflation expectations due to inflation targeting—may be at work for all countries. The similarity in terms of the downward sloping long-run Phillips curve in the period ranging from mid-1970s to the announcement of inflation targeting is an interesting topic for further research.

9. Concluding remarks

In this paper, we document the inflation-unemployment relationship for Australia in the frequency domain. Our approach identifies both long-run and business-cycle relationship in a unified framework without relying on identifying restrictions on the relationship.

We first document that the long-run inflation-unemployment relationship can be distinguished in three distinct periods based on the monetary policy regimes in Australia: pre-1977, 1977-1993 and post-1993. Our main empirical analysis relies on the gain, squared coherence and phase spectrum to depict the relationship at each frequency. In the first period, there is a positive relationship between inflation and unemployment at the high frequency component of the long-run; more specifically, this relationship exists in the medium than in the long run. However, in the pre-1974 period the relationship exists at the even higher frequency component of the long-run. In the second period, there is a strong negative long-run relationship. We attribute the increase in wage rigidity as a result of changes in labor market regulation and institutions as the reason for downward sloping medium-run Phillips curve. Unemployment leads inflation in the first period, while inflation leads unemployment in the second period. Finally, there is no long-run relationship in the last period (a very flat slope as shown by low-pass filtered data). The flattening of the Phillips curve occurs at the low inflation rate. There is an inflation-unemployment trade-off at business-cycle frequencies in all periods although the magnitude fluctuates across periods and frequencies.

We also briefly document that the observed patterns in the inflation-unemployment relationship is not unique in the case of Australia but also true in the case of several other industrialized countries that adopted inflation targeting. The flattening of the Phillips curve has raised concerns about the efficacy of conventional monetary policy of inflation targeting in output stabilization because at low inflation unemployment cost of deflation is very large (Svensson, forthcoming). Gordon (2013) argues that a flattened Phillips curve depends on the choice of specification, and short-run unemployment equation tracks the actual inflation tightly. If the objective of monetary policy is to stabilize fluctuations over the business cycles, then its role has not diminished since the Phillips curve remains downward sloping and the slope is steep in the post-1993 inflation-targeting period. Therefore, our results have important implications for the conduction of monetary policy.

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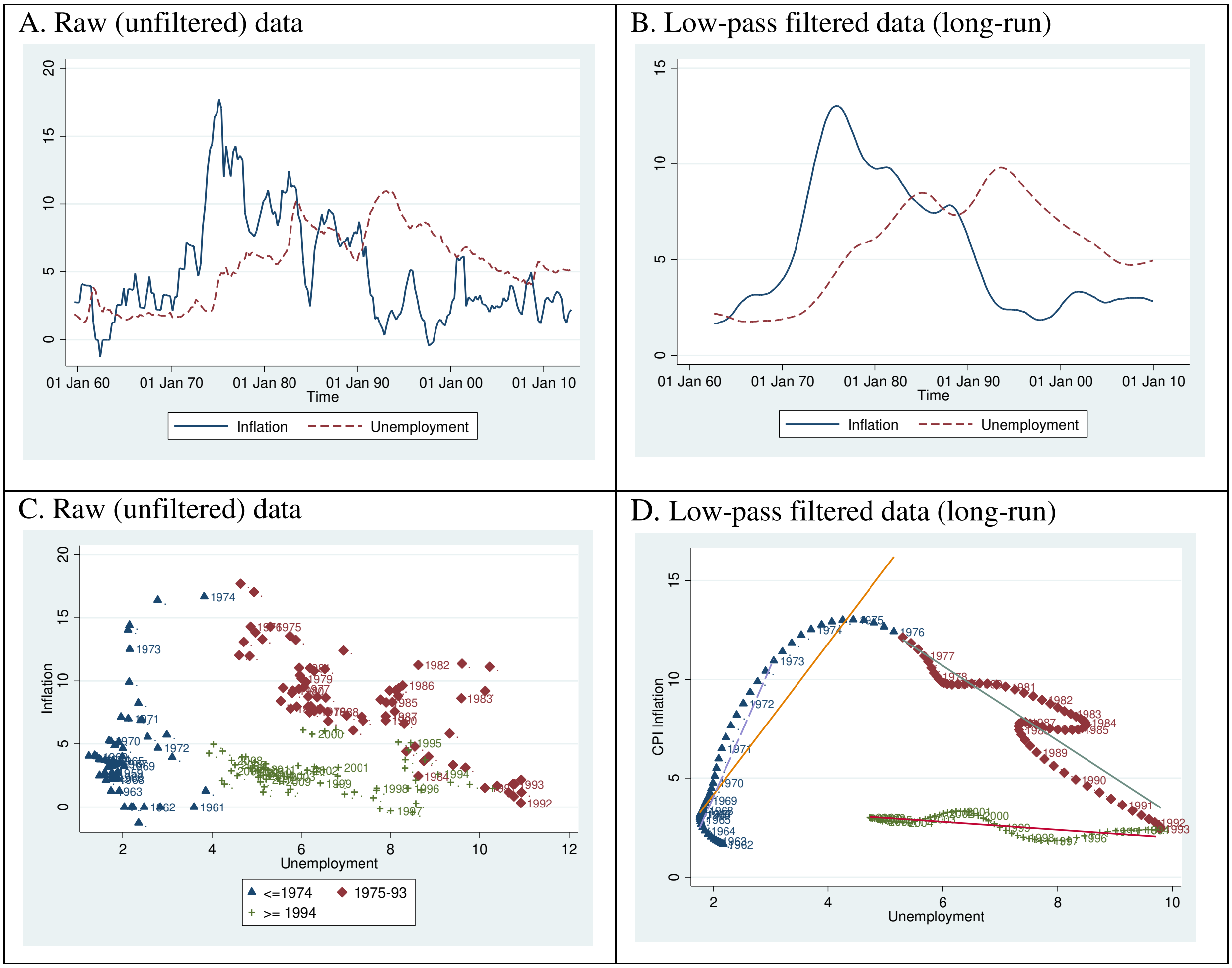
Figures

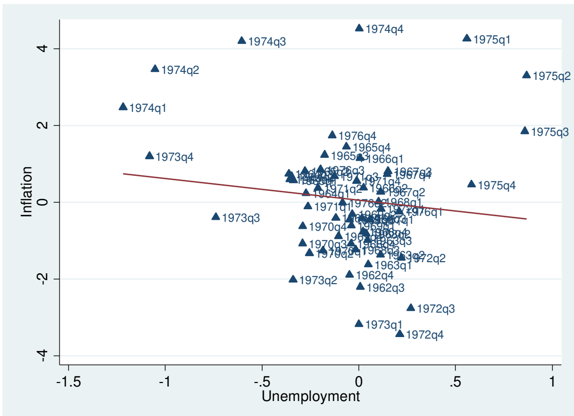
Figure-1: Inflation-unemployment relationship over different frequency ranges for the period 1959:3-2012:4



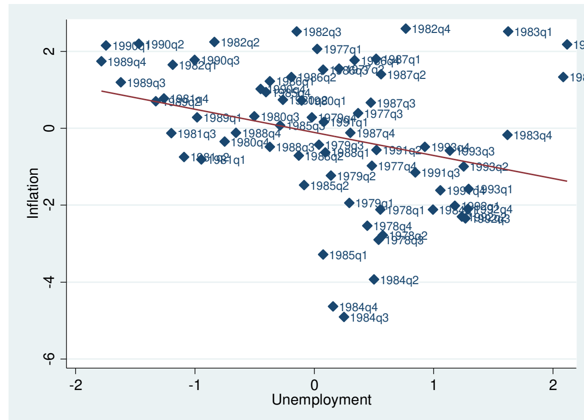
Note: The broken upward sloping straight line in Figure-1D is the linear fit for the 1959:3-1973:4 period. The solid upward sloping straight line is the linear fit for the 1959:3-1976:4 period.

Figure-2: Inflation-unemployment relationship over business-cycle frequency ranges for different sub-periods

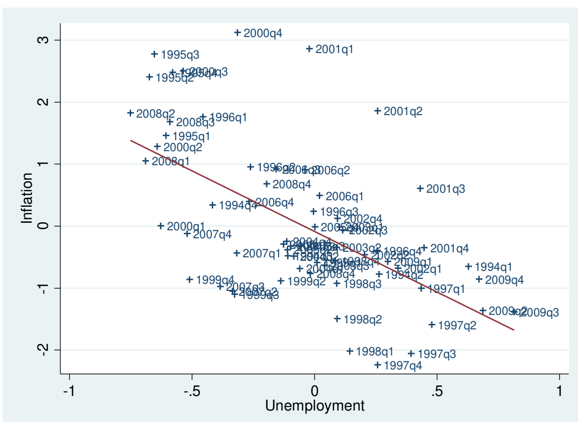
A. For 1959:3-1976:4



B. For 1977:1-1993:4



C. For 1994:1-2012:4



D. For 1959:3-2012:4

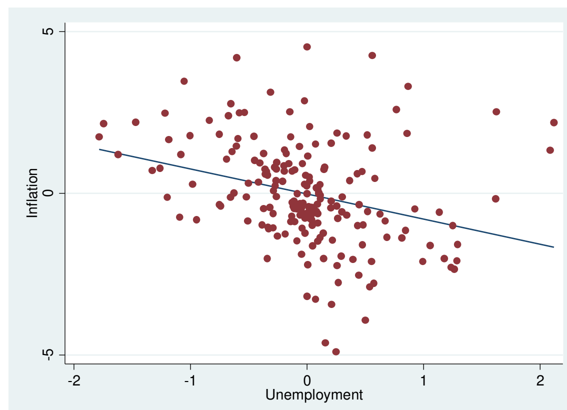
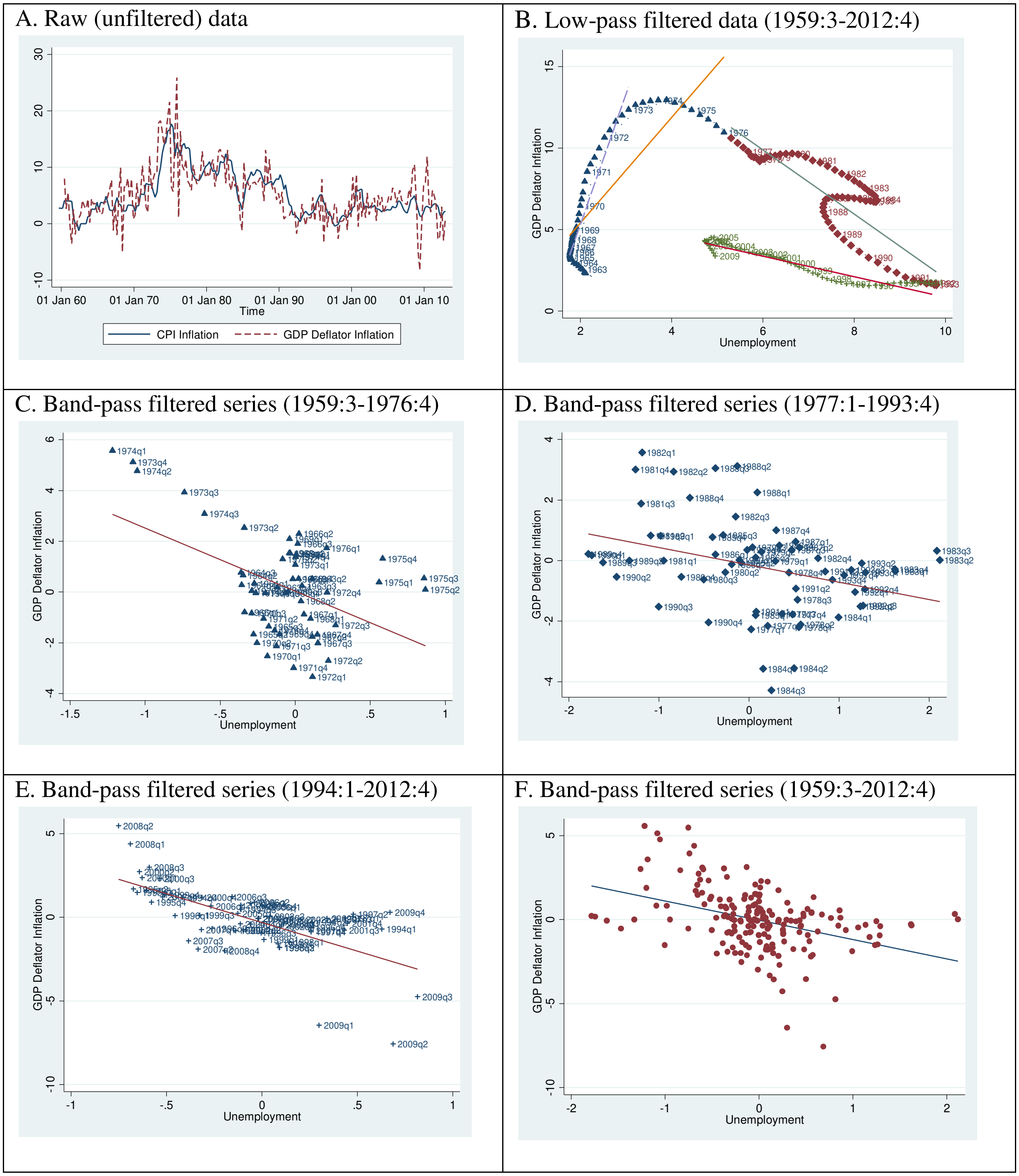


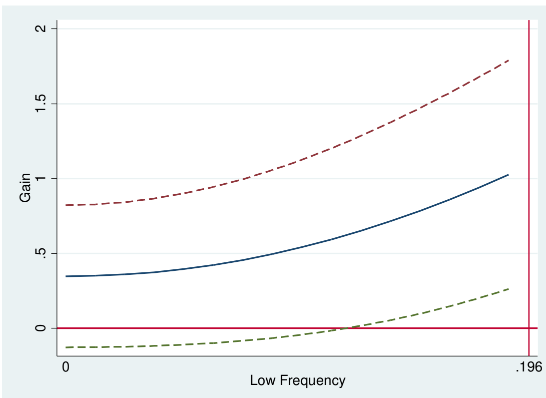
Figure-3: Inflation-unemployment relationship: Inflation measured as change in GDP deflator



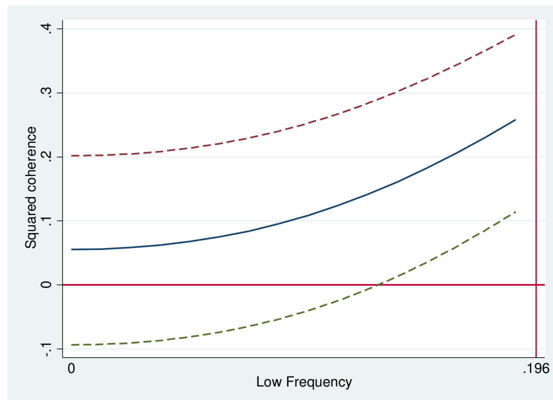
Note: The broken upward sloping straight line in Figure-XXB is the linear fit for the 1959:3-1973:4 period. The solid upward sloping straight line is the linear fit for the 1959:3-1976:4 period.

Figure 4: Long-run relationship (0-0.196 frequency range) for the 1959:3-1976:4 period

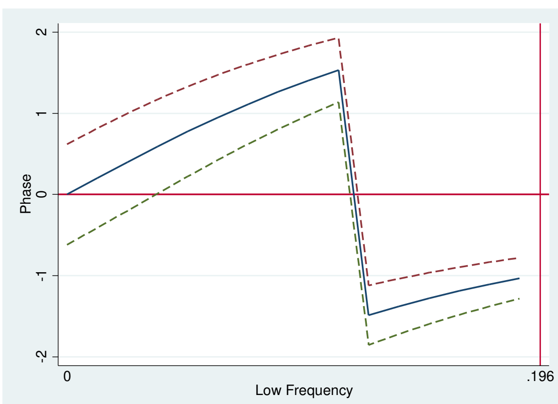
A. Gain



B. Squared coherence



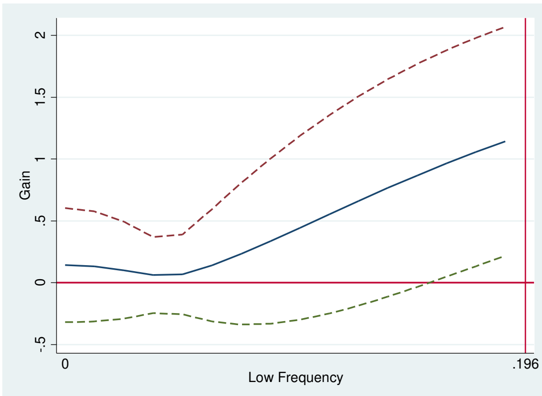
C. Phase



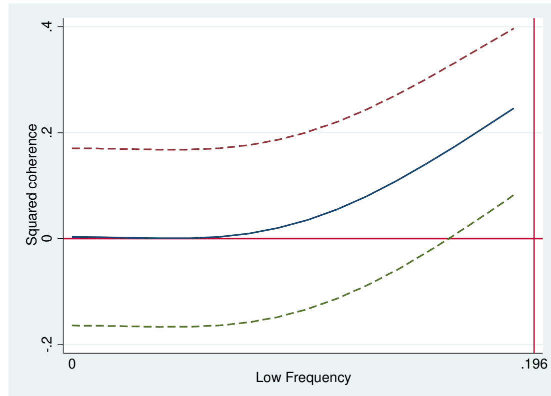
Note: Dotted lines represent the 95% confidence interval.

Figure 5: Long-run relationship (0-0.196 frequency range) for the 1959:3-1973:4 period

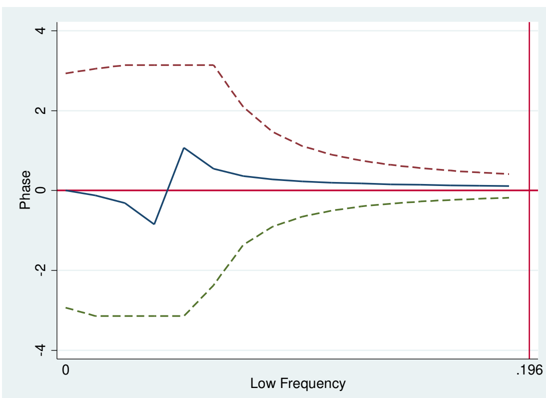
A. Gain



B. Squared coherence

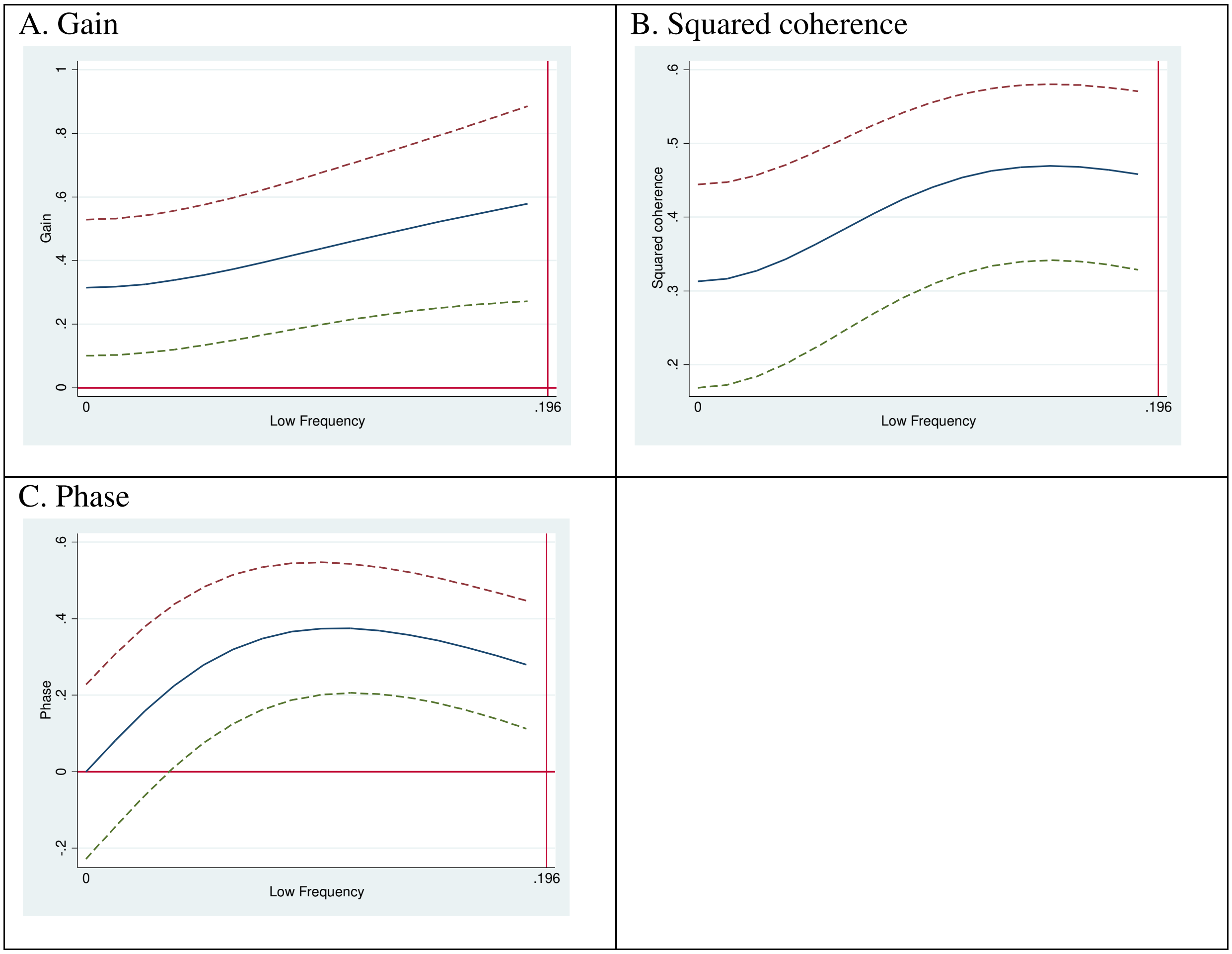


C. Phase



Note: Dotted lines represent the 95% confidence interval.

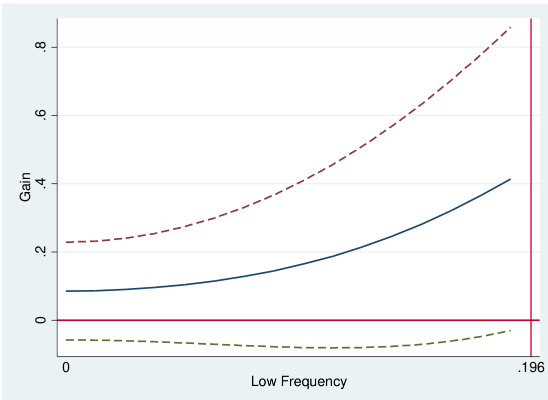
Figure 6: Long-run relationship (0-0.196 frequency range) for the 1977:1-1993:4 period



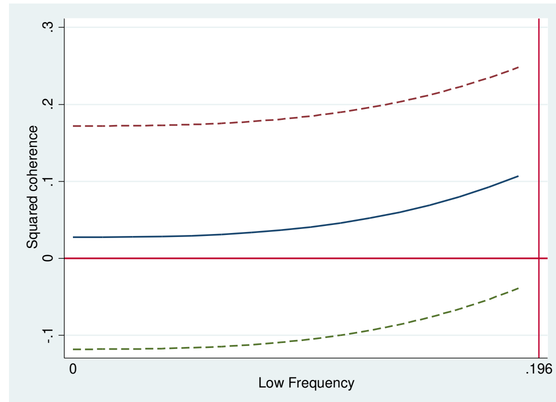
Note: Dotted lines represent the 95% confidence interval.

Figure 7: Long-run relationship (0-0.196 frequency range) for the 1994:1-2012:4 period

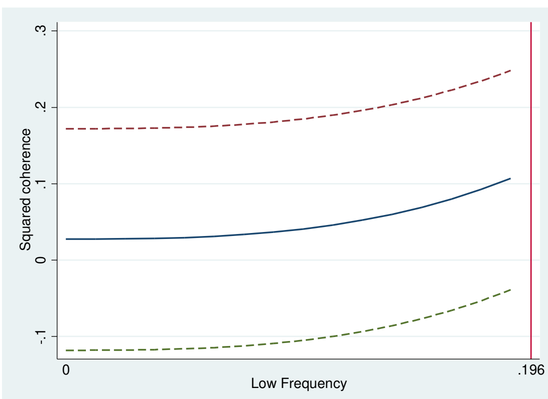
A. Gain



B. Squared coherence



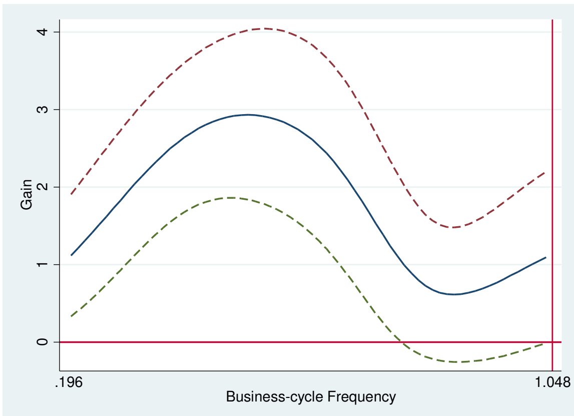
C. Phase



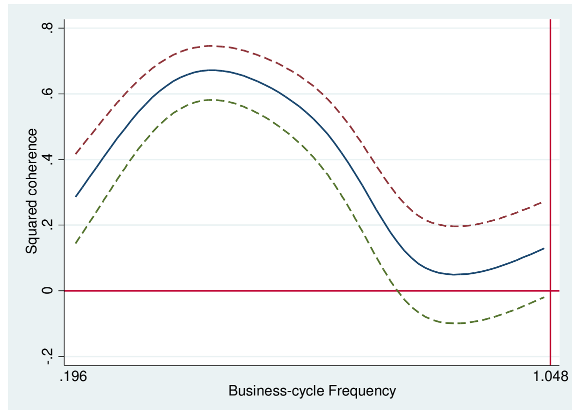
Note: Dotted lines represent the 95% confidence interval.

Figure 8: Business-cycle relationship (0.196-1.048 frequency range) for the 1959:3-1976:4 period

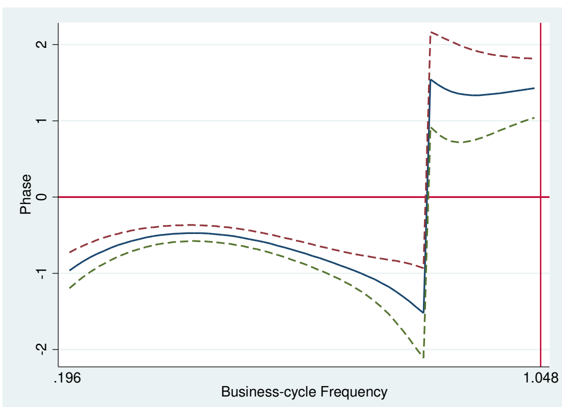
A. Gain



B. Squared coherence



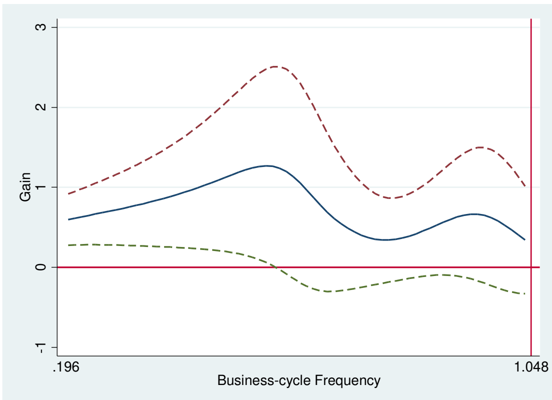
C. Phase



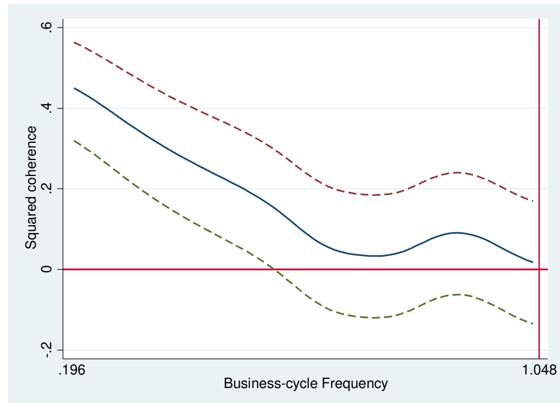
Note: Dotted lines represent the 95% confidence interval.

Figure 9: Business-cycle relationship (0.196-1.048 frequency range) for the 1977:1-1993:4 period

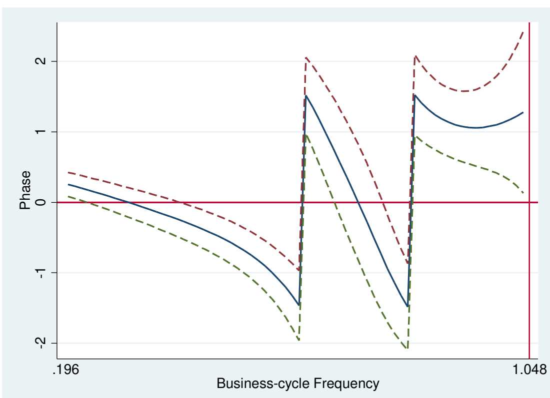
A. Gain



B. Squared coherence



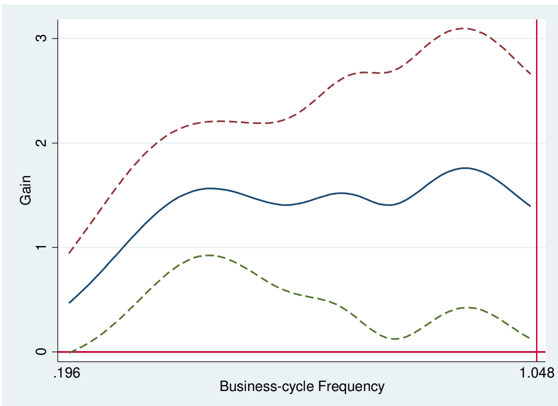
C. Phase



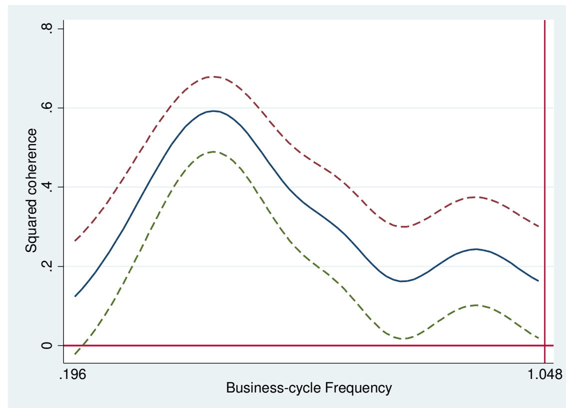
Note: Dotted lines represent the 95% confidence interval.

Figure 10: Business-cycle relationship (0.196-1.048 frequency range) for the 1994:1-2012:4 period

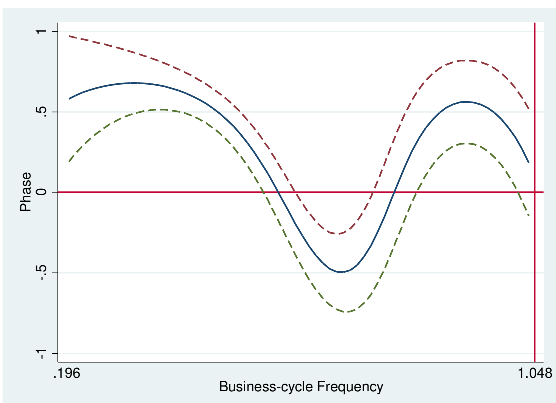
A. Gain



B. Squared coherence



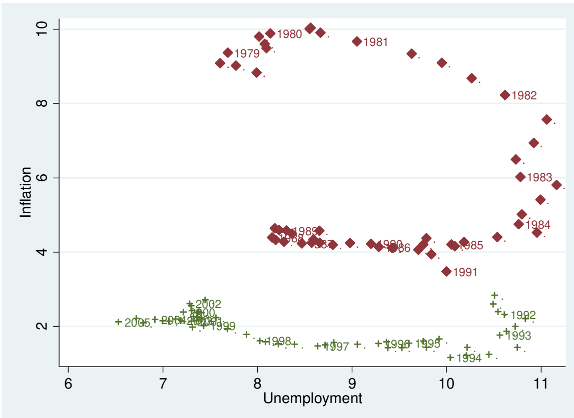
C. Phase



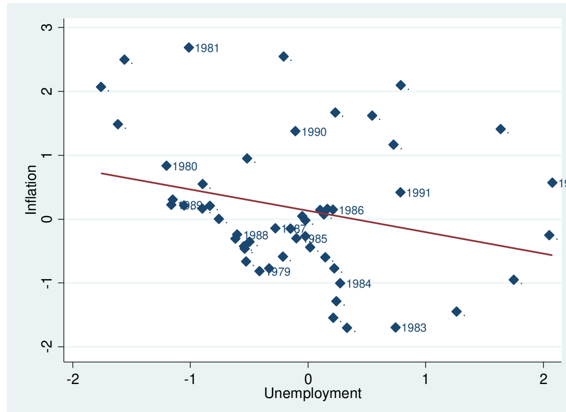
Note: Dotted lines represent the 95% confidence interval.

Figure-11: Inflation-unemployment relationship over different frequency ranges for Canada (Inflation targeting in 1991)

A. Low-pass filtered data (long-run)



B. Band-pass filtered data (1975-1991)



C. Band-pass filtered data (1992-2008)

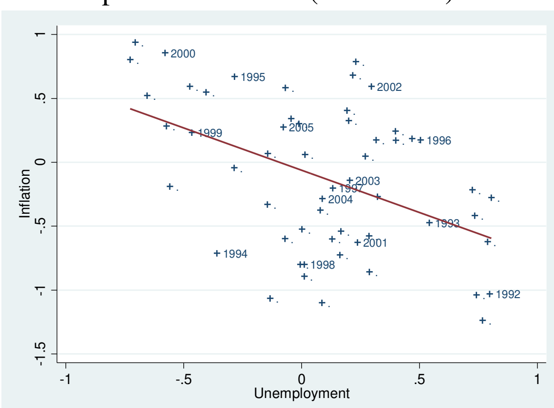
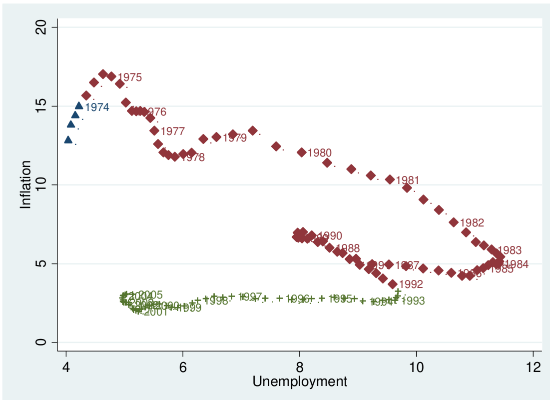
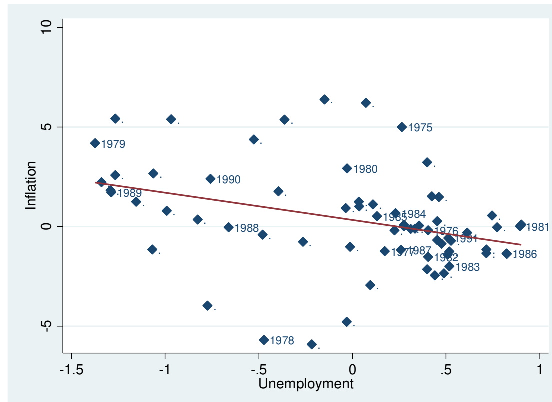


Figure-12: Inflation-unemployment relationship over different frequency ranges for the UK (Inflation targeting in 1992)

A. Low-pass filtered data (long-run)



B. Band-pass filtered data (1975-1992)



C. Band-pass filtered data (1993-2009)

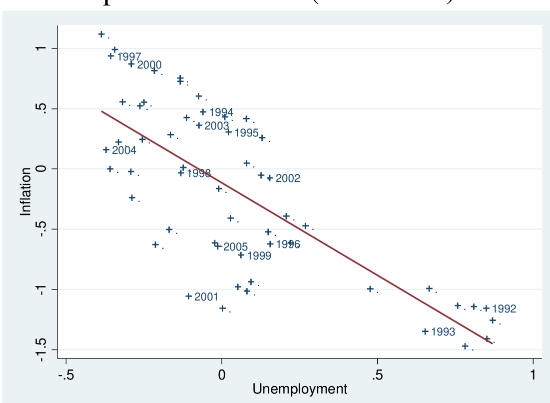
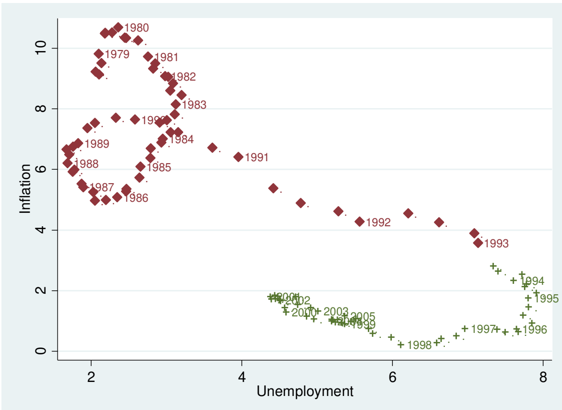
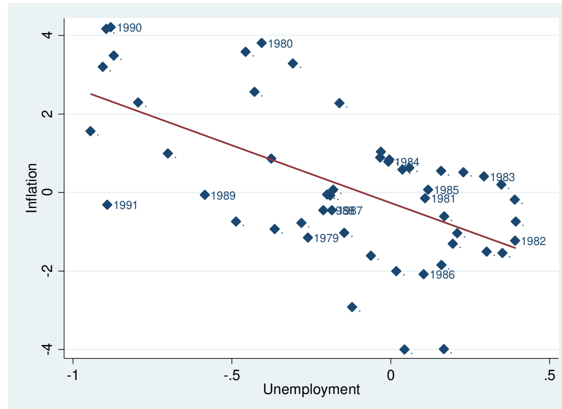


Figure-13: Inflation-unemployment relationship over different frequency ranges for Sweden (Inflation targeting in 1993)

A. Low-pass filtered data (long-run)



B. Band-pass filtered data (1975-1993)



C. Band-pass filtered data (1994-2009)

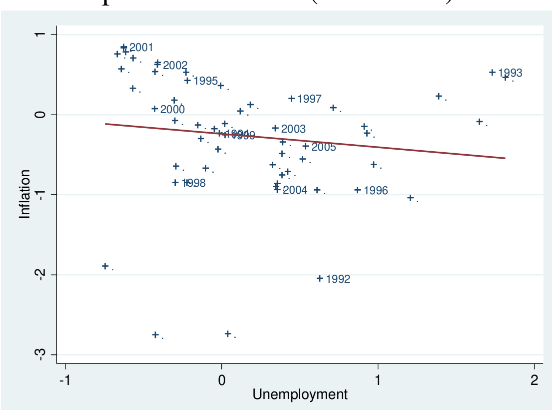
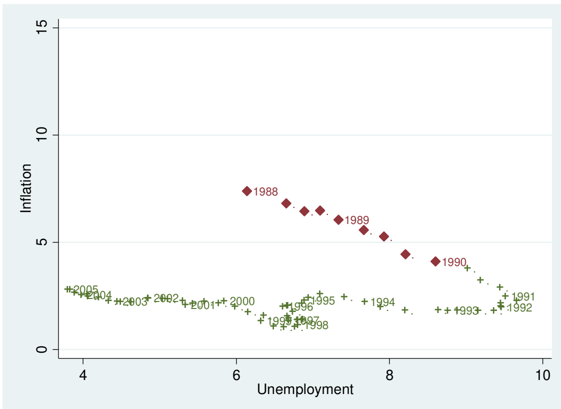
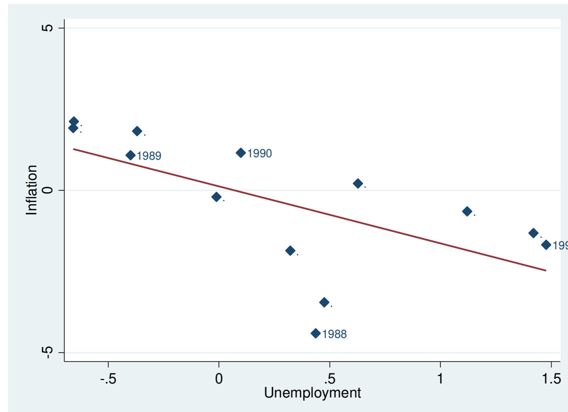


Figure-14: Inflation-unemployment relationship over different frequency ranges for New Zealand (Inflation targeting in 1990)

A. Low-pass filtered data (long-run)



B. Band-pass filtered data (1975-1990)



C. Band-pass filtered data (1991-2009)

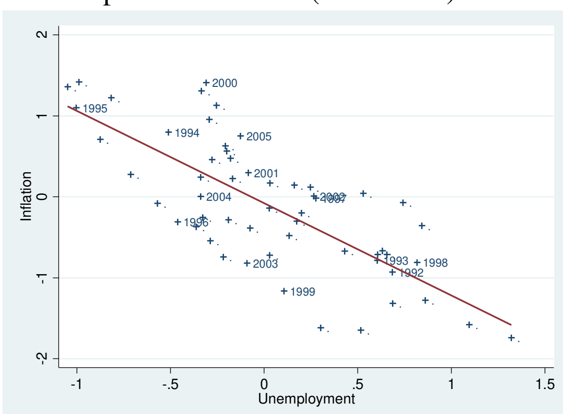
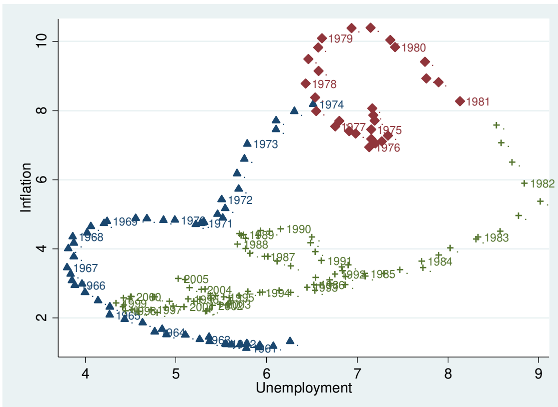
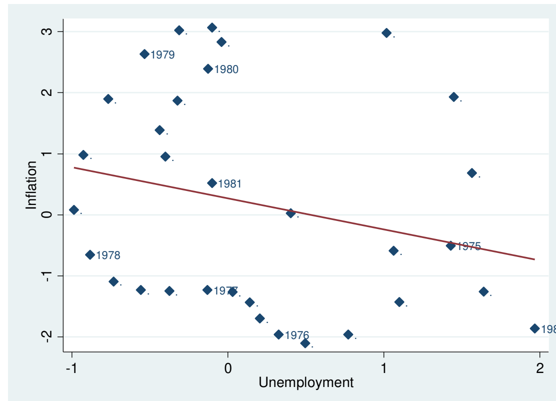


Figure-15: Inflation-unemployment relationship over different frequency ranges for the USA (No explicit inflation targeting; Volcker recession in 1982)

A. Low-pass filtered data (long-run)



B. Band-pass filtered data (1975-1982)



C. Band-pass filtered data (1983-2009)